A round robin campaign on the hygric properties of porous building materials

The reliable determination of the hygric properties of porous building materials is important. In earlier round robin campaigns large discrepancies of measured hygric properties were found among different labs. Later studies indicated that differences in lab conditions and more importantly, personnel's operation procedures and data processing methods, might have the greatest impact. To gain further insight, a new round robin campaign has been launched by KU Leuven (Belgium), to which another eight institutes contributed. A relatively stable and homogeneous ceramic brick is tested, and 3 standard tests are performed: the vacuum saturation test, the capillary absorption test and the cup test. During the campaign, two rounds of measurements are performed. In the 1st round, tests are performed according to participants' respective experimental protocols. Next, a strict and detailed common protocol is prescribed. This paper reports on the results obtained in the 1st round of measurements. Results show that not much progress has been made since the EC HAMSTAD project: the vacuum saturation test leads to the most consistent results, while the cup test produces the largest discrepancies, most probably originating from sample sealing and humidity control.

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Durability of vertically cast mortar joints in Pearl-Chain Bridges

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Contributors: Lund, M. S. M., Hansen, K. K., Arvidsson, M.
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Evaluation of freeze-thaw durability of pervious concrete by use of operational modal analysis

It is well-known that laboratory testing of pervious concrete's freeze-thaw performance is too harsh and does not agree well with field observations. The most commonly used laboratory freeze-thaw test method for pervious concrete is similar to that used for conventional concrete even though the void structure of the two materials is completely different. In the present study, a new freeze-thaw test method for pervious concrete is suggested and tested on one baseline mix, with three different contents of entrained air. The evaluation of freeze-thaw damage on pervious concrete beams was evaluated from the decrease in mass and from operational modal analysis which provides an accurate determination of the change in natural frequencies with freeze-thaw exposure. Operational modal analysis was also used to determine the Young's modulus, shear modulus, and Poisson's ratio of the pervious concrete mix.

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Publication date: 2018
Influence of alkali-silica reaction and crack orientation on the uniaxial compressive strength of concrete cores from slab bridges.

For a reliable structural analysis and risk assessment of concrete structures damaged by alkali-silica reaction (ASR), knowledge of the concrete compressive strength is essential. This comprehensive study investigates the residual compressive strength of concrete cores drilled from three severely ASR-damaged flat slab bridges in service. Furthermore, the influence of the ASR-induced crack orientation on the compressive strength and the Young's modulus is investigated. Uniaxial compression tests, visual observations, and thin section examinations were performed on more than 100 cores drilled from the three severely ASR-damaged flat slab bridges. It was found that the orientation of ASR-induced cracks has a significant influence on the uniaxial compressive strength and the stress strain relationship of the tested cores. The compressive strength in a direction parallel to ASR cracks can be significantly higher than the strength in the direction perpendicular to ASR cracks. It is proposed that for an increasing amount of ASR-induced cracks in the extracted cores the anisotropic concrete behaviour in compression will be reduced. (C) 2018 Elsevier Ltd. All rights reserved.

Lichen growth on concrete elements for sustainable facade design

The potential use of a new type of green façade based on the growth of lichens on a concrete substrate is investigated. Lichens are unique life forms characterized by a symbiotic relationship between a fungus and an alga, drawing all its nutrients from the air and the rain.

The strategy was to use limestone and calcined clay in the mix design. The replacement of 35% of the cement by a blend of limestone and calcined clay reduces the level of CO₂ emissions significantly compared to ordinary concrete with comparable mechanical performances. The use of this blend presents an additional advantage for this context, by allowing
a faster carbonation which reduces the pH of the material and therefore facilitates the colonization and growth of lichens. A series of concrete tiles were casted using different mix designs and surface treatments to assess their efficiency as a substrate for lichen growth while their water exchange properties at different relative humidity were tested. The experiments showed that the substrate provided a more suitable substrate for the seeding and the transplantation of the lichen Xanthoria parietina compared to a reference ordinary Portland cement concrete. However, it showed a higher permeability, impairing the micro-climatic environment on the surface.

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**Obituary: Preben Hoffmeyer (1939-2018)**

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**Performance of hydrophobized historic solid masonry – Experimental approach**
The hygrothermal conditions in historic solid masonry are expected to change for the worse, with the application of internal insulation. Nevertheless, internal insulation plays a role in a holistic energy retrofit of historic buildings. With careful considerations and correct application, hydrophobic treatment may help remedy moisture ingress from external rain loads. This study includes experimental investigations of the effect on hygrothermal performance of various hydrophobization treatments on both brick and air lime mortar. An investigation of water migration through masonry applied with imitated climatic loads is also reported. The study showed a larger efficiency of hydrophobization on specimens of brick compared to the efficiency of hydrophobization of specimens of air lime mortar, which may be problematic in cases where mortar joints are the primary means for water ingress. Silane-based treatments generally proved to be most efficient in brick, whereas a variety of other active components were most successful in air lime mortar treatment. The investigation of water migration showed a distinct effect of silane, cream hydrophobization, though most evident in the external part of the brick.

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Organisations: Department of Civil Engineering, Design and Processes, Materials and Durability, Danish Building Research Institute
Contributors: Hansen, T., Bjarløv, S. P., Peuhkuri, R. H., Hansen, K.
Number of pages: 14
Residual shear strength of a severely ASR-damaged flat slab bridge

Although the residual shear strength of ASR-damaged slab bridges without shear reinforcement has been discussed for several decades, the amount of published research on this topic is very limited. This paper presents the results of a test series on 18 reinforced beams sawn from a severely ASR-damaged flat slab bridge. Flexural failure as well as shear failure were observed. The test results indicate that the ASR cracks in the beams strongly influenced the propagation of load-induced cracks. Generally, the calculated moment capacity of beams tested in three-point bending was lower than the maximum moment carried by the beams. For the beams tested in asymmetric four-point bending, an increase in the shear span-to-effective depth ratio resulted in a decrease in the measured shear strength. The measured shear strengths were compared with calculated shear strengths using the Eurocode 2. Calculations based on the compressive strength of drilled cores were rather conservative at low shear span-to-effective depth ratios. However, the conservatism of the Eurocode 2 decreased with increasing shear span-to-effective depth ratios. With the inclusion of ASR-induced pre-stress effect, the calculated shear strengths correlated better with the measured shear strengths. The test results indicated that the ASR-induced pre-stress effect can, to some extent, compensate for the significant loss in material properties.

Self-compacting pervious concrete mix design for permeable concrete soakaway rings

Permeable concrete soakaways store surface rainwater and let it seep slowly into the soil. This minimizes the risk of flooding, which is an increasingly larger problem because of climate change causing heavier and heavier rainfalls. In the present study, a self-compacting pervious concrete mix design is developed to use for permeable soakaway rings. A self-compacting mix design ensures a more uniform void distribution throughout the soakaway ring compared to the use of a conventional stiff pervious concrete mix design. The study is divided into two main parts: laboratory testing, in which the
influence of the casting height on the void distribution is also considered, and full-scale casting of a 2.25-m-high pervious concrete soakaway ring. The overall conclusion is that a successful self-compacting pervious concrete mix design was developed by carefully balancing the use of a superplasticizer and stabilizer. Thereby, it was also possible to perform a successful full-scale casting.

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Time Domain Reflectometry

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Alkali Release from Typical Danish Aggregates to Potential ASR Reactive Concrete
Alkali-silica reaction (ASR) in concrete is a well-known deterioration mechanism affecting the long term durability of Danish concrete structures. Deleterious ASR cracking can be significantly reduced or prevented by limiting the total alkali content of concrete under a certain threshold limit, which in Denmark is recommended to 3 kg/m³ Na₂O eq. However, this threshold limit does not account for the possible internal contribution of alkali to the concrete pore solution by release from aggregates or external contributions from various sources. This study indicates that certain Danish aggregates are capable of releasing more than 0.46 kg/m³ Na₂O eq. at 13 weeks of exposure in laboratory test which may increase the risk for deleterious cracking due to an increase in alkali content in the concrete.

