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Discussion

A discussion of the review paper "Delayed ettringite formation" by H.F.W. Taylor, C. Famy and K.L. Scrivener

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It is a pleasure to read Taylor et al.'s narrative of the DEF research — also very appropriate as the first Della M. Roy lecture at the American Ceramic Society 102nd Annual Meeting.

The science-based DEF research from the late 1980s in North America and Europe was from the commencement tailored to clarify the chemistry and mechanics of the reaction, because the knowledge was required for investigations of cases of damage to field concrete. Some of these were made for the defense in litigations and confronted by opposing investigations. This rather new funding basis for concrete research is not necessarily bad. The funding investments have been a substantial addition to the otherwise available means for concrete research. The adversarial procedure exposes results and judgments to thorough scrutiny. The involved scientists are compelled to exercise communication qualities and to relate their findings to given realities. However, the legal utilization of such research makes independent reviews such as the present one indispensable for extraction of general, progressive knowledge from the multifarious sources.

The authors of the review of the communication history of the DEF emphasize the need for caution by interpretation of laboratory tests as reliable modeling of field concrete behavior and "even more" against establishing basic chemistry from field concrete observations. The need exists, however, to use detailed chemical, physical and mechanical characterization of evidence of deterioration in field concrete as the outset for explanatory, science-based studies of deleterious reactions.

Fig. 4, p. 687, in the review illustrates the warnings well. It depicts cracking in cement paste associated with loosening of the bond between aggregate particles and the paste due to DEF. This reaction has been found to occur in concrete, which has been exposed to curing temperatures above about 70 °C. Such curing temperatures are prone also to cause initial thermal cracking in cement paste. The subsequent cooling is likely to close this kind of cracks but not to heal them. (In laboratory studies, the initial thermal cracking can be deliberate provoked, observed and explained but not as reliable modeling of how it happens in larger bodies of concrete.) Cement paste expansion and cracking due to DEF happen after the curing phase, and such cracks do not close.

Cases of field concrete with alkali-silica reaction are further complicating the picture. Harmful ASR makes the internal fracturing of the reacting aggregate particles radiate out in ambient cement paste (along with exudation into the cracks of alkali-silica gel). This results in a fracturing pattern significantly different from the above mentioned.

However, caution is still required. In concrete cured at higher than 60–70 °C (thus weakened by thermal cracking and a potential candidate for later DEF), ASR may also have occurred initially, because the high curing temperatures decrease the calcium concentration in the pore liquid and simultaneously increase the rate of ASR.

The development in the course of such complex deleterious reactivity is actually further complicated by possibly contributing autogenous and drying shrinkage. In fact, concrete affected by internal expansion, either due to DEF or harmful ASR or both, will develop surface crack patterns, which reflect that the surface is shrinking relative to the expanding interior mass, and the appearance will be like surface cracking due to drying shrinkage in concrete with no internal expansion. Altogether, assessments of causality by studies of deteriorated concrete require thorough, expert investigations of affected field concrete *supported by access to advanced basic cement and concrete chemistry, physics, mechanics and mineralogy knowledge*, such as presented regarding DEF with the present review.

Incidentally, ettringite, portlandite, calcite and other crystalline phases in concrete have their names after miner-

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als, which have been discovered in natural rocks by field geologists. Subsequently, basic chemistry, physics and mechanics have been applied for examinations of their properties and the processes of their formation in the natural rocks. In this work, laboratory modeling experiments have been less used than in concrete research. Among other things, because the problem of transfer from model to nature has been recognized to be insurmountable. Field geologists have therefore systematized thorough field investigation methods and relied on intellectual deductions regarding the tectonics and physical/chemical processes of formation and subsequent geological developments in nature.

One more aspect of the DEF research deserves a few comments. It has not resulted in discoveries leading to progressive new cement technology developments. Neither has it provided input for new concrete technology practice, because the limitation of peak curing temperatures to 70°C (or better 60°C) has been part of the maturity monitoring curing systems since the 1980s — with the purpose to prevent thermal cracking.

Thus, the returns on the investments in the DEF research are its use to attain less ambiguity of experts investigations in cases of complex deterioration of field concrete, improved guidance regarding the inability of laboratory modeling results to represent field concrete conditions, implicit appeal to concrete engineering practice to further develop systematic recording of concrete materials properties, processing and field exposure conditions and — last but not least — the general information to engineering practice that basic and applied cement and concrete research is the indispensable foundation for high performance quality of concrete.