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Assessment of test methods for characterizing the hydrophobic nature of surface-treated High Performance Concrete

Sandro Weisheit [a], Seraphin Hubert Unterberger [b,c], Tobias Bader [b,c], Roman Lackner [b,c,*]

[a] Institute for Materials Research and Testing at Bauhaus-University Weimar, Department Building Materials, Coudraystraße 9, 99423 Weimar, Germany
[b] Unit of Material Technology, University of Innsbruck, Technikerstraße 13, 6020 Innsbruck, Austria
[c] Christian Doppler Laboratory for Cement and Concrete Technology, Technikerstraße 13, 6020 Innsbruck, Austria

HIGHLIGHTS

- Silane/siloxane based surface water repellent treatment for *High Performance Concrete* (HPC).
- Comparison between untreated, treated and naturally weathered specimens.
- Direct and indirect methods to evaluate hydrophobic performance.
- In case of HPC, indirect methods reach their limits.
- Direct methods IR spectroscopy and Energy Dispersive X-ray Analysis show promising performance.

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ABSTRACT

The durability of concrete and concrete structures is significantly influenced by environmental conditions, resulting in e.g. the ingress of water and incorporated aggressive agents, with the latter being responsible for initiating and progress of deterioration processes within the material system. In order to reduce the ingress of water, water repellent agents are applied onto the concrete surface (surface treatment), with its performance strongly depending on the agent itself, the mode of application, environmental conditions etc. For the assessment of the performance of surface-treated concrete, standard test methods, such as Karsten-Tube penetration test, contact angle measurement, hydrophobic quality test, as well as more refined test methods, such as Infrared Spectroscopy (IR), moisture sorption analysis, and scanning electron microscopy coupled with elemental X-ray analysis (SEM/EDS) are used. These methods are commonly employed for the assessment of surface-treated ordinary concrete, leaving the question on their applicability to material systems exhibiting a denser microstructure, such as High Performance Concrete (HPC), unanswered. Within this experimental study, the aforementioned test methods are critically reviewed regarding their potential application to HPC, finally providing recommendations for evaluating the performance and durability of water-repellent surface treatment when applied to HPC.

1. Introduction

Concrete is the most frequently used porous building material that absorbs water due to capillary forces. The ingress of water and incorporated aggressive agents (chloride, sulfate, carbon dioxide) are responsible for the initiation and progress of deterioration processes reducing the durability of concrete and concrete structures. The aforementioned deterioration may result from physical (e.g. freeze–thaw cycles [1]) and chemical action (e.g. efflorescence/ salt crystallization [2,3], carbonation [4] and chloride-induced corrosion [5]). In order to avoid the ingress of water associated with the mentioned deterioration processes, the permeability of concrete itself may be reduced by the use of permeable formwork, decreasing the water/cement-ratio (w/c-ratio) leading to a reduced pore space and permeability up to 20 mm of depth [5]. Alternatively, the ingress of water may be reduced by surface treatment, such as [6]: (i) hydrophobic impregnation, (ii) impregnation, and (iii) coating (see Fig. 1).

* Corresponding author at: Unit of Material Technology, University of Innsbruck, Technikerstraße 13, 6020 Innsbruck, Austria.
E-mail address: roman.lackner@uibk.ac.at (R. Lackner).

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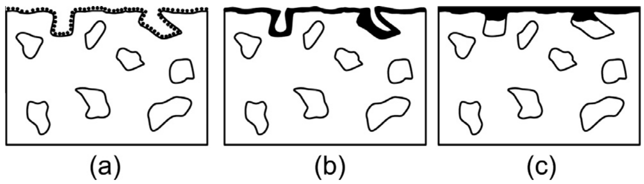

Fig. 1. Schematic illustration of the three major types of surface treatment of concrete: (a) hydrophobic impregnation, (b) impregnation, and (c) coating (adapted from [6]).

In case of hydrophobic impregnation, the pore space is lined with a thin layer of active ingredient making the surface water repellent. Consequently, capillary absorption of liquid water is reduced while the water–vapor permeability is hardly influenced. Most frequently used water repellent agents are silane/siloxane based [7–10]. Impregnation, on the other hand, reduces the permeability by partially or totally filling the pore space near the concrete surface, also affecting the water–vapor diffusion [11]. Coating is characterized by a continous layer on the surface sealing the pore space [6].

The performance of concrete surface treatment is most commonly investigated by:

(i) capillary water uptake using the *Karsten-Tube* penetration test [12,13],
(ii) SEM/EDS analysis [14,15],
(iii) contact-angle measurements [16,17],
(iv) FT-IR spectroscopy [14,18],
(v) hydrophobic quality test [10], and
(vi) neutron radiography [19–21].