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Organisations: Department of Civil Engineering, Section for Building Design, Ramboll Group AS
Mix design for improved strength and freeze-thaw durability of pervious concrete fill in Pearl-Chain Bridges

Pearl-Chain Bridges are an innovative precast arch bridge technology which can utilize pervious concrete as fill material. The present study investigates how the mix design of the pervious concrete fill can be influenced by use of an air-entraining admixture, a high-range water reducing admixture, fibers, and by internal curing using lightweight aggregate to best possibly meet the requirements for a fill material in Pearl-Chain Bridges. The 28-day compressive strength, splitting tensile strength, shear strength, permeability, and freeze-thaw durability were determined and compared for eight different mixture proportions using two different sizes of granite coarse aggregate and at two different water-to-cement ratios. The specimens had an average void content of 24-28%. Specimens containing air entraining and high-range water reducing admixtures were most workable, as determined by fresh density, and thus the easiest to place. The addition of a high-range water reducing admixture and lightweight sand (expanded shale) for internal curing improved the 28-day compressive strength and splitting tensile strength. The coarse aggregate gradation had a large influence on permeability; however, all tested permeabilities were high enough to drain the rain from a 100-year rain event in Denmark. The air entraining agent dosage used was not sufficiently high to create the necessary protective air content in the cement paste, and the freeze-thaw durability of the specimens were generally poor for the utilized test procedure; however, the mix design containing lightweight sand showed improved freeze-thaw durability compared to the other mix designs.

Moisture damage with magnesium oxide boards in Danish facade structures

Magnesium oxide boards have been widely used on facades in Denmark during 2010-2015. However, the magnesium salts absorb humidity from the ambient, and they begin to leak salty water, which is highly corrosive, and leads to moisture and mould problems in wooden members of the structures. MgO-boards were not tested for their hygrothermal function before being used on exterior wall structures, which has had detrimental consequences, such as an expected cost of repair of around 2 billion DKK. Properties for moisture transport and retention properties have been determined and will be shown together with some examples of damaged structures.
A lime based mortar for thermal insulation of medieval church vaults

There are 1700 medieval churches in Denmark, and many of these have brick vaults. The thickness is only 12 – 15 cm, and the heat loss through this building component is large. Thermal insulation has not been permitted until now in respect for the antiquarian values and doubts about the effect on water vapour transport through the vault, and the risk of condensation inside the insulation. A new mortar was developed for thermal insulation of bricks vaults, consisting mainly of expanded perlite, mixed with slaked lime. These materials are compatible with the fired clay bricks and the lime mortar joints. The insulation mortar is applied to the top side of the vault in a thickness of 10 cm, and covered by 10 mm lime plaster, reinforced with cattle hair. This assembly is resistant to the weight of a person, working with maintenance of the roof. The thermal conductivity of the insulation mortar was measured to 0.08 W/mK, which is twice the value for mineral wool. It has 1/3 of the resistance to water vapour diffusion as brick, and a high capacity for liquid water absorption. This is a benefit in the case of rain leaking from the roof, because the water does not penetrate further down into the bricks.
Evaluation and Comparison of Freeze-Thaw Tests and Air Void Analysis of Pervious Concrete

Pearl-Chain Bridge technology is an innovative precast arch bridge solution which uses pervious concrete as fill material. To ensure longevity of the bridge superstructure it is necessary that the pervious concrete fill is designed to be freeze-thaw durable; however, no standards exist on how to evaluate the freeze-thaw resistance of fresh or hardened pervious concrete and correspondingly what constitutes acceptable freeze-thaw durability. A greater understanding of the correlation between the freeze-thaw performance and the air void structure of pervious concrete is needed. In the present study six pervious concrete mixes were exposed to freeze-thaw testing, and their air void structure was analyzed using an automated linear-traverse method. It was found that there is a miscorrelation between these two test methods in their assumption of whether or not the large interconnected voids effectively relieve the pressure when water freezes.

Experimental investigation of different fill materials in arch bridges with particular focus on Pearl-Chain Bridges

Pearl-Chain Bridge technology is a recently developed prefabricated arch solution for road and railway bridges allowing faster, more environmentally friendly, and cheaper bridge construction. This study compared the strength and durability properties of three different types of fill material to find the most optimal fill for Pearl-Chain Bridges. Sub-base gravel, cement-stabilized gravel, and pervious concrete were tested with respect to compressive strength, stiffness, splitting tensile strength, permeability, freeze-thaw durability, and shrinkage. This paper summarizes the advantages and disadvantages of implementing the different types of fill material in arch bridges, particularly in Pearl-Chain Bridges.
This study investigates frost susceptibility of sub-base gravel determined by the ASTM D5918-13 standard as a
conservative estimate of the frost heave risk of fill in overfilled arch bridges, particularly in Pearl-Chain Bridges. Frost
heave of granular materials has been of great research interest from the end of the 1920s until the present day. Most new
literature relates to empirical results that are several decades old. This is also the case for Danish tender specifications
according to which the frost susceptibility of a sub-base gravel is solely assessed from its fines content. However, no
actual frost tests have been carried out to verify this assumption. In the present study, the frost susceptibility of four
different Danish gravel materials is categorised from their heave rate. We test two Danish sub-base gravel materials, with
particle size distributions of 0–8 mm and 0–31.5 mm, respectively, and also two modified sub-base gravel materials with
increased and reduced fines contents. The fines content of the gravel materials is analysed by laser diffraction, and
compared with two common frost susceptibility criteria, Casagrande’s and Schaible’s, and with Danish tender
specifications. Even though the two sub-base gravel materials are expected to be frost safe, 0–31.5 mm sub-base gravel
shows medium frost susceptibility, whereas 0–8 mm sub-base gravel shows negligible frost susceptibility. The gravel
materials with increased and reduced fines content are categorised as having low to medium frost susceptibility and low
frost susceptibility, respectively. The permeability of the gravel materials is determined, and the permeability coefficient
of 0–31.5 mm sub-base gravel is five times greater than that of 0–8 mm sub-base gravel. The results suggest that the
criterion used to classify the frost susceptibility of Danish sub-base gravel materials based solely on their fines content is
insufficient, and that the permeability coefficient should also be considered.

Frost susceptibility of sub-base gravel used in Pearl-Chain Bridges: an experimental investigation
This study investigates frost susceptibility of sub-base gravel determined by the ASTM D5918-13 standard as a
conservative estimate of the frost heave risk of fill in overfilled arch bridges, particularly in Pearl-Chain Bridges. Frost
heave of granular materials has been of great research interest from the end of the 1920s until the present day. Most new
literature relates to empirical results that are several decades old. This is also the case for Danish tender specifications
according to which the frost susceptibility of a sub-base gravel is solely assessed from its fines content. However, no
actual frost tests have been carried out to verify this assumption. In the present study, the frost susceptibility of four
different Danish gravel materials is categorised from their heave rate. We test two Danish sub-base gravel materials, with
particle size distributions of 0–8 mm and 0–31.5 mm, respectively, and also two modified sub-base gravel materials with
increased and reduced fines contents. The fines content of the gravel materials is analysed by laser diffraction, and
compared with two common frost susceptibility criteria, Casagrande’s and Schaible’s, and with Danish tender
specifications. Even though the two sub-base gravel materials are expected to be frost safe, 0–31.5 mm sub-base gravel
shows medium frost susceptibility, whereas 0–8 mm sub-base gravel shows negligible frost susceptibility. The gravel
materials with increased and reduced fines content are categorised as having low to medium frost susceptibility and low
frost susceptibility, respectively. The permeability of the gravel materials is determined, and the permeability coefficient
of 0–31.5 mm sub-base gravel is five times greater than that of 0–8 mm sub-base gravel. The results suggest that the
criterion used to classify the frost susceptibility of Danish sub-base gravel materials based solely on their fines content is
insufficient, and that the permeability coefficient should also be considered.

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Magnesium-oxide boards cause moisture damage inside facades in new Danish buildings

Magnesium oxide board, “MgO-board”, is a factory-made sheathing board product, which has been widely used in the last 5 years in ventilated facades on new or renovated buildings in Denmark. In winter 2014/15, a number of problems began to appear with these boards since the boards and adjoining building elements seemed to suffer from some sort of disease, which manifested itself by damages such as significant moisture, boards leaking salty water (‘tears’), corrosion of fittings and anchors and mould growth.

The damages were caused by the fact that MgO-boards absorb moisture from outside air in periods with high outdoor humidity (90-100% RH) and form water drops on the surfaces. The drops contain a high amount of soluble chloride ions and appear on the surfaces of the boards and may often run down the boards and to adjacent structures. Metal fixtures for the MgO-and siding boards may corrode heavily within a few years. The binder in MgO-boards is formed by chemical reaction between MgO and MgCl₂, known as magnesium oxychloride cement or Sorel cement. Also organic matter can be found in the material. The paper presents results of investigations of properties for moisture ab- and desorption curves and transport of MgO-boards.

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Pervious concrete fill in Pearl-Chain Bridges: Using small-scale results in full-scale implementation

Pearl-Chain Bridge technology is a new prefabricated arch solution for highway bridges. This study investigates the feasibility of pervious concrete as a filling material in Pearl-Chain Bridges. The study is divided into two steps: (1) small-scale tests where the variation in vertical void distribution and strength properties is determined for 800 mm high blocks cast in different numbers of layers, and (2) full-scale implementation in a 26 m long Pearl-Chain Bridge. With a layer thickness of 27 cm, the small-scale tests indicated homogenous results; however, for the full-scale implementation, the same degree of homogeneity was not shown. (C) 2015 Elsevier Ltd. All rights reserved.

