



CARBONATION OF CONCRETE: HISTORICAL DEVELOPMENT AND CHANGING INTERPRETATIONS

KARBONATYZACJA BETONU: ROZWÓJ HISTORYCZNY I ZMIENIAJĄCE SIĘ INTERPRETACJE

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Abstract

Carbonation of cement-based materials has been interpreted in different ways during the development of building materials and concrete technology. This paper presents a selective narrative review of the main milestones that changed the meaning of carbonation: from the useful hardening of lime binders, through the durability problem of reinforced concrete, to present discussions on blended and low-clinker binders, accelerated testing and CO₂ uptake. The review was based on historically important, methodologically relevant and currently influential literature. Particular attention was paid to the changing interpretation of carbonation in relation to binder composition, exposure conditions, reinforcement corrosion, testing methodology and the growing use of supplementary cementitious materials. The review shows that carbonation cannot be treated as a single, universal durability indicator. Its meaning depends on the type of binder, moisture conditions, pore structure, alkaline reserve, presence of reinforcement and the aim of assessment. The main conclusion is that concepts developed for ordinary Portland cement systems cannot be directly transferred to concretes rich in supplementary cementitious materials without additional interpretation and method-specific validation.

Keywords: carbonation, accelerated carbonation, concrete durability, reinforced concrete, supplementary cementitious materials, CO₂ uptake

Streszczenie

Karbonatyzacja materiałów na bazie cementu była różnie interpretowana na kolejnych etapach rozwoju materiałów budowlanych i technologii betonu. W artykule przedstawiono selektywny przegląd narracyjny najważniejszych kamieni milowych, które zmieniały znaczenie karbonatyzacji: od korzystnego twardnienia spoiw wapiennych, przez problem trwałości żelbetu, aż po współczesne dyskusje dotyczące spoiw mieszanych i niskoklinkierowych, badań przyspieszonych oraz pochłaniania CO₂. Przegląd oparto na literaturze o znaczeniu historycznym, metodologicznym i współczesnym. Szczególną uwagę zwrócono na zmieniającą się interpretację karbonatyzacji w odniesieniu do składu spoiwa, warunków ekspozycji, korozji zbrojenia, metod badawczych oraz rosnącego stosowania dodatkowych materiałów cementowych. Przegląd pokazuje, że karbonatyzacja nie może być traktowana jako jeden uniwersalny wskaźnik trwałości. Jej znaczenie zależy od rodzaju spoiwa, warunków wilgotnościowych, struktury porów, rezerwy alkalicznej, obecności zbrojenia oraz celu oceny. Główny wniosek jest taki, że pojęć wypracowanych dla układów opartych na cemencie portlandzkim nie można bezpośrednio przenosić na betony bogate w dodatkowe materiały cementowe bez dodatkowej interpretacji i walidacji właściwej dla danej metody badawczej.

Słowa kluczowe: karbonatyzacja; karbonatyzacja przyspieszona; trwałość betonu; żelbet; dodatkowe materiały cementowe; pochłanianie CO₂

