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DISCUSSION

A DISCUSSION OF THE PAPER "INFLUENCE OF MINERAL ADDITIVES ON THE ALKALI-AGGREGATE REACTION," BY P.J.M. MONTEIRO, K. WANG, G. SPOSITO, M.C. DOS SANTOS AND W.P. DE ANDRADE[1]

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Prof. Monteiro et al. (1) have usefully shown that low fly ash replacement levels for Portland cement did not reduce the alkali aggregate reaction (AAR) expansion, whereas higher replacement levels gave a significant reduction in the observed expansion. Indeed, AAR expansion was practically nonexistent at the higher replacement levels. Also, the alkali content in the natural pozzolans employed in some of their experiments did not have a major effect upon the overall performance of the pozzolan. Not all of the alkali-silica gels were equally expansive. Alkali and calcium contents in these gels play important roles in the expansion capability of mortar or of concrete. The higher the $CaO/(Na_2O)e$ ratio is in the alkali-silica gel, the lower is the capacity for gel expansion. Their results demonstrated that there is a strong negative correlation between expansion and charge fraction of bivalent cations in the gel, which was predicted by utilisation of the double layer theory (1).

The work reported by the authors (1) referred specifically to the most common form of AAR, namely alkali-silica reaction (ASR). Other forms of AAR are less commonly encountered on a worldwide basis. Alkali-carbonate reaction (ACR) occurs where certain argillaceous dolomitic limestone aggregates containing clays or feldspars can swell following dedolomitisation by the alkalis from the cement (2,3). Alkali-silicate reaction is really alkali-silica reaction of a type in which certain layered phyllosilicate aggregates expand due to a combination of alkali attack and water absorption (4,5). Tang et al. (4) reported that the phyllosilicate minerals themselves are nonreactive and that the reactive components are microcrystalline quartz or chalcedony formed within these rocks by intergrowth or metamorphosis.

Where ASR arises, the alkali silicate gels produced are invariably impure and are not simply hydrated alkali silicates (6). Apart from the expected sodium, potassium, and silicate ions and water, other ions are present within the gel structures, such as those of calcium, magnesium, aluminium and carbonate. These impurity concentrations influence the ability of the gels to swell. For instance, although both sodium and potassium ions contribute to ASR, the effects of the sodium ions are, in relative terms, appreciably greater than those of the

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[1] Cem. Concr. Res. 27, 1899–1909 (1997).

potassium ions, as sodium silicate gels generally tend to imbibe more water than the corresponding potassium silicate gels (6).

There are two aspects, the general and the specific, that need to be borne in mind when considering the effects of ASR. General aspects involve the behaviour of the alkali and silicate ions in the presence of water with the different forms of silica present in the coarse and fine aggregates. Specific aspects involve the particular compositions of the expansive gel formations in given practical situations, which arise from the actual cements and aggregates employed; the latter give rise to the particular impure alkali silicate gel compositions that influence the precise swelling behaviour observed. In practice this means that the actual threshold levels at which appreciable expansion and microcracking take place (leading to the ASR damage seen), can and do vary for different types of cement compositions and aggregates utilised. Exemplification can be found in the work by Sibbick and Page (7).

The risk of ASR can, of course, be minimised or shown not to present a practical problem by eliminating one or more of the key factors that are known to facilitate ASR. These key factors are enough moisture, sufficiently high alkalis (normally in the cement), a critical amount of reactive silica in the aggregate, and calcