Pergamon

Cement and Concrete Research, Vol. 26, No. 6, pp. 979-980, 1996

0008-8846/96 $15.00 + .00

PII S0008-8846(96)00080-4

LETTER TO THE EDITOR

ON THE DISTINCTION BETWEEN DELAYED AND SECONDARY ETTRINGITE FORMATION IN CONCRETE

Yan Fu* and J.J. Beaudoin**

*Department of Civil Engineering, University of Ottawa, Ottawa, Ontario, Canada, K1N 6N5

**Materials Laboratory, Institute for Research in Construction, National Research Council, Ottawa, Ontario, Canada, K1A 0R6

(Received March 28, 1996; in final form April 12, 1996)

The terms "delayed ettringite formation (DEF)" and "secondary ettringite formation (SEF)" are used interchangeably in the literature and often confused [1]. They both occur in concretes under different conditions. A comparison of the DEF and SEF is provided in Table 1.

The chronology for the evaluation of the term DEF is briefly given as follows. Lerch et al. [3] postulated that the sulfate in cement systems could be bound in the C-S-H gel structure to form a new phase called "phase X". Kalousek and Adams [4] suggested that "phase X" was a gel containing all the oxide constituents of cement. Odler [5] reported that about 9.8% gypsum could be bound in hydrated C_3S. The effect of temperature on the "phase X" formation and sulfate desorption characteristics has been reported [6]. C-S-H gel will adsorb sulfate faster at high temperature resulting in a relatively quick disappearance of the gypsum phase in C-S-H-gypsum mixtures. C-S-H gel, containing sulfate adsorbed at high temperature, will desorb the sulfate more slowly than gel that has adsorbed sulfate at normal temperature. Slower release of sulfate from an internal sulfate source (i.e. phase X) causes DEF in high temperature cured Portland cement paste. It appears that two competitive reactions in terms of gypsum consumption exist between C-S-H gel and hydrated calcium aluminates in the hydrated cement-gypsum-water system. The increase of temperature apparently accelerates sulfate adsorption by C-S-H gel.

TABLE 1

Comparison of DEF and SEF

	Type of Concretes	Causes	Ettringite Formation	Expansion Rates
DEF	Steam cured precast concrete products.	Sulfate adsorption in C-S-H gel during steam curing.	Sulfate slowly releases from C-S-H gel, migrates into cracks and reacts with local Al-bearing materials.	Relatively slow.
SEF	Any concrete member.	Calcium sulfate forms from decomposition of AFt or AFm phases by severe drying [2].	Calcium sulfate quickly dissolves upon re-wetting and sulfate migrates into cracks to react with local Al-bearing materials.	Relatively quick.

An example of damage of some concretes due possibly to SEF as opposed to DEF is provided by the Duggan test [2]. The accelerated test involves several thermal-drying/rewetting cycles followed by length-change measurements on concrete cores in water. The concretes may, or may not, be cured initially at high temperature. Therefore, the internal source of sulfate may not be the same as that formed in high temperature moist-cured concrete. It is more likely to be in the form of calcium sulfate solid formed by decomposition of one of the calcium sulphoaluminate phases, e.g. AFt or AFm. C-S-H gel may not be able to adsorb sulfate since "phase X" is difficult to form in a relatively dry condition typical of that resulting from the drying process of the Duggan test. Sulfate ions from calcium sulfate, upon re-wetting, can readily migrate into the nearest cracks, react with the aluminate phase and re-crystallize in the form of ettringite. Therefore in the Duggan test, the terminology "SEF" appears more suitable than "DEF". However, the expansion of concrete in the Duggan test could be a single result of SEF or combined result of both SEF and DEF. Oberholster et al. [7] argued that on the basis of their investigation, the Duggan test showed that all tested concrete sleepers were potentially deleteriously expansive. However, some of the sleepers did not show any signs of cracking after more than 10 years of service. Idorn and Skalny [8] doubted that a high expansive potential indicated by the Duggan test (even when the curing temperature of the precast concrete products did not meet the critical condition for DEF) was realistic. The Duggan test not only creates microcracks simulating an accelerated weathering process, but also creates an extra internal sulfate source for "secondary" ettringite formation, which may not originally exist in the concrete. Aluminate hydrates combine with sulfates to form AFt or AFm phases in normal temperature cured concrete at early ages. They are relatively stable if no severe thermal treatment is applied. DEF usually does not occur in concrete cured at normal temperature.

References

1. Day, R. L., "The effect of secondary ettringite formation an the durability of concrete: a literature analysis", Res. and Dev. Bull, RD 108T, PCA, Skokie, Ill., 115 p., (1992).
2. Grabowski, E., Czamecki, B., Gillott, J. E., Duggan, C. R. and Scott, J. F., ACI Mater. J., **89**(5), 469(1992).
3. Lerch, W., Ashton, F. W. and Bogue, R. H., J. of Res. of Nati. Bureau of Standards, **2**(4), 715(1929).
4. Kalousek, G. L. and Adams, M., J. of ACI, *Title No. 48-7*, Sept., 77(1951).
5. Odler, I., "Interaction between gypsum and the C-S-H phase formed in C_3S hydration", 7th Intnl. Cong. Chem. Cem., Paris, **IV**, 493(1980).
6. Fu, Y., Xie, P., Gu, P. and Beaudoin, J. J., Cem. Concr. Res., **24**(8), 1428(1994).
7. Oberholster, R. E., Maree, H., and Brand, J. H. B., "Cracked prestressed concrete railway sleepers: alkali-silica reaction or delayed ettringite formation", 9th Intl. Conf. on Alkali-Agg. Reaction in Concr., The Concr. Soc., Wexham, Slough, UK, 739(1992).
8. Idorn, G. M., and Skalny, J., ACI Materials J., **90**(4), 383(1993).