REFERENCES

- [1] Elsen J., Van Balen K., Mertens G., *Hydraulicity in Historic Lime Mortars: A Review*, in: Válek J., Hughes J.J., Groot C.J.W.P. (eds.), *Historic Mortars: Characterisation, Assessment and Repair*, RILEM Bookseries, vol. 7, Springer, Dordrecht, 2012, pp. 125-139.
- [2] Von Greve-Dierfeld S., Lothenbach B., Vollpracht A. et al., *Understanding the carbonation of concrete with supplementary cementitious materials: a critical review by RILEM TC 281-CCC*, Materials and Structures, 53, 2020, 136.
- [3] Stefanoni M., Angst U., Elsener B., *Corrosion rate of carbon steel in carbonated concrete: a critical review*, Cement and Concrete Research, 103, 2018, pp. 35-48.
- [4] Angst U.M., *Steel corrosion in concrete – Achilles' heel for sustainable concrete?*, Cement and Concrete Research, 172, 2023, 107239.
- [5] Bernal S.A., Dhandapani Y., Elakneswaran Y. et al., *Report of RILEM TC 281-CCC: a critical review of the standardised testing methods to determine carbonation resistance of concrete*, Materials and Structures, 57, 2024, 173.
- [6] Vollpracht A., Gluth G.J.G., Rogiers B. et al., *Report of RILEM TC 281-CCC: insights into factors affecting the carbonation rate of concrete with SCMs revealed by data mining and machine learning approaches*, Materials and Structures, 57, 2024, 206.
- [7] De Belie N., Bernal S.A., *Closing Letter of RILEM TC 281-CCC: Carbonation of Concrete with Supplementary Cementitious Materials*, RILEM Technical Letters, 10, 2025, pp. 22-32.
- [8] Bernal S.A., Angst U.M., Provis J.L. et al., *Recommendation of RILEM TC 281-CCC: RILEM CPC-18R1-guideline for measuring the carbonation depth of hardened concrete using a pH indicator solution*, Materials and Structures, 59(3), 2026, 137.
- [9] Xi F., Davis S.J., Ciais P. et al., *Substantial global carbon uptake by cement carbonation*, Nature Geoscience, 9, 2016, pp. 880-883.
- [10] Vicat L.J., *A Practical and Scientific Treatise on Calcareous Mortars and Cements, Artificial and Natural*, John Weale, London, 1837.
- [11] Aspdin J., *An Improvement in the Mode of Producing an Artificial Stone*, British Patent No. 5022, 21 October 1824.
- [12] Wu S., Shao Z. et al., *Global CO₂ uptake by cement materials accounts 1930-2023*, Scientific Data, 11, 2024, 1409..
- [13] Andrade C., Sanjuán M.Á., *Carbon dioxide uptake by pure Portland and blended cement pastes*, Developments in the Built Environment, 8, 2021, 100063.
- [14] Vitruvius, *The Ten Books on Architecture*, translated by Morris H. Morgan, Harvard University Press, Cambridge, MA, 1914.
- [15] Encyclopaedia Britannica, Joseph Monier.
- [16] Verbeck G.J., *Carbonation of Hydrated Portland Cement*, Portland Cement Association, Research Department Bulletin 87, 1958.
- [17] Hamada M., *Neutralization (Carbonation) of Concrete and Corrosion of Reinforcing Steel*, in: Proceedings of the 5th International Symposium on the Chemistry of Cement, Tokyo (1968), vol. 3, 1969, pp. 343-368.
- [18] Tuutti K., *Corrosion of Steel in Concrete*, Swedish Cement and Concrete Research Institute, Stockholm, 1982.
- [19] Parrott L.J., *Damage caused by carbonation of reinforced concrete*, Materials and Structures, 23, 1990, pp. 230-234.
- [20] Parrott L.J., *A study of carbonation-induced corrosion*, Magazine of Concrete Research, 46 (166), 1994, pp. 23-28.
- [21] Papadakis V.G., Vayenas C.G., Fardis M.N., *A reaction engineering approach to the problem of concrete carbonation*, AIChE Journal, 35(10), 1989, pp. 1639-1650.
- [22] Papadakis V.G., Vayenas C.G., Fardis M.N., *Fundamental modeling and experimental investigation of concrete carbonation*, ACI Materials Journal, 88(4), 1991, pp. 363-373.
- [23] IEA, *Cement*, in: Breakthrough Agenda Report 2023, International Energy Agency, Paris, 2023.
- [24] Cavalett O., Watanabe M.D.B., Voldsund M., Roussanally S., Cherubini F., *Paving the way for sustainable decarbonization of the European cement industry*, Nature Sustainability, 7(5), 2024, pp. 568-580.
- [25] Dunant C.F., Joseph S., Prajapati R., Allwood J.M., *Electric recycling of Portland cement at scale*, Nature, 629, 2024, pp. 1055-1061.
- [26] Kaddah F., Ranaivomanana H., Amiri O., Rozière E., *Accelerated carbonation of recycled concrete aggregates: Investigation on the microstructure and transport properties at cement paste and mortar scales*, Journal of CO₂ Utilization, 57, 2022, 101885.
- [27] Ahmed O., Ahmad S., Adekunle S.K., *Carbon dioxide sequestration in cementitious materials: A review of techniques, material performance, and environmental impact*, Journal of CO₂ Utilization, 83, 2024, 102812.