

A19: Hygrothermal material and corrosion model for concrete

Christian Bludau^{*a}, Tobias Schöner^a, Eri Tanaka^a, Daniel Zirkelbach^a,
Christoph Dauberschmidt^b, Patrick Breugl^b

a Fraunhofer Institute for Building Physics (IBP), Department Hygrothermics, Valley, Germany
b Munich University of applied Sciences, München, Germany

* Corresponding author: christian.bludau@ibp.fraunhofer.de

How to cite: Bludau, C. Schöner, T., Tanaka, E., Zirkelbach, D., Dauberschmidt, C., Breugl, P. (2025) Hygrothermal material and corrosion model for concrete. In: Abstracts of *the 3rd International Conference on Moisture in Buildings 2025*, 23-24 Oct 2025, Portugal. *UCL Open Environment*: UCL Press; 2025. Pp 1-3. DOI: 10.14324/111.444/ucloe.icmb25.a19

Peer review statement

This abstract has undergone single blind review by the ICMB25 Conference Scientific Committee.

Copyright and open access

©2025 The Authors. Creative Commons Attribution Licence (CC BY) 4.0 International licence
<https://creativecommons.org/licenses/by/4.0/>

Open access

This is an open access article distributed under the terms of the Creative Commons Attribution Licence (CC BY) 4.0 <https://creativecommons.org/licenses/by/4.0/>, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

About the conference

The following abstract is from the 3rd International Conference on Moisture in Buildings (<https://ukcmb.org/icmb25>) held in UM Guimarães, Portugal, on the 23-24 Oct 2025. All abstracts published here underwent single blind review by the Conference Scientific Committee.

Abstract

The investigation of the moisture behaviour in concrete is crucial for assessing the corrosion risk of reinforcements. In the CRUFI and NAVE projects, literature review on corrosion in concrete was evaluated and various concrete specimens with different chloride contents were investigated and their hygrothermal properties and corrosion behaviour were analysed. Furthermore, a three-stage evaluation procedure for determining corrosion risk in concrete was created. Additionally, material-dependent corrosion maps were created to assess the long-term corrosion behaviour of steel.

Peer-review under the responsibility of the organizing committee of the ICMB25.

Keywords: Concrete; moisture distribution; liquid transport; transient corrosion prediction; chloride induced corrosion

Nomenclature

IBP Fraunhofer Institute for Building Physics (IBP) MUAS Munich University of Applied Sciences
WUFI Wärme und Feuchte instationär (Transient heat and moisture) – scientific hygrothermal calculation tool

1. Introduction/Background

Compared to other materials, concrete is quite moisture-resistant with rather high diffusion resistance and low liquid transport. For this reason, hygrothermal simulation tools have not played an important role in moisture safety design of concrete structures in the past. Instead, vapour diffusion calculations neglecting capillary flow have

mostly been used to assess the moisture behaviour of concrete. However, if the risk of reinforcement corrosion is to be analysed, these approaches are not appropriate.

To improve the moisture transport models and develop a transient prediction model for corrosion in concrete, two publicly funded research projects have been carried out: CRUFI [1], dealing with moisture related material properties and improvement of hygrothermal simulation tools for concrete and NAVE [2]. As part of CRUFI, the corrosion behaviour of concrete without and with chloride content is investigated to create corrosion maps as basis for the corrosion evaluation.

2. Investigations on concrete, modelling and corrosion

For CRUFI, different types of normal and recycling concrete were investigated at MUAS and test specimens were produced and conditioned to determine material properties and perform corrosion tests. The test specimens were prepared according to two basic mix designs with CEM I and CEM III, w/c ratio 0.55 and additional specimens containing chloride at various concentrations (1.5 wt.-%, 2 wt.-%, 3 wt.-%) were produced.

The material properties, required for hygrothermal simulation, were measured in the IBP laboratory: true density, bulk density, free water saturation, water vapour diffusion resistance, equilibrium moisture content and water absorption coefficient (A value). Furthermore, the sorption isotherms for the materials are created based on the equilibrium moisture content at different RH levels. From the A value and free saturation tests, liquid transport coefficients were determined according to [3]. Material data sets were generated, and concrete specimen tests served as benchmark for the WUFI-simulations. Some of the specimens were also exposed at the IBP field test site to investigate their long-term behaviour under real weather conditions.

Previous studies have shown [4] that capillary transport in concrete may be affected over time under natural weathering. Several possible causes have been suggested to explain liquid flow inhibition by swelling and even blocking of the capillary pores by particles in the material. However, simulations cannot reproduce this effect based on material properties determined in the lab, as the liquid transport coefficients in the models can only change depending on the moisture content but not over time.

Research on a capillary barrier in concrete [5] has shown that liquid water transport only occurs close to the surface of the concrete up to a depth of a few centimetres. However, the exact depths could not be determined. The concrete is therefore separated into three layers, with liquid transport in the surface layers and only vapour diffusion transport in the core layer. The boundary layers are in exchange with the surrounding climate and allow the absorption and redistribution of precipitation by liquid transport and diffusion. The core layer, on the other hand, has an increased diffusion resistance and does not allow for liquid transport at all. The model as well as the thicknesses of the surface layers are calibrated using actual measurements from field tests.

