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Discussion

Reply to the discussion by William G. Hime and Stella L. Marusin of the paper "Chemical changes in concrete due to the ingress of chemical species"☆

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We had the opportunity to examine samples of ~10-year-old concretes from residences in Southern California. There is a diverse literature describing concretes prepared at normal w/c ratios and subjected to various exposure conditions. However, we could not find citations systematically describing microstructural variations in high w/c ratio field concretes subjected to the intrusion of chloride, sulfate, and magnesium by contact with moist soil.

Because of the mild climate in Southern California, freezing and thawing damage to concrete is not a concern. Perhaps, in part for this reason, high w/c ratio concretes were occasionally used in slabs and foundations of homes built there during the last decade. These mix designs typically specified 4.5–5 sacks of cement per cubic yard of concrete and w/c ratios of 0.66 or more. These cement contents are lower [1], and the w/c ratios are much higher than would be regarded as appropriate [2]. Summarizing Powers, Hearn et al. [3] illustrated cement pastes produced with w/c ratios in this range are at best minimally capable of developing effective systems of capillary breaks. Thus, because of their high permeabilities, the durabilities of such concretes are particularly dependent on the cement compositions. Recognition of the probability of sulfate exposure had typically resulted in the specification of a Type II or V cement.

While the soil types on which residential slabs and foundations in Southern California are placed may vary, the presence of sulfate is not unusual. Analyses of soils showed sulfate concentrations that range from a few ppm to values in excess of 10,000 ppm. The geology of this region indicates that some soils were ancient seabeds. Such soils typically contain high sulfate and chloride contents. The cations most commonly associated with sulfate and chloride are Na^+, Ca^{2+}, and Mg^{2+}.

It is not uncommon to observe white deposits on the surfaces of residential concretes in Southern California produced at high w/c ratios. Analyses of these efflorescence deposits routinely reveal them to contain sodium sulfate and calcium sulfate. While observed somewhat less commonly, it was not unusual to find sodium chloride and magnesium sulfate as well. Thus, the compositions of the efflorescence deposits on high w/c, high permeability concretes reflect the compositions of the soluble salts in the adjacent soil and ground water.

The condition of concrete on which efflorescence had been appearing became a issue of concern in the mid 1980s. Homes built in the late 1960s and early 1970s were showing deterioration to the extent that the California State Legislature funded a study to determine the cause of the phenomenon [4]. The compounds observed [5] were listed in our paper, and we observed many of these compounds in the concretes we studied.

Although Hime and Marusin have made a variety of comments, the majority of them are not relevant to the content of the paper. They claim three of our equations to be erroneous, apparently not recognizing the commonly used subscript "aq" is shorthand referring to species in aqueous solution. We chose this nomenclature because our objective was to provide a broad mechanistic overview to explain the microstructures observed. This study was not intended to fully elaborate the solution chemistries of the carbonate salts observed, the kinetics of sulfate formation, the distributions of those sulfates in the concretes, nor the mechanical consequences of the microstructures that developed.

Hime and Marusin infer that the $Mg(OH)_2$ observed may be from the cement itself. In the analyses of other concretes,

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we have observed periclase (MgO) particles in the cement pastes that had partially hydrated to brucite ($Mg(OH)_2$) [6]; the features we showed in the present paper are microstructurally distinct from partially hydrated periclase grains. Anhydrous magnesium silicates can be distinguished from those presently observed in a variety of ways. The thaumasite shown in Fig. 3 in our paper has both the appropriate microstructural features and EDS spectrum. We do not dispute that Hime and Marusin can contrive to produce claims of EDS spectra similar to those presented.

We do not wish to stray from technical issues. However, the tenor of the Hime and Maursin comments obligates us to point out that separate juries on two recent occasions have recommended substantial awards to homeowners to repair or replace concrete which Hime and Marusin, on behalf of concrete installers, had claimed to be undamaged by sulfate attack.

References

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