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Web of Science (2016): Indexed yes
Shear capacity of ASR damaged structures – in-depth analysis of some in-situ shear tests on bridge slabs

This paper deals with the influence of alkali-silica reaction (ASR) on the shear capacity for concrete slabs without shear reinforcement. An experimental full-scale in-situ program consisting of four slabs from a bridge (Vosnæsvej) has been carried out and the results have been published in ref. [1] with the principal author of this paper as co-author. After the experiments, a detailed measurement of the test specimens was conducted. Based on these measurements a thorough analysis of the experimental results was carried out and evaluated by a plastic model for shear capacity, Crack Sliding Model (CSM) and Eurocode 2 (EN 1992-1-1). The analysis shows that three experiments were highly affected by the preparation of the experimental setup. Only one experiment contained useful information about the shear capacity. The analysis of this experiment shows that the shear capacity is not reduced as much as the measured concrete compressive strength indicates. Furthermore, the analysis shows that the ASR-induced prestress may be the reason for this phenomenon.
Homogeneity and Strength of Mortar Joints in Pearl-Chain Bridges

The load carrying mortar joints in Pearl-Chain Bridges are cast vertically which means that they have a placing depth of up to 2.40 m. In the present paper, the feasibility of casting 2.40 m high homogeneous vertical mortar joints is examined. Three high-strength, expansive, self-compacting, ready-to-mix mortar products are tested. To the authors' knowledge, no previous published work has documented the homogeneity and properties of mortar joints of such a height. Hence, the present study documents a practical test procedure where the homogeneity of three mortar joints measuring 20 x 220 x 2400 mm has been tested and compared by measuring compressive strength, variation in rebound value, variation in density, and separation. In addition, the appearance of the surface texture has been visually assessed. The measurements indicate that, for all three mortars tested, it is possible to cast homogeneous 2.40 m high mortar joints. Moreover, the strength of the three mortars meets the requirements for the Pearl-Chain Bridge application. However, when inspected two of the mortars had many surface air bubbles which is a serious concern regarding durability of the mortar joints.

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Using X-ray transmission/attenuation to quantify fluid absorption in cracked concrete
Cracks can alter the rate of fluid transport in concrete. Unfortunately, however, quantitative information is lacking to provide definitive statements regarding the extent to which cracks reduce durability or long-term performance. This paper describes a study that used X-ray transmission/attenuation to determine the influence of cracking on the absorption of fluid in concrete. Specifically, an experimental method is presented which uses a wedge splitting test to pre-crack specimens. These pre-cracked specimens were dried and ponded with water. At various times after the start of water ponding, X-ray attenuation measurements were taken using a grid of points around the crack. By repeating this measurement and comparing the change in X-ray transmission/attenuation, the ingress of the fluid could be determined by locating the position of the moisture front. An approach is presented to determine the geometry of the crack by using water absorption perimeter measurements of the wetting front in the concrete.

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Can painted glass felt or glass fibre cloth be used as vapour barrier?
In most Nordic homes the interior surfaces of walls and ceilings have some kind of surface treatment for aesthetical reasons. The treatments can for example be glass felt or glass fibre cloth which are painted afterwards. To evaluate the hygrothermal performance of walls and ceilings it is essential to know how much influence a surface treatment has on the water vapour transport. Traditionally, there has been most focus on paints that affect the permeability as little as possible. However, sometimes water vapour resistance is desirable. Especially, this is relevant in existing buildings with a ventilated attic where the ceiling may be air tight but has no vapour barrier; post-insulation of the attic may cause the need for a vapour barrier. Placing a vapour barrier above the ceiling can be tiresome and it is difficult to ensure tightness. A simpler way is to paint a vapour barrier directly on the ceiling e.g. as an ordinary paint. This paper presents the results of an investigation of the water vapour resistance of surface treatments which are commonly used in-door. The water vapour resistance was measured by the cup method. Aerated concrete was investigated with and without various surface treatments. The surface treatments were glass felt or glass fibre cloth with different types of paints or just paint. The paint types were acrylic paint and silicate paint. The results show that the paint type has high influence on the water vapour resistance while the underlay i.e. glass felt or glass fibre cloth has very little impact. The measured water vapour resistance for specimens with acrylic paint was the highest, these were measured to be up to approximately $3 \times 10^9$ Pa·m²·s/kg which is considerably less than $50 \times 10^9$ Pa·m²·s/kg as recommended for a vapour barrier. Therefore, two layers of ordinary acrylic paint on glass felt or glass fibre cloth cannot be used instead of a vapour barrier.

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Publisher: Norsk Betongforening
Experimental Study of Properties of Pervious Concrete used for Bridge Superstructure

One of the main advantages of pervious concrete is its ability to drain water easily. Moreover, earlier studies on pervious concrete have shown that it can be designed to perform well in freeze-thaw regions. Bridge superstructures placed in regions where the temperature during winter time varies around freezing point are exposed to a harsh freeze-thaw impact, since bridges are not only cooled from the topside, as a normal road bed, but also from underneath. Hence, the demands to the moisture properties of the superstructure are strict in order to ensure the necessary durability. Pearl-Chain Bridges are a new patented bridge technology consisting of a number of Super-Light Deck elements, which are post-tensioned to create an arch bridge used for example for highways. The present study investigates how pervious concrete can be applied as a stabilizing filling material between the arch substructure and the wearing course. One pervious concrete mixture containing air entrainment is designed and tested. The tests include investigations of compaction methods, compressive strength, stiffness, frost resistance and permeability.

General information
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Organisations: Department of Civil Engineering, Section for Construction Materials, Section for Building Design
Contributors: Lund, M. S. M., Hansen, K. K., Hertz, K. D.
Number of pages: 10
Publication date: 2014

Host publication information
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Electronic versions:
CONCRETEROAD2014_Mia_Lund.pdf
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Source-ID: 102536476
Research output: Chapter in Book/Report/Conference proceeding → Article in proceedings – Annual report year: 2014 → Research → peer-review

Frost Resistance and Permeability of Cement Stabilized Gravel used as Filling Material for Pearl-Chain Bridges

The Pearl-Chain Bridge Technology introduces a new innovative arch bridge solution which combines the statical advantages of an arch bridge with a minimum of traffic disturbance. The arch-shaped substructure is stabilized by a filling material, e.g. cement stabilized gravel, which should meet several requirements on its moisture properties. In this paper the frost resistance, the liquid water permeability and the water vapour permeability of cement stabilized gravel are examined for two different cement contents. It is found that a small increase in cement content from 4% to 5% increases the 28-days compressive strength from 6.2 MPa to 12.3 MPa. The frost resistance of cement stabilized gravel with 5% cement content is better than for cement stabilized gravel with 4% cement content. The liquid water permeability coefficient and the water vapour permeability coefficient are significantly higher for a cement content of 4% compared to 5%.

General information
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Organisations: Department of Civil Engineering, Section for Construction Materials, Section for Building Design
Contributors: Lund, M. S. M., Hansen, K. K., Hertz, K. D.
Number of pages: 6
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Title of host publication: Proceedings of 10th fib International PhD Symposium in Civil Engineering
Electronic versions:
Measurement of water vapour transport through a porous non-hygroscopic material in a temperature gradient
This was an experiment to identify the driving potential for water vapour diffusion through porous materials in a temperature gradient. The specimen of mineral fibre insulation was placed between a space with controlled temperature and relative humidity and a space with a controlled, higher temperature, and a measured but not controlled relative humidity (RH). This assembly was allowed to reach equilibrium with no vapour movement between the spaces, as tested by a constant RH on each side and by zero flux of water vapour measured in the cold side chamber. The RH and temperature values were converted to partial vapour pressure and to vapour concentration in g/m³. The concentrations proved to be more equal on either side of the specimen than the partial vapour pressures. This supports an argument that it is concentration difference that drives diffusion of gases. Isothermal diffusion cannot be tested experimentally in this way, but it is reasonable to assume that concentration is the driving potential. The close equality of the concentrations makes it unnecessary to invoke temperature difference as a third possible potential for driving diffusion.