An assessment of these methods when applied to ordinary concrete treated with surface water repellent impregnation is reported in [9,22]. As these test methods were originally developed for application to ordinary concrete, with a water/cement-ratio ranging from 0.45 to 0.60, their performance when applied to material systems showing a denser pore space in consequence of e.g. decreased w/c-ratio (as it is the case at High Performance Concrete, see Fig. 2) is questionable, especially in cases where the ingress of liquids into the pore space is monitored by standard testing procedures such as the mentioned Karsten-Tube penetration test.

Accordingly, the questions of experimental testing of the concrete-surface treatment in case of High Performance Concrete is addressed in this paper, with the goal of establishing a proper testing procedure to be, later on, applied to locally assessment of different water repellent agents at the construction.

2. Materials

2.1. Cementitious Material

The investigated *High Performance Concrete (HPC)* was produced using a CEM I 42.5 R and as additives microsilica and metakaolin. The total amount of fines, comprising cement, additives, and fines of sand (<125 μm) was 970 kg/m^3. The water/binder-ratio (w/b-ratio) was 0.38. The maximum aggregate size of used crushed sand was 0.8 mm.

After 28 days of water curing the so-obtained HPC showed a compressive strength of 110 N/mm^2 and a flexural strength of 12 N/mm^2. The total porosity of the investigated HPC was determined in previous research using mercury intrusion porosimetry (MIP), with Fig. 3 showing the pore-size distribution of three measured samples [24]. The average pore size is 0.013 μm and the total amount of porosity is about 9%, reflecting the aforementioned denser structure of the employed HPC with respect to an ordinary concrete [5].

2.2. Water repellent

The used water repellent is based on silane/siloxane copolymer. This copolymer was developed especially for HPC and is not commercially available. For application purposes, an aqueous solution, containing 31 vol-% of active substance, was mixed. For detailed information about the properties of the used water repellent, see Table 1.

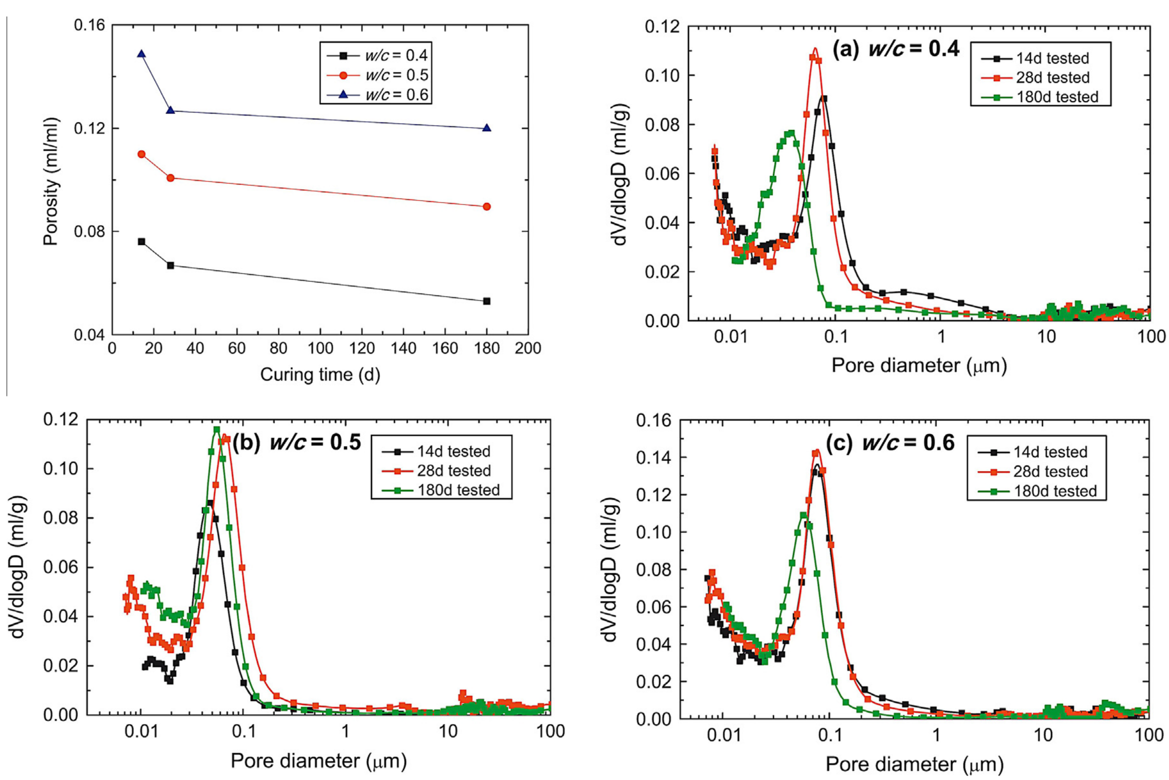

Fig. 2. Effect of w/c-ratio and curing time on porosity with corresponding differential intruded volume vs. pore diameter for cement mortar [23].