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Black, L orcid.org/0000-0001-8531-4989 (2020) Editorial. Advances in Cement Research, 32 (4). pp. 137-138. ISSN 0951-7197

https://doi.org/10.1680/jadcr.2020.32.4.137

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Editorial: Themed Issue on non-standard durability testing of cementitious materials

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This issue of Advances in Cement Research brings together a selection of articles around the common theme of non-standard durability testing. It is likely a similar situation across the globe, but 50% of the UK's national construction budget being spent on maintenance and repair. Thus, there is an urgent need to understand the long-term performance of materials. This is nothing new, and this has been a focus of many researchers for many years. Indeed, there is a host of standards focussing on the durability of cementitious materials. However, two issues arise which stress the need for a more detailed understanding of deterioration mechanisms.

Firstly, the palette of cementitious materials available to the civil engineer is expanding. The effects of supplementary cementitious materials on microstructure and phase assemblage are known, but with moves towards ternary and quaternary blends, plus the development of non-Portland cements, there is a need to look beyond standard testing methods which were often developed with pure Portland cement systems in mind. For example, standard freeze-thaw testing will often involve pre-conditioning of concrete specimens in water prior to exposure to a thermal cycle. It has recently been shown that leaching of portlandite from samples leads to excessive deterioration of slag cements and ternary slag-limestone cements (Adu-Amankwah, 2018). This diminished performance under artificial ageing may well hinder the adoption of innovative low-carbon cements.

Secondly, many standard durability tests expose materials to single stresses, for example elevated CO_2 atmospheres, without considering any potential interplay between multiple stresses, for example freeze-thaw induced cracking leading to accelerated deterioration by chloride ingress. Some of these issues were recently raised by Hooton (2019) noting, for example, the impact of sulphates on chloride ingress, and the lack of a standard test for determining the threshold chloride concentration that will depassivate embedded steel, with huge variations in this critical value being reported depending on the method used.

The limitations of standard testing with modern cements or when considering multiple stresses highlights the need for detailed understanding of the underlying materials science underpinning cement performance. The papers in this themed issue all attempt to address this, considering not just performance under aggressive environments, but also trying to explain this performance by considering the microstructure and/or phase assemblage of the hardened cement paste.

Lee & Kurtis have examined the long-term effectiveness of photocatalytic cements upon exposure to combinations of nitrogen dioxide, UV radiation plus wetting and drying cycles. The addition of photocatalytic titania to cements has the potential to reduce urban smog, thus improving public health. However, the findings in this study have shown that ageing of the cement surface leads to gradual loss of photocatalytic performance. This was ascribed to a number of possible phenomena, including: carbonation leading to pore blocking and covering of the titania particles, and loss of titania, possibly due to acidic leaching. These results suggest that the long-term performance of photocatalytic cements cannot be assured and that the long-term performance of field samples is perhaps an area for further investigation.

Balapour et al., meanwhile, have attempted to find empirical relationships between chloride resistance and mechanical performance for a range of composite cements. They used electrical resistivity as a measure of a cement's ability to resist chloride ingress, showing that resistivity decreased non-linearly with falling chloride migration coefficient. They found improved chloride resistance with decreasing water absorption, primarily due to a drop in capillary porosity. They went on to show improved chloride resistance with increasing strength for blends containing rice husk ash, but not for those containing sugarcane bagasse ash. However, porosity refinement induced by the addition of SCMs meant that chloride resistance improved with increasing replacement levels.

Hao et al. studied the interplay of chemical and physical deterioration, examining the effects of aggressive agents on erosion resistance. Specifically, they simulated the aggressive environments of Inner Mongolia, with combined freeze-thaw exposure coupled with combined chloride and sulphate attack, with bombardment from typical Mongolian desert sands. The extent of erosion was found to be dependent on the angle of impact, with a change in the nature of the erosion from "ploughing" at low incident angle and cratering at high incident angle. Furthermore, there was found to be subtle changes in performance depending on the weathering of the mortar surface. During the early stages of weathering, erosion resistance actually increased, due to the precipitation of sulphate phases leading to surface hardening. Further weathering then led to increased erosion, presumably as the micro-cracks formed by freeze-thaw exposure started to predominate.

Staying with the topic of combined sulphate-chloride attack, Song et al. have looked at the development of a repair material for marine environments. By blending a ternary cement comprising Portland cement, calcium aluminate cement and gypsum with slag, they were able to achieve a strong, dense binder capable of withstanding chloride ingress. They concluded that the addition of slag greatly improved performance, in agreement with recent work of Ukpata et al (2018) looking at combined chloride-sulphate attack in binary slag blends.

The final two articles in this themed issue examined slightly more specific examples of extreme durability concerns. Li et al. examined crystallisation attack of piles in extremely sulphate-rich ground. Using a combination of modelling, laboratory simulations and case studies, they proposed a four-stage deterioration model; ingress, evaporation and sulphate precipitation, complete filling of pore space and stressing of the concrete, and finally visible cracking and spalling. Their model resembled that of Scherer (2004) and highlighted the importance of key factors in determining pile service life, namely sulphate concentration, depth of groundwater and solar radiation. The latter may seem odd for a pile, but reflected the degree of evaporation and hence salt crystallisation.

Finally, the situation of leaching under the hypersaline conditions was studied by Boulard and Kautenburger. Such conditions may be experienced by cementitious binders surrounding nuclear waste repositories, thus their stability is of immense importance. Increasing chloride concentrations in leachants led to increased release of almost all elements from the cements. However, the addition of sulphates led to more complex results, with reduced leaching of most of the principal elements present in Portland cement, i.e. Ca, Si and Al. but increased release for many of the trace elements (Cs, Sr, Ba, Cr and Mo). Of key importance was the observation that the leachate contained multi-valent cations which are likely to compete with radioactive elements, thus potentially increasing the release of radionuclides. This study opens up the potential for further study, looking at how artificial leachate from concrete will affect radionuclide mobility within waste repositories.

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Order of papers

1. Lee & Kurtis
2. Balapour et al.
3. Hao et al.
4. Song et al.
5. Li et al
6. Boulard & Kautenburger