RELEVANCE of STAR 211-PAE

Concrete is subjected to processes of degradation when exposed to natural environments such as soft waters, sea waters or ground waters, or man-made such as industrial environments, and treated water or wastewater and polluted environments. The scale of the problem means that the consequences are severe. Concrete failure can adversely affect the well-being of human communities and disturb ecological balances. There are also large direct costs from the need to maintain and sometimes replace deteriorated infrastructure, and indirect costs linked with suspension of production or reduction in transport mobility during maintenance work. This all places a great burden on society. With these problems in mind, RILEM Technical Committee TC 211-PAE was formed in 2005 and STAR 211-PAE was published in 2013 as the result of the work of this TC.

STAR in a nutshell 211-PAE
"Performance of Cement-Based Materials in Aggressive Aqueous Environments"

Concrete is a multiphase, porous, strongly basic material. The pH of the interstitial solution is approximately 13 which is beneficial and essential to protect embedded steel from corrosion. The characteristics of the pore network, dimensions (usually between 10^{-9} and 10^{-5} m) and connectivity of the capillary porosity determine the transfer of aggressive species inside the matrix. In the case of aqueous environments, the main form of degradation relates to the alteration of the hydrated cement compounds due to ion exchanges, additions, or substitutions. The chemical reactions and physical mechanisms lead to a breakdown of the matrix microstructure and weakening of the material. The most common evidences of these degradation processes are i) cracks due to crystallization pressure and/or ii) strength loss and disintegration due to decalcification.

All aqueous solutions should be considered aggressive to cement-based materials, from pure (ion-free) waters (leading to leaching) to highly saline solutions (leading to ion addition and exchange reactions). Here, the emphasis is on the following groups of aggressive agents: 1) sulfates; 2) magnesium, 3) pure waters and strong acids, 4) ammonium nitrate and 5) organic acids.

1) External sulfate attack (ESA) often arises from an increased sulfate concentration in the service environment, as it is the case when concrete structures get in contact with sulfate-bearing soils and groundwaters, seawater and wastewaters. The effects of the chemical reactions between sulfate and solid hydration compounds of cement is generally the formation of expansive products that lead to cracks.

2) While sodium chloride is the dominant salt in marine waters which is detrimental for reinforcement corrosion, there is also a substantial amount of magnesium sulfate. The attack by the magnesium ion is particularly noteworthy, as it can cause a complete disintegration of the C-S-H in the long term. Damage in real structures manifests in the form of loss of adhesion and strength, rather than expansion and cracking that is commonly observed in laboratory tests.

3) Highly alkaline Portland cement is easily attacked by pure water and acidic solutions. The attack by acidic waters occurs more often than in the past because of growing urban and

industrial activities. Pure or low mineralized water attack becomes crucial in the durability and safety of major concrete facilities and of water-conveying pipes and dams. The degradation is due to the leaching of cementitious materials, resulting in higher porosity and loss of strength.

4) Even though ammonium nitrate, a commonly used fertilizer, may cause severe degradation in fertilizer factories or in storage silos, it still represents a very scarce risk for concrete structures. Ammonium nitrate is actually used in laboratories to simulate leaching in accelerated conditions. The high aggressiveness of its attack is not only due to the high solubility of salts, but also (and first) to the affinity of the ammonium ion for the calcium-bearing phases of the cement matrix and to an additional acid-base reaction with NH_4^+/NH_3. Concentrations used in lab tests are very high, around 6 mol/L. Lower concentrations mean far less aggressive attacks. Ammonium nitrate solutions produce rapid decalcification due to the high solubility of its calcium salts. Degradation reactions related to ammonium nitrate solutions are swift and severe.

5) The effluents from agricultural and agrofood industries have complex compositions but share some common characteristics: the content of complex organic compounds and a large population of micro-organisms. The metabolism of the micro-organisms produces organic acids, whose attacks are of variable intensity but cause the progressive deterioration of concrete together with the formation of biofilms on its surface.

In recent years, models have been developed specifically to address sulfate attack, acid exposure, and calcium leaching. Whereas a model for chloride corrosion relies largely on a single transport parameter, reliable models for other degradation mechanisms presented above must also account for the effects of changes within the microstructure. A fully coupled thermal-hydro-mechanical (THM), multi-ionic chemical model involves numerical and computational efforts that are challenging. However, progress has been made since the publication of this STAR. Some RILEM Technical Committees are currently focusing on these aspects. The goal of implementing a complex transport, chemistry and mechanics in a single model is reachable and getting closer and closer.

The review of test methods to assess the performance of cementitious materials in aggressive aqueous environments, as well as test methods which can be used to characterise and rate relative performance (long term predictions), show the existence of many standard and non-standard tests. Parameters such as the scale of the test method, physical state of the attacking medium, nature of counter ions, the pH and concentration of the solution, temperature, rate of replenishment, mechanical action, alternate wetting and drying, alternate heating and cooling, pressure, etc. should be carefully selected. The measured degradation marker plays a crucial role and often a combination of multiple relevant indicators is necessary.

There are degrees of arbitrariness in turning the theoretical information about aqueous attacks into specifications or codes for practical purposes. The engineering community is still awaiting reliable tests for many concrete durability properties for performance prediction, mathematical models of deterioration that can be applied in practice, and a probabilistic approach to durability design.

RELATED DOCUMENTS:

1) Recommendation of RILEM Technical Committee 246-TDC: Test methods to determine durability of concrete under combined environmental actions and mechanical load, Materials and Structures volume 50, 155 (2017)
2) Beushausen H., Fernandez-Luco L. (eds) Performance-Based Specifications and Control of Concrete Durability - State-of-the-Art Report of RILEM Technical Committee 230-PSC (2015)