Moisture assessment by fast and non-destructive in situ measurements
A building inspection report is made in connection with the resale of 90% of all single-family houses in Denmark. The building inspection is visual with the option of using simple hand-held instruments but with no destructive measures allowed. However, many construction components have a high moisture content, which is not revealed by this inspection. The moisture content may become a problem for the buyers. This problem might have been avoided if the moisture content of the Building materials was measured on inspection. This is easily done in wood-based materials but for example in concrete and brick the moisture content is difficult to determine within a short period time. There is political pressure to include moisture measurements in the report if it does not increase the cost of the inspection significantly. Therefore, a moisture-measuring method is needed that is non-destructive, fast to use, easily applicable and suitable for most porous building materials. Furthermore, the measurements must be reliable at the high end of the hygroscopic area and describe absolute moisture content or corresponding relative humidity. The existing methods for moisture measuring cannot meet these requirements, and those who come close are very expensive. This paper describes a method under development; with simple means and within a few hours, the method can measure the absolute moisture content or the corresponding relative humidity in constructions in a non-destructive way. The method is based on measurements of the relative humidity of the air in a small hood placed tightly and sealed to the surface of the construction. Results with aerated concrete covered with acrylic paint are presented.
Shrinkage Properties of Cement Stabilized Gravel

Cement stabilized gravel is an attractive material in road construction because its strength properties are accommodating the increasingly higher requirements to the bearing capacity of a base course. However, reflection cracking of cement stabilized gravel is a major concern. In this paper the shrinkage properties of cement stabilized gravel have been documented under various temperature and relative humidity conditions. Two cement contents corresponding to a 28-days compressive strength of 6.2 MPa and 12.3 MPa have been tested and compared. It is found that the coefficient of linear expansion for the two cement contents is $9.9 \times 10^{-6} \, {^\circ}{C}^{-1}$ and $11.3 \times 10^{-6} \, {^\circ}{C}^{-1}$, respectively. Furthermore, it is found that reflecting cracking can mainly be explained by temperature dependent shrinkage rather than moisture dependent shrinkage.

Non-isothermal Laboratory Measurements of Moisture Profiles in Calcium Silicate for Interior Insulation Applications

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Building Physics and Services, Section for Construction Materials, Golder Associates A/S, Bygge- og Miljøteknik A/S
Contributors: Kirkeskov Jensen, S., Rode, C., Hansen, K. K., Kloch, N. P.
Pages: 97-106
Publication date: 2013

Host publication information
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Source-ID: u::9903
The effects of moisture and temperature variations on the long term durability of polymer concrete

The use of polymer concrete to precast products in construction presents normally many advantages compared to traditional concrete. Higher strength, lower permeability, shorter curing periods, better chemical resistances and a better durability is normally predicated, however this is a research field where published data are scarce. Durability and constantly high and good physical properties are some of the most important properties of the materials used in the building industry. Thermal durability, i.e. the ability of a material to retain its original physical-mechanical properties during and after exposure to different thermal conditions is very important. In this paper, an experimental study concerning the influence of temperature and moisture in cyclic conditions on the durability of polymer concrete based on an unsaturated polyester resin is described and the results are presented. The change of some physical-chemical properties before, during and after exposure to different thermal conditions is measured. This study was initiated by an in-situ investigation on failures which have occurred on a number of steps on some heavily trafficked public outdoor stairs. © (2013) Trans Tech Publications, Switzerland.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Construction Materials, Ramboll Group AS, Polysan A/S
Contributors: Barbosa, R., Hansen, K. K., Grelk, B., Wibholm, E.
Pages: 136-143
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Source: dtu
Source-ID: n::oai:DTIC-ART:compendex/387703731::28995
Research output: Contribution to journal › Conference article – Annual report year: 2013 › Research › peer-review

Diffusion and electromigration in clay bricks influenced by differences in the pore system resulting from firing

Ion transport in porous materials has been subject of study for several decades. However, the interaction between the pores and the overall pore system make it complicated to obtain a clear picture and predict diffusion and electromigration (transport induced by an applied electric field). Specific bricks were examined with respect to shape, size and interconnection of the pores. The pores were studied at a microscopic level, the interconnected pore system at a macroscopic level and the results obtained were compared with the measurement of the corresponding ion transport of Cl− and Na+ through the pore system to contribute to an overall understanding of ion transport in porous materials. The pore system in bricks is influenced by the firing degree, clay mixture composition and ion content. The present paper focuses on the pore system and effects from clay mixture composition and ion content were neglected by using the same brick type from the same brickwork (delivered at the same pallet). The used bricks were fired in a circular kiln were uneven heating during firing occurs. Significant color differences were visible between the bricks in the pallet and for the investigation purpose they were subdivided into three groups: bright, medium and dark colored bricks. The increasing color intensity is most probably caused by increasing firing temperatures. These three groups of bricks were investigated for saturation coefficient, open porosity, dry density and water absorption coefficient which revealed significant differences were encountered. The pore system was studied by using thin sections which demonstrated a change from relatively many fine pores to fewer wide pores with increasing brick firing temperatures. An additional significant difference in the pore system of each brick was found to be related to the distance to the surface. The influence of the pore system on ion transport through the water saturated pore system of the bricks was supported by measurements for calculation of the electrical resistance and an increasing resistance was found for increasing brick firing temperatures. The effective diffusion coefficient was empirically determined for chloride and sodium through the application of an electric DC field across the bricks. The lowest effective diffusion coefficient was found for the dark colored brick, increasing for the medium and bright colored respectively. This finding suggests that in clay bricks the presence of many fine pores improves ion transport compared to fewer wider pores.

General information
Publication status: Published
Organisations: Section for Construction Materials, Department of Civil Engineering
Contributors: Rörig-Dalgaard, I., Ottosen, L. M., Hansen, K. K.
Chloride Ingress into Concrete under Water Pressure

The chloride ingress into concrete under water pressures of 100 kPa and 800 kPa have been investigated by experiments. The specimens were exposed to a 10% NaCl solution and water mixture. For the concrete having w/c = 0.35 the experimental results show the chloride diffusion coefficient at 800 kPa (~8 atm.) is 12 times greater than at 100 kPa (~1 atm.). For w/c = 0.45 and w/c = 0.55 the chloride diffusion coefficients are 7 and 3 times greater. This means that a change in pressure highly influences the chloride ingress into the concrete and thereby the life length models for concrete structures.

General information

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Organisations: Department of Civil Engineering, Section for Construction Materials, Technical University of Denmark
Contributors: Lund, M. S., Sander, L. B., Grelk, B., Hansen, K. K.
Pages: 207-210
Publication date: 2011

Hysteresis and Temperature Dependency of Moisture Sorption – New Measurements

It is well known that sorption characteristics of building materials exhibit hysteresis in the way the equilibrium curves develop between adsorption and desorption, and that the sorption curves are also somewhat temperature dependent. However, these two facts are most often neglected in models for combined heat and moisture transport in materials. There is a need for further elaboration of the importance of these issues, and it is the intent of this paper to contribute to such elaboration. The paper seeks to contribute to the knowledge base about such sorption characteristic by presenting some new measurements of hysteresis and temperature dependency of the moisture sorption characteristics of three different porous building materials: aerated concrete, cement paste and spruce. Scanning curves are measured for all three materials where periods with adsorption and desorption interrupt each other intermittently. For one of the materials,
aerated concrete, the sorption curves are determined at three different temperatures.

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Valuation of the 12 year old Concrete in the Ulkebugt Bridge, Sisimiut, Greenland

The Ulkebugt bridge is a vital connection for the town Sisimiut, as it is the only link between the airport and the town. The bridge is a box girder bridge with one central pillar. Most of the pillar’s concrete surface is exposed to seawater, with a tide variation around 4 meters. In addition to the seawater the bridge is exposed to the rough arctic climate. Furthermore, the mean temperature is below 0 °C for two thirds of the year with many freeze-thaw passages in late autumn and early spring, which increases the opportunity for severe frost damages. The focus has been to evaluate the quality and condition of the concrete pillar in terms of composition and the extent of the present deterioration mechanisms, best represented by frost damage and chloride ingress. Results show critical chloride content in the concrete will be reached in approximately 10 years at the depth of the reinforcement bars. However, the results also reveal the presence of some surface defects which probably is related to problems with workmanship, i.e. placing and compaction of the fresh concrete.

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Bjergarter

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Bibliographical note

Edited by The Nordic Concrete Federation.
Source: orbit
Source-ID: 282338
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2011 › Research › peer-review
Determination of resistance to salt crystallization on natural stone measured with ultrasonic wave

The use of panels as facade cladding has increased substantially during the last few decades. However, during recent years reports of facade problems have increased dramatically. Facade cladding has, in some cases, suffered from problems with durability such as exfoliation, disintegration of macrostructure and loss of strength. The damage may to some extent be accelerated by salt crystallization. This is an investigation of the durability of stones exposed to salt crystallization, by means of ultrasonic velocity measurements, compressive strength measurements and analysis of thin sections before and after salt exposure. Four different stones are investigated: the limestone Bateig Azul, the sandstone Oberkirchener, the limestone Perlatino, and the limestone Travertine. The procedure for the salt crystallization test is EN 12370 standard "Natural stone test methods – Determination of resistance to salt crystallization". Furthermore, ultrasonic velocity measurements are performed for each specimen during the salt crystallization test cycles. The ultrasonic velocity decreases from undamaged to damaged stones. The compressive strength also decreases with increasing number of cycles. After 19 cycles Bateig Azul has 1.45 km/s decrease in ultrasonic velocity and 66.3 % decrease in mean compressive strength after only 9 cycles, while Perlatino has 0.80 km/s decrease in ultrasonic velocity and corresponding 2.7 % decrease in mean compressive strength after 19 cycles. Bateig Azul has 18.4 % in open porosity while Perlatino has 1.1 % in open porosity. By means of ultrasonic measurements it is possible to detect damage in stones exposed to salt crystallization cycles. The results show a tendency to less resistance of salt crystallization for more porous materials.

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Organisations: Section for Construction Materials, Department of Civil Engineering, Ramboll Group AS
Contributors: Alm, D., Brix, S., Kjærgaard, H. H., Hansen, K. K., Grelk, B.
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Hygrothermal Properties and Performance of Sea Grass Insulation

In the attempt to obtain knowledge of the hygrothermal properties of sea grass as thermal insulation, experiments have been carried out in the laboratory to determine the thermal conductivity, sorption properties and the water vapour permeability of the material. In order to investigate the hygrothermal performance in the field, four test walls have been built. The relative humidity and temperature in the constructions have been measured during a winter period and are presented in this paper.

General information
Publication status: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Section for Construction Materials, Technical University of Denmark
Contributors: Eriksen, M. S. H., Laursen, T. B., Rode, C., Hansen, K. K.
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Publication date: 2008

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Title of host publication: Proceedings of the 8th Symposium on Building Physics in the Nordic Countries
Place of publication: Kgs. Lyngby, Denmark
Publisher: Technical University of Denmark, Department of Civil Engineering
Non-isothermal Moisture Transport Through Insulation Materials

An experimental investigation was conducted in order to draw some conclusions on the magnitude of moisture transport due to temperature gradient on a range of porous light-weight building materials. A special constructed non-isothermal set-up allowed the creation of a temperature gradient of 10K and given humidity gradient over the sample. The resulting moisture flow as well as the hygrothermal states around and within the material were monitored. The hypothesis of relative humidity being a driving force for non-isothermal moisture transport already in the hygroscopic range could not be confirmed. On the contrary, indications exist that the temperature gradient itself is driving the moisture from the warm side towards the cold side. An attempt to identify and quantify the single contributions of the different transport forms involved is also presented. The different results gave, however, diverging conclusions and therefore the question about existence of the type of transport forms driven by the non-isothermal effects remains open. Rather surprisingly, all the materials, including the almost non-hygroscopic materials (e.g. rock wool) and very hygroscopic materials (e.g. cellulose insulation) showed the same characteristics.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Building Physics and Services, Section for Construction Materials
Contributors: Peuhkuri, R. H., Rode, C., Hansen, K. K.
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Research output: Contribution to journal › Journal article – Annual report year: 2008 › Research › peer-review

Plast

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Organisations: Section for Construction Materials, Department of Civil Engineering
Contributors: Hansen, K. K.
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Pages: 143-165
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URLs:
The influence of surface treatment on mass transfer between air and building material
The processes of mass transfer between air and building structure and in the material influence not only the conditions within the material but also inside the connected air spaces. The material which absorbs and desorbs water vapour can be used to moderate the amplitude of indoor relative humidity and therefore to participate in the improvement of the indoor air quality and energy saving. Many parameters influence water vapour exchange between indoor air and building material. The aim of this work is to present the change of mass transfer under different climatic and material conditions. The measurements were performed at the Technical University of Denmark (DTU), Department of Civil Engineering. Two climatic chambers were used for the tests, the first one for dynamic and the second for steady state conditions. Two commonly used building materials exposed to the indoor environment were chosen for the experiments: gypsum board and calcium silicate. The wallpaper and paint were used as finishing materials. Impact of the following parameters for changes of RH was studied: coating, temperature and air movement. The measurements showed that acryl paint (diffusion open) can significantly decrease mass uptake. It was shown also that higher air velocity speeds up the process of mass exchange between indoor air and materials but apparently decreases the total amount of exchanged water after a longer period. The experiment allows not only to check the influence of surface treatment on mass transfer, but can be used also as validation for simulation programs. At the end of the article, a mass uptake calculation using the HUMIMUR model is presented.

General information
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Organisations: Section for Building Physics and Services, Department of Civil Engineering, Section for Construction Materials, Universite Claude Bernard Lyon 1
Contributors: Kwiatkowski, J., Rode, C., Hansen, K. K., Woloszyn, M., Roux, J.
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Publication date: 2008

Improved suction technique for the characterization of construction materials
The suction technique is a method from soil science that is used for the study of moisture storage capacity in porous construction materials at high relative humidity levels (above approximately 93 %). The samples to be studied are placed in a pressurized container (an extractor) on a water saturated ceramic disk or membrane. The pressure corresponding to a certain relative humidity level is established and moisture is expelled from the samples until moisture equilibrium is reached. This paper presents two adjustments to this method and their applicability. The first adjustment is a new procedure for determining the equilibrium moisture content of samples during the experiment. The method (referred to as the balance method) is to simply keep track of all water entering and leaving the system and use these data to estimate the moisture content of the samples. The advantage of this approach is that the experiment does not need to be stopped and restarted for each relative humidity level tested. The main disadvantage of the method is that the estimation of the moisture content in the samples depends on a correct estimation of the moisture content of the ceramic disk. The second adjustment is the development of a pressure regulation system that keeps the pressure constant (±0.015 bar) within an extractor for weeks.

General information
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Organisations: Section for Construction Materials, Department of Civil Engineering
Contributors: Thygesen, L. G., Hansen, K. K.
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Pages: Paper ID JAI100335
Publication date: 2007
Improved Suction Technique for the Characterization of Construction Materials

The suction technique is a method from soil science that is used for the study of moisture storage capacity in porous construction materials at high relative humidity levels (above approximately 93%). The samples to be studied are placed in a pressurized container (an extractor) on a water saturated ceramic disc or membrane. The pressure corresponding to a certain relative humidity level is established and moisture is expelled from the samples until moisture equilibrium is reached. This paper presents two adjustments to this method and their applicability. The first adjustment is a new procedure for determining the equilibrium moisture content of samples during the experiment. The method (referred to as the balance method) is to simply keep track of all water entering and leaving the system and use these data to estimate the moisture content of the samples. The advantage of this approach is that the experiment does not need to be stopped and restarted for each relative humidity level tested. The main disadvantage of the method is that the estimation of the moisture content in the samples depends on a correct estimation of the moisture content of the ceramic disc. The second adjustment is the development of a pressure regulation system that keeps the pressure constant (±0.015 bar) within an extractor for weeks.

Moisture buffer value: A comprehensive analysis of essential parameters

There is an increasing focus on the possibilities of utilizing the absorptive ability of porous materials to create passive control of relative humidity (RH) variations in the indoor air. This has led to the need for determination of a new parameter that can be used for characterization of materials. The dynamic nature of the buffering phenomena makes it difficult to use the standard hygrothermal material properties directly for this purpose. In this paper some experimental results on aerated cellular concrete are used for pointing out the methodological and experimental use of dynamic tests for determination of the moisture buffer value of building materials. Special focus is given to the significance of e.g. the equilibrium state, the step size in the RH and whether one is studying absorption or desorption steps. In addition, the paper summarizes shortly the experience until now of studying the moisture buffer phenomenon. In the experiments the material samples were exposed to a sudden change in the RH of the ambient air which were either consecutive absorption and desorption steps or periodically varying cyclic steps.
Etching and image analysis of the microstructure in marble

The use of thin marble panels as facade cladding has increased substantially during the last few decades. However, during recent years reports of facade failure have increased dramatically. Facade cladding of marble has, in several cases, suffered from problems with permanent expansion bowing and loss of strength. Investigation of materials microstructure by means of image analysis has given useful information in the process of finding the mechanisms causing the failure. Two different marble types are investigated. Weather resistant marble types with xenoblastic microstructure having narrower inter granular spaces and more irregular borders than the other type with granoblastic microstructure. In the preparation process of thin sections of each of the marble types the grain boundaries are intensified by an etching process. The contact length between grains on a surface and the number of grains exposed on that surface are measured on the microscope images using image analysis by the program Adobe Photoshop 7.0 with Image Processing Toolkit 4.0. The parameters measured by the program on microscope images of thin sections of two marble types are used for calculation of the coefficient of irregularity for the microstructure. The etching method and the image analysis method used for analyzing microscope images work well and the procedure gives good results for the total length of the grain boundaries and the number of grains in the same section, which are used in further investigations.

