NOVEL INSIGHTS INTO THE CARBONATION OF CONCRETE WITH SUPPLEMENTARY CEMENTITIOUS MATERIALS – RESULTS OF RILEM TC 281-CCC

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ABSTRACT

Substitution of part of the Portland cement clinker by supplementary cementitious materials (SCMs) to compose blended cements, is one of the proposed measures for reducing carbon dioxide emissions associated with concrete production. However, lowering the clinker content can lead to an increasing risk of carbonation, decreasing the pH in the concrete pore solution and potentially leading to reinforcement corrosion. Carbonation of concrete with SCMs differs from carbonation of Portland cement concrete, because of the differences in hydrate assemblage and pore solution chemistry, pore structure and transport properties. The carbonation mechanism and kinetics also depend on the saturation degree of the concrete and the carbonation exposure conditions (e.g. relative humidity, moisture load, temperature, CO_2 partial pressure), which in turn influence the microstructural changes identified upon carbonation. RILEM technical committee 281-CCC "Carbonation of Concrete with Supplementary Cementitious Materials", has worked 6 years to provide a deeper insight in the effect of different SCM characteristics, exposure environments and curing conditions on the carbonation mechanism and kinetics. The findings are presented in a topical collection of journal papers, and will be summarized in this lecture.

Apart from an extensive literature review, TC 281-CCC has carried out an interlaboratory comparison with 22 participating laboratories to determine carbonation coefficients for mortar and concrete with three cement types (CEM I, CEM II/B-V, CEM III/B) by following different (inter)national standards (varying in sample curing, pre-conditioning and carbonation exposure conditions). Results of natural indoor and outdoor exposure have been compared with accelerated carbonation results.

Furthermore, a comprehensive database has been established, collected from the literature, own results, and unpublished testing reports, consisting of 1044 concrete and mortar mixes with their associated carbonation depth data over time. The database has been analysed to investigate the effects of binder composition and mix design, curing and preconditioning, and relative humidity on the carbonation rate. Furthermore, the accuracy of accelerated carbonation testing as well as possible correlations between compressive strength and carbonation resistance were evaluated. The analysis revealed that the $w/CaO_{reactive}$ ratio is a decisive factor for carbonation resistance, while curing and exposure conditions also influence carbonation. Probabilistic inference suggests that both accelerated and natural carbonation processes follow a square-root-of-time behavior, though they cannot be converted into each other without corrections. Additionally, a machine learning technique was employed to assess the influence of parameters governing the carbonation progress.

Carbonation data for alkali-activated concrete and mortar from the literature and for blended Portland cement-based concrete with a high percentage of SCMs (≥ 66 % of the binder) indicated that a better indicator of the carbonation resistance of alkali-activated concrete appeared to be their $w/(CaO + MgO_{eq} + Na_2O_{eq} + K_2O_{eq})$ ratio, where the index 'eq' indicates an equivalent amount based on molar masses. In addition, it seemed that for low-Ca alkali-activated concrete, even at the relatively modest concentration of 1 % CO_2, accelerated testing may lead to inaccurate predictions of the carbonation resistance under natural exposure conditions.

In addition, five different laboratories from RILEM TC 281-CCC conducted comparative testing of Portland cement (PC) concrete with and without SCMs under the combined action of carbonation and mechanical loading. The results indicated that the carbonation depth of concrete undergoing mechanical loading is lower in the case of a limited compressive load, and higher in the case of a high compressive load or tensile load, compared with unloaded specimens. The relative carbonation depth was decreased by 9%-16% at 30% of the failure load in compression, independent of CO_2 concentration and the presence of SCMs, while it was increased up to 13% at a 60% load level. Tension made the carbonation depth gradually increase and up to 70% higher carbonation depth was reached at 60% of the tensile

failure load. The combined effect of carbonation in concrete with SCMs and mechanical loading should therefore not be neglected in the service life prediction of concrete structures.
Carbonation of concrete is generally assumed to lead to reinforcing steel corrosion. However, a critical review of the mechanisms, combined with practical experience, indicated that this widely held view is too simplistic. In fact, there are many cases from engineering practice where carbonation of the concrete matrix surrounding the steel did not lead to noticeable corrosion. The influencing factors that can lead to considerable corrosion damage are identified as the moisture state, the microstructure of the carbonated concrete, various species that may be present in the concrete pore solution, and the cover depth.

Presenter

Nele De Belie is professor in Durability of Cement Bound Materials at Ghent University since 2000. Since 2018 she is director of the Magnel-Vandepitte Laboratory for Structural Engineering and Building Materials, with about 140 staff members. She is head of the "Concrete and Environment" research group of around 15 postdoc and Ph.D. researchers. Her research focuses on sustainable concrete with supplementary cementitious materials, concrete durability, biodeterioration, bioconsolidation, smart concrete with self-healing or self-cleaning properties, circular economy and life cycle assessment. She has supervised more than 60 (inter)national projects in these areas, has been vice chair of the recent COST action SARCOS and is coordinator of the European Marie Curie ITN SMARTINCS. She is president elect of RILEM (International Union of Laboratories and Experts in Construction Materials, Systems and Structures), outgoing chair of the Technical Activities Committee (coordinating ~40 Technical Committees) and chair of TC 281-CCC on Carbonation of concrete with SCM (>100 members). She is author of > 350 WoS publications and 20 book chapters, editor of 10 books, inventor in 4 patent applications, editorial board member of 3 SCI-indexed scientific journals. She is laureate of several awards in recognition of her scientific work, such as the Robert L'Hermite medal (2010). Since 2022 she is appointed as a member of the Royal Flemish Academy of Belgium for Science and the Arts.