A three-stage evaluation procedure was created to assess the corrosion risk of reinforcement in mortar/concrete, lime mortar and gypsum. The temperature and humidity conditions at the position of the embedded steel are determined using hygrothermal simulations. In stage I, the result evaluation is only based on a limit moisture level (<80% RH for concrete and <60% RH for non-cementitious materials) below which no corrosion is to be expected. In stage II, a temperature and moisture dependent limit curve is used which should not be exceeded by hourly conditions (Fig. 1a). In stage III, the corrosion behaviour over time is rated depending on corrosion conditions and binder types using corrosion maps. Thus, the temporal corrosion behaviour of the steel is determined (Fig. 1b). This evaluation can be done with the software WUFI[®] Corr [6].

Material dependent corrosion maps are required for stage III. For this reason, three-electrode corrosion tests (Fig. 1c) were performed by MUAS. The corrosion progress was consolidated and observed under defined conditions (20°C, 98% rel. humidity). The corrosion parameters are then determined by potentiostatic corrosion and resistance measurements. Afterwards, the samples are stored in an indoor climate, and additional electrochemical measurements (polarization resistances) are carried out. The corrosion potential was measured on the anodes over the conditioned period against a silver/silver nitrate reference electrode. Simultaneously the corrosion currents were monitored using TMMO cathodes within the specimen. The current densities for the CEM I samples with chlorides remain in an uncritical range. The results of the CEM III samples show a higher corrosion activity which decreases over time (Fig. 1d). The measurements were in an early stage and had not yet been completed at the time, the abstract was written. The actual state will be presented at the conference. After completion, these results are used to produce corrosion maps for steel in concrete.

(a)

(b)

(c)

(d)

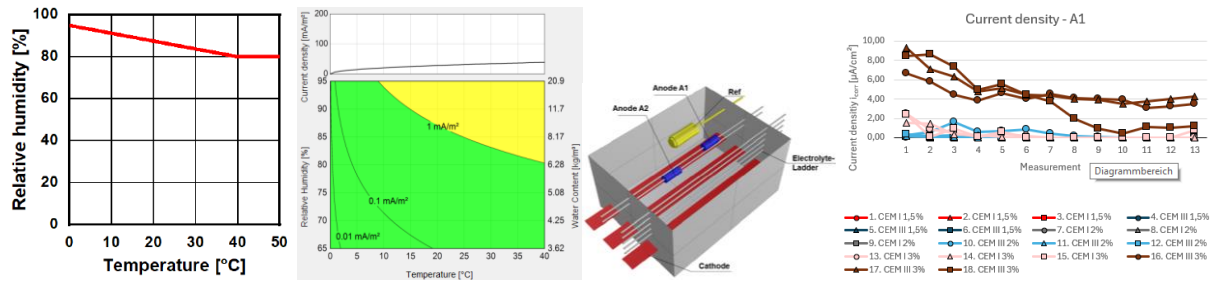


Figure 1. (a) Limit stage II; (b) corrosion map for concrete; (c) corrosion test specimen; (d) current density in concrete test specimen

3. Conclusion

The determination of the material properties of different concretes and the improvement of the simulation model for concrete allows reliably predict the hygrothermal conditions at the reinforcement layer. In addition, different concretes without and with chlorides have been studied to create material-related corrosion maps for the assessment of corrosion. Both together allows a transient prediction of risk an potential progression of corrosion of the reinforcement.

References

- [1] CRUFI Report not yet finished - <https://www.ibp.fraunhofer.de/en/projects-references/crufi.html>
- [2] Zirkelbach et. al. (2022): Nachweisverfahren für die schadenfreie energetische Bestandssanierung und Neubauplanung (NaVe). Abschlussbericht 2022, BMWi 03ET1649 A/B.
- [3] Krus, M. (1996). Moisture transport and storage coefficients of porous mineral building materials: Theoretical principles and new test methods. Dissertation Uni Stuttgart
- [4] Holm, A., Krus, M., & Künzel, H. M. (2000). Beton aus feuchtetechnischer Sicht: Kennwerte und rechnerische Bewertungsansätze für Klimawirkungen in Betonaußenbauteilen. IRB-Verlag. Stuttgart
- [5] Holm, A., Krus, M., & Künzel, H. M. (1999). Grenzen der Feuchtetransportberechnung bei Betonaußenbauteilen. *Tagungsband 5. Internationales Kolloquium - Werkstoffwissenschaften und Bauinstandsetzen*, 5, 405-414, Freiburg.
- [6] WUFI Corr - <https://wufi.de/en/software/wufi-add-ons/>

Publisher note

The abstracts published in this Supplement have been typeset from electronic submissions and camera-ready copies prepared by the authors. Every effort has been made to reproduce faithfully the abstracts as submitted. These abstracts have been prepared in accordance with the requirements of the International Conference on Moisture in Buildings 2025 and the UK Centre for Moisture in Buildings and have not been subjected to review nor editing by the journal *UCL Open Environment* (published by UCL Press). However, no responsibility is assumed by the organisers or publisher for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of methods, products, instructions or ideas contained in the material herein.