Effect of method, step size and drying temperature on sorption isotherms

The use of thin marble panels as facade cladding has increased substantially during the last few decades. However, during recent years reports of facade failure have increased dramatically. Facade cladding of marble has, in several cases, suffered from problems with permanent expansion bowing and loss of strength. Investigation of materials microstructure by means of image analysis has given useful information in the process of finding the mechanisms causing the failure. Two different marble types are investigated. Weather resistant marble types with xenoblastic microstructure having narrower inter granular spaces and more irregular borders than the other type with granoblastic microstructure. In the preparation process of thin sections of each of the marble types the grain boundaries are intensified by an etching process. The contact length between grains on a surface and the number of grains exposed on that surface are measured on the microscope images using image analysis by the program Adobe Photoshop 7.0 with Image Processing Toolkit 4.0. The parameters measured by the program on microscope images of thin sections of two marble types are used for calculation of the coefficient of irregularity for the microstructure. The etching method and the image analysis method used for analyzing microscope images work well and the procedure gives good results for the total length of the grain boundaries and the number of grains in the same section, which are used in further investigations.

Bibliographical note
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MODELING THE INITIAL PACKING OF CEMENT-BASED MATERIALS

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Moisture Buffering of Building Materials

General information
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Number of pages: 78
Publication date: 2005

Moisture Buffer Value of Materials in Buildings

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Publication status: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Section for Building Materials and Geotechnics, Norwegian Building Research Institute, Lund University, VTT - Technical Research Centre of Finland
Contributors: Rode, C., Peuhkuri, R. H., Hansen, K. K., Time, B., Svennberg, K., Arfvidsson, J., Ojanen, T.
Pages: 108-115
Publication date: 2005
Moisture penetration in a chair seat as a response to daily RH variations in the indoor air: Climatic chamber measurements and calculations

In the indoor environment there are a number of materials with potential to act as moisture buffers including both building materials and furnishing materials. For daily moisture variations in the indoor air furniture with upholstery can play an important role as moisture buffers. Material properties and calculation models describing the response to moisture variations in the ambient climate for these material combinations are limited. In this project the moisture properties for a chair seat with a wool fabric and plastic foam padding were determined. The moisture penetration in the chair seat was measured using small temperature and relative humidity sensors. A numerical calculation model describing the step-response as well as the response to ramp variations is described. A comparison between measurements and theoretical calculations was performed. The difficulties with determination of material properties for highly permeable materials are also discussed as well as suitable methods and special considerations.

General information
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Contributors: Svennberg, K., Claesson, J., Hansen, K. K.
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Moisture Transport in Wood: An Experimental and Numerical Study

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Building Materials and Geotechnics, Aalborg University
Contributors: Astrup, T., Hansen, K. K., Hoffmeyer, P., Damkilde, L.
Pages: 157-164
Publication date: 2005

NORDTEST Project on Moisture Buffer Value of Materials

Building materials and furnishing used in contact with indoor air have some effect to moderate the variations of indoor humidity in occupied buildings. Very low humidity can be alleviated in winter, as well as can high indoor humidity in summer and during high occupancy loads. Thus, materials can possibly be used as a passive means of establishing indoor climatic conditions, which are comfortable for human occupancy. But so far there has been a lack of a standardized figure to characterize the moisture buffering ability of materials. It has been the objective of a Nordic project, which is currently being completed, to develop a definition, and to declare it in the form of a NORDTEST method. Apart from the definition of the term Moisture Buffer Value, the project also declares a test protocol which expresses how materials should be tested. Finally as a part of the project, some Round Robin Tests have been carried out on various typical building materials. The paper gives an account on the definition of the Moisture Buffer Value, it outlines the content of the test protocol, and it gives some examples of results from the Round Robin Tests.

General information
Publication status: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Section for Building Materials and Geotechnics, Norwegian Building Research Institute, Lund University, VTT - Technical Research Centre of Finland
Contributors: Rode, C., Peuhkuri, R. H., Hansen, K. K., Time, B., Svennberg, K., Arvidsson, J., Ojanen, T.
Pages: 47-52
Publication date: 2005
Response of insulation materials on non-isothermal moisture transport: Final results

General information
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Organisations: Section for Building Physics and Services, Department of Civil Engineering, Section for Building Materials and Geotechnics
Contributors: Peuhkuri, R. H., Rode, C., Hansen, K. K.
Pages: 1080-1087
Publication date: 2005

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Source-ID: 184613
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Research: peer-review

The influence of moisture content on the water vapour resistance of surface coated spruce

Two series of cup tests are carried out. The first series is performed on spruce specimens having moisture transport in either radial direction (R-direction) or in tangential direction (T-direction). The T-direction tests are made as wet cup tests having 93 %RH inside the cups, while the R-direction tests are made as dry cup tests having 33 %RH in the cups. The RH in the outside climate is 60 % for both R- and T-direction. The temperature during the tests is 23 degree C. The second cup test series is performed on the same spruce specimens and at the same climatic conditions as in the first series, but now with one layer of paint (60 g/m^2) on one surface of the wood specimens. The results show that the RH level significantly influences the water vapour resistance of the paint. For wet cup tests a water vapour resistance of the paint of 6.5\times 10^8 Pa\cdot m^2\cdot s/kg in average is found. In contrast, the permeability of the specimens are not reduced by the paint for the dry cup tests.

General information
Publication status: Published
Organisations: Section for Building Materials and Geotechnics, Department of Civil Engineering
Contributors: Engelund, E., Ulriksen, L., Hansen, K. K., Astrup, T., Hoffmeyer, P.
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Publication date: 2005

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ISBN (Print): 9979-9174-4-X
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Research: peer-review

Fugttekniske undersøgelser af papiruld med en ny formulering af imprægneringen

General information
Publication status: Published
Organisations: Section for Building Materials and Geotechnics, Department of Civil Engineering
Contributors: Hansen, K. K.
Publication date: 2004
Moisture buffer capacity of different insulation materials

There is an increasing focus on the possibilities of utilizing the absorptive ability of porous materials to create passive control of humidity variations in the indoor air. These variations result in peaks in the indoor air humidity due to moisture production, or in the exterior building envelope due to the diurnal variations of outdoor air temperature and humidity. A passive control of the humidity of the indoor air - particularly together with passive thermal control - may lead to smaller energy use for climatization of buildings. For exterior envelopes, the choice of right materials can lead to more durable constructions. In this paper, a large range of very different thermal insulation materials have been tested in specially constructed laboratory facilities to determine their moisture buffer capacity. Both isothermal and nonisothermal experimental set-ups have been used. In the isothermal tests the material samples were exposed to the same change in the relative humidity of the ambient air on both sides, while the samples were exposed to variations in relative humidity only on the cold side in the non-isothermal tests. The results of these rather different measurement principles are discussed, and different ways are presented how to determine the moisture buffer capacity of the materials using partly standard material parameters and partly parameters determined from the actual measurements. The results so far show that the determination of moisture buffer capacity is very sensitive to the used analysis method and therefore great care has to be taken when comparing results of different experiments. This paper discusses this issue and will come with a recommendation of a simple and consistent way to present the moisture buffer capacity of the materials in contact with the indoor air on the basis of experimental results.

General information
Publication status: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Section for Building Materials and Geotechnics
Contributors: Peuhkuri, R. H., Rode, C., Hansen, K. K.
Marble exposed to temperature cycles at high relative humidity (RH) under laboratory conditions lose strength similar to loss of strength for the same marble exposed to natural climate. Two marble types from three different building facades in Copenhagen are studied. From each building a marble cladding panel exposed for the south facing natural climate during 29, 60 and 61 years, respectively, and a cladding panel of each of the marble types only exposed for indoor climate are cut in bars of size 30x30x300 mm. The bars from indoor are exposed to temperature cycles between 10 °C and 60 °C at nearly 100% RH and at nearly 0% RH. The strength of the natural exposed marble as well as the laboratory-exposed marble are measured as flexural strength under concentrated load using four-point loading. Analysis of the strength test show that it is possible to transfer test results for laboratory exposed marble to results for natural exposed marble.
Comparison of Experimental Methods for the Measurement of Non-Isothermal Moisture Transport

General information
Publication status: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Section for Building Materials and Geotechnics
Publication date: 2003

Host publication information
Title of host publication: Proceedings of the 2nd Int. Building Physics Conference
Source: orbit
Source-ID: 23795

Fugtfordeling i absorberende isoleringsmaterialer: Moisture distribution in absorbent insulation

General information
Publication status: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Section for Construction Materials
Contributors: Peuhkuri, R. H., Rode, C., Padfield, T., Hansen, K. K., Mortensen, L. H.
Publication date: 2003

Publication information
Original language: Danish
(ByG Sagsrapport; No. SR 03-11).
Electronic versions:
SR-03-11.pdf
Source: orbit
Source-ID: 190467

Fugtfordeling i absorberende isoleringsmaterialer: Moisture distribution in absorbent insulation

General information
Publication status: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Section for Building Materials and Geotechnics
Contributors: Peuhkuri, R. H., Rode, C., Padfield, T., Hansen, K. K., Hedegaard, L. G.
Number of pages: 53
Publication date: 2003

Publication information
Place of publication: Lyngby
Publisher: DTU Byg, Danmarks Tekniske Universitet
Original language: English
(Sagsrapport; No. SR-03-11).
URLs:
http://www.byg.dtu.dk
Source: orbit
Source-ID: 60979

Isoteric vapor pressure: Temperature data for water sorption in hardened cement paste: enthalpy, entropy and sorption isotherms at different temperatures

General information
Moisture movements in render on brick wall

A three-layer render on brick wall used for building facades is studied in the laboratory. The vertical render surface is held in contact with water for 24 hours simulating driving rain while it is measured with non-destructive X-ray equipment every hour in order to follow the moisture front through the render and into the brick. The test specimen is placed between the source and the detector. The test specimens are all scanned before they are exposed to water. In that way the loss of counts from the dry scan to the wet scan qualitatively shows the presence of water. The results show nearly no penetration of water through the render and into the brick, and the results are independent of the start condition of the test specimens. Also drying experiments are performed. The results show a small difference in the rate of drying, in favour of the bricks without render.

Drying of Concrete

Estimated and measured relative humidity (RH) change during drying are compared for two concretes, 1: w/c=0.46 and 2: w/(c+0.5fa+2sf)=0.50. The estimations were undertaken by means of the Swedish program TorkaS 1.0. Measurements were performed by RH-sensors type Humi-Guard. Drying of 150 mm thick samples from sides at 60% RH and 22 °C took place from 4 to 56 days after casting. At the end of the drying period the measured RH was about 4% lower than the estimated RH at 1/5th depth from the exposed surface for both concretes. In the middle of the samples, the measured RH of concretes 1 and 2 were 2% lower and 2% higher, respectively, than estimated values.
Natural stone panels for building facades. Loss of strength caused by temperature cycles

Five different types of natural stone used for building facades are studied. Test specimens have been exposed to 1, 10 or 20 temperature cycles between about 25°C and 70°C at 100% RH or 0% RH. Test specimens stored at laboratory climate are used as reference. The strength of each type of stone is measured before and after exposures. The strength is measured as flexural strength under concentrated load using quarter-point loading.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Ramboll Group AS
Contributors: Lemvig, J., Rasmussen, J., Jensen, J., Olsson, M., Schultz, J., Hansen, K. K., Greik, B.
Pages: 683-690
Publication date: 2002

Event information
Event: 6th Symposium on Building Physics in Nordic Countries
Location: Trondheim, Norway
Source: orbit
Source-ID: 64313
Research output: Chapter in Book/Report/Conference proceeding » Article in proceedings – Annual report year: 2002 » Research » peer-review

Non-isothermal water vapour transmission through porous insulation. Part 1

General information
Publication status: Published
Event information
Event: 6th Symposium on Building Physics in Nordic Countries
Location: Trondheim, Norway
Source: orbit
Source-ID: 90458
Research output: Non-textual form » Sound/Visual production (digital) – Annual report year: 2002 » Research

Non-isothermal water vapour transmission through porous insulation. Part 1

General information
Publication status: Published
Non-isothermal water vapour transmission through porous insulation. Part 2

General information
Publication status: Published
Organisations: Department of Civil Engineering, Technical University of Denmark
Contributors: Peuhkuri, R. H., Padfield, T., Rode, C., Hansen, K. K.
Number of pages: 920
Pages: 421-428
Publication date: 2002

Host publication information
Title of host publication: Building Physics in the Nordic Countries
Volume: Volume 1
Place of publication: Trondheim, Norway
Publisher: Norwegian University of Science and Technology
ISBN (Print): 82-91412-02-2
Source-ID: 64023
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2002
Research: peer-review

Unfired clay bricks – moisture properties and compressive strength
Apparatus, methods and test results from an experimental investigation of (1) the properties for moisture performance of the materials, including water vapour sorption and water vapour transmission, (2) humidity buffering of the indoor climate by an absorbent material, and (3) the compressive strength are presented.

General information
Publication status: Published
Organisations: Department of Civil Engineering
Contributors: Hansen, E. D. P., Hansen, K. K.
Pages: 453-460
Publication date: 2002

Host publication information
Title of host publication: Proceedings of the 6th Symposium on Building Physics in the Nordic Countries
Volume: 2
Place of publication: Trondheim, Norway
Publisher: Skipnes AS
ISBN (Print): 82-91412-02-2
Source-ID: 64311
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2002
Research: peer-review

Unfired clay bricks – retention curves and liquid diffusivities
This paper presents retention curves and liquid diffusivities of two different types of unfired clay bricks, both produced in Denmark on commercial basis. The retention curves are determined by use of pressure plate and pressure membrane
apparatuses. The liquid diffusivity is calculated on the basis of capillary rise of water measured by use of X-ray equipment. The data from the capillary rise of water is transformed by the Boltzmann transformation.
Influence of Cement Particle-Size Distribution on Early Age Autogenous Strains and Stresses in Cement-Based Materials

The influence of cement particle-size distribution on autogenous strains and stresses in cement pastes of identical water-to-cement ratios is examined for cement powders of four different finenesses. Experimental measurements include chemical shrinkage, to quantify degree of hydration; internal relative humidity development; autogenous deformation; and eigenstress development, using a novel embedded spherical stress sensor. Because the latter three measurements are conducted under sealed conditions, whereas chemical-shrinkage measurements are made under "saturated" conditions, the National Institute of Standards and Technology cement hydration and microstructure development model is used to separate the effects of differences in hydration rates (kinetics) from those caused by the different initial spatial arrangement of the cement particles. The initial arrangement of the cement particles controls the initial pore-size distribution of the cement paste, which, in turn, regulates the magnitude of the induced autogenous shrinkage stresses produced by the water/air menisci in the air-filled pores formed throughout the hydration process. The experimental results indicate that a small autogenous expansion (probably the result of ettringite formation), as opposed to a shrinkage, may be produced and early age cracking possibly avoided through the use of coarser cements.

Intercomparison on measurement of water vapour permeability

Three different materials are tested - hard woodfibre board - damp proof course - underlay for roofing The water vapour permeability has been measured according to EN ISO 12572 (2001).
Shrinkage-reducing admixtures and early-age desiccation in cement pastes and mortars

Fundamental studies of the early-age desiccation of cement-based materials with and without a shrinkage-reducing admixture (SRA) have been performed. Studies have been conducted under both sealed and drying conditions. Physical measurements include mass loss, surface tension, X-ray absorption to map the drying profile, internal relative humidity (RH), and autogenous deformation. Interestingly, although the SRA accelerates the drying of bulk solutions, in cement paste with a water-to-cement (w/c) ratio of 0.35, it actually reduces the measured drying rate. Based on the accompanying X-ray absorption measurements and a simple three-dimensional microstructure model, an explanation for this observation is proposed. In sealed systems, at equivalent hydration times, the SRA maintains a greater internal RH and reduces the induced autogenous deformation. Thus, these admixtures should be beneficial to low w/c ratio concretes undergoing self-desiccation, in addition to their normal usage to reduce drying shrinkage.
Preliminary observations of water movement in cement pastes during curing using X-ray absorption

X-ray absorption and concurrent mass measurements are used in quantifying water movement in 4 to 5 mm thick cement paste specimens with their top surface exposed to drying. Experimental variables examined in this preliminary study include water-to-cement (w/c) ratio and open vs. capped samples. Layered specimens (e.g., 0.3 w/c ratio paste over 0.45 w/c ratio paste) are also examined to monitor the preferential water movement from less dense (higher w/c ratio) paste to denser paste due to capillary forces. For the open samples examined in this study, the initial drying is observed to occur uniformly throughout the thickness of the specimen, as opposed to proceeding as a sharp front progressing inward from the surface exposed to the external environment. In the layered specimens, the higher w/c ratio paste layer is seen to "dry out" first regardless of its location within the composite. The implications of these experimental observations for curing of concrete and application of repair materials are discussed.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Building Design, National Institute of Standards and Technology
Contributors: Bentz, D. P., Hansen, K. K.
Number of pages: 12
Pages: 1157-1168
Publication date: 2000
Peer-reviewed: Yes

Publication information
Journal: Cement and Concrete Research
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Issue number: 7
ISSN (Print): 0008-8846
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Scopus rating (2000): SJR 0.625 SNIP 1.418
Original language: English
Keywords: Cement paste, Curing, Drying, Water movement, X-ray absorption
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Research output: Contribution to journal › Journal article – Annual report year: 2000 › Research › peer-review

Concrete, hardened: Self desiccation
The test method covers the determination of internal relative humidity (RH) in hardened concrete and cement mortar using RH instruments. The determination of RH is done on crushed samples of concrete or cement mortar. This test method is only for measuring equipment which gives off or takes up humidity to a limited extent, so that a stable RH value can be obtained within 24 hours.

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials, Lund Institute of Technology
Contributors: Hansen, E. J. D. P., Hansen, K. K., Persson, B.
Publication date: 1999

Publication information
Original language: English
Source: orbit
Source-ID: 171045
Research output: Book/Report › Report – Annual report year: 1999 › Research › peer-review

Dual-energy X-ray absorptiometry for the simultaneous determination of Density and Moisture Content in Porous Structural Materials

General information
Publication status: Published
Organisations: Department of Physics, Guru Nanak Dev University
Durability of cracked fibre reinforced concrete structures exposed to chlorides

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials, Technical University of Denmark
Contributors: Hansen, E. J. D. P., Ekman, T., Hansen, K. K.
Pages: 280-289
Publication date: 1999

Host publication information
Title of host publication: Durability of Building Materials & Components 8. Service Life and Asset Management
Place of publication: Ottawa, Canada
Publisher: NRC Research Press
Source: orbit
Source-ID: 172381
Research output: Chapter in Book/Report/Conference proceeding > Article in proceedings – Annual report year: 1999 > Research > peer-review

Durability of fibre reinforced concrete structures exposed to combined mechanical and environmental load

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials
Contributors: Hansen, E. J. D. P., Hansen, K. K.
Publication date: 1999

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Title of host publication: Proc. Nordic Concrete Research Meeting, Reykjavik, Iceland, 1999
Place of publication: Oslo
Publisher: Norsk Betongforening
Source: orbit
Source-ID: 172771
Research output: Chapter in Book/Report/Conference proceeding > Article in proceedings – Annual report year: 1999 > Research > peer-review

Hovedrapport. Varme- og fugttekniske undersøgelser af alternative isoleringsmaterialer

General information
Publication status: Published
Organisations: Department of Buildings and Energy
Contributors: Hansen, K. K., Hansen, E. J. D. P., Padfield, T., Rode, C., Kristiansen, F. H.
Publication date: 1999

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http://www.bkm.dtu.dk
Source: orbit
Source-ID: 174835
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Kapillarsugning: Del af Varme- og fugttekniske undersøgelser af alternative isoleringsmaterialer

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials
Contributors: Hansen, K. K., Hansen, E. J. D. P.
Publication date: 1999

Publication information
Original language: Danish
URLs:
http://www.bkm.dtu.dk
Source: orbit
Source-ID: 174837
Research output: Book/Report › Report – Annual report year: 1999 › Research › peer-review

Measured moisture properties for alternative insulation products

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials, National Museum of Denmark
Contributors: Hansen, E. J. D. P., Hansen, K. K., Padfield, T.
Pages: 121-128
Publication date: 1999

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Place of publication: Göteborg, Sweden
Publisher: Chalmers tekniska högskola
Source: orbit
Source-ID: 172736
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 1999 › Research

Sorptionsisotmer: Del af Varme- og fugttekniske undersøgelser af alternative isoleringsmaterialer

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials
Contributors: Hansen, E. J. D. P., Hansen, K. K.
Publication date: 1999

Publication information
Original language: Danish
URLs:
http://www.bkm.dtu.dk
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Source-ID: 174838
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General information
Publication status: Published
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Contributors: Hansen, E. J. D. P., Hansen, K. K.
Publication date: 1999

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http://www.bkm.dtu.dk
Betons selvudtørring. Rapportering af Fase I fra NORDTEST projekt nr. 1325-97

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials, Lund University
Contributors: Hansen, K. K., Hansen, E. J. D. P., Persson, B.
Number of pages: 63
Publication date: 1998

Original language: Danish

Drying of concrete. Part I: A comparison of instruments for measuring the relative humidity in concrete structures

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials
Contributors: Hansen, K. K., Christensen, S. L.
Pages: 279-287
Publication date: 1998

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Title of host publication: Papers and Abstracts from the Third International Symposium on Humidity and Moisture
Place of publication: Teddington, UK
Publisher: National Physical Laboratory, Teddington
Source: orbit
Source-ID: 170665
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 1998 – Research

Drying of concrete. Part II: The drying time of concrete structures

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials
Contributors: Hansen, K. K., Christensen, S. L.
Pages: 295-301
Publication date: 1998

Host publication information
Title of host publication: Papers and Abstracts from the Third International Symposium on Humidity and Moisture
Place of publication: Teddington, UK
Publisher: National Physical Laboratory
Source: orbit
Source-ID: 170676
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 1998 – Research

"Sorpvej" for Sorption Curves - A Windows Program for collecting Weighing Data and determining Equilibrium State

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials
Contributors: Strømdahl, K., Hansen, K. K.
Pages: 252-253
Publication date: 1998
Host publication information
Title of host publication: Proceedings of International Symposium on Humidity & Moisture
Place of publication: London
Source: orbit
Source-ID: 170780
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 1998 › Research › peer-review

Vejledning til brugen af Brüel & Kjær Multichannel Signal Analyzer type 3550 ... med en kort introduktion til brugen af Brüel & Kjær DeltaTron-accelerometre

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials
Contributors: Madsen, H., Rohde, V. W., Hansen, K. K.
Number of pages: 32
Publication date: 1998

Publication information
Original language: Danish
Source: orbit
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Equipment for measuring autogenous RH-change and autogenous deformation in cement paste and concrete

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials
Contributors: Hansen, K. K., Jensen, O. M.
Pages: 27-30
Publication date: 1997

Host publication information
Title of host publication: Self-desiccation and its importance in concrete technology
Place of publication: Lund
Publisher: Lund Institute of Technology
Source: orbit
Source-ID: 165495
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 1997 › Research › peer-review

Porosity and liquid absorption of cement paste

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials, Fraunhofer-Gesellschaft
Contributors: Krus, M., Hansen, K. K., Kunzel, H. M.
Pages: 394-398
Publication date: 1997
Peer-reviewed: Yes

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Journal: Materials and Structures
Volume: 30
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Source-ID: 168878
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Durability of fibre reinforced concrete structures

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials
Contributors: Hansen, E. J. D. P., Hansen, K. K.
Pages: 277-278
Publication date: 1996

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Place of publication: Oslo, Norway
Publisher: Norsk Betongforening, Postboks 2312 Solli, N-0201 Oslo
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Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 1996 – Research

Experimental drying shrinkage of hardened cement pastes as a function of relative humidity

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials, LCPC Laboratoire Central des Ponts et Chaussees
Contributors: Hansen, K. K., Baroghel, V.
Pages: 18-19
Publication date: 1996

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Title of host publication: Nordic Concrete Research. Research Projects 1996
Place of publication: Oslo
Publisher: Norsk Betongforening, Postboks 2312 Solli
Source: orbit
Source-ID: 166126
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 1996 – Research

Microstructure in hardened cement pastes measured by mercury intrusion porosimetry and low temperature microcalorimetry

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials, LCPC Laboratoire Central des Ponts et Chaussees, Fraunhofer-Gesellschafter
Contributors: Hansen, K. K., Baroghel, V., Künzel, H.
Pages: 27-28
Publication date: 1996

Host publication information
Title of host publication: Nordic Concrete Research. Research Projects 1996
Place of publication: Oslo
Publisher: Norsk Betongforening, Postboks 2312 Solli
Source: orbit
Source-ID: 166125
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 1996 – Research

Microstructure in hardened cement pastes measured by mercury intrusion porosimetry and low temperature microcalorimetry

General information
Publication status: Published
Organisations: Department of Structural Engineering and Materials, LCPC Laboratoire Central des Ponts et Chaussees, Fraunhofer-Gesellschafter
Vejledning til Windows-programmet SorpVej til sorptionsmåling

Combined heat and moisture transfer in building constructions

Fugtfysik: Kopmetoden - kritisk analyse og metodeudvikling
Sorption isotherms: A catalogue
In the present catalogue sorption isotherms for more than 100 materials are plotted. A page of the catalogue shows both data values and a figure with data points and approximated curves. The data base has been built up using an IBM PC.

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Organisations: Section for Construction Materials, Department of Civil Engineering
Contributors: Hansen, K. K.
Number of pages: 137
Publication date: 1986

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Original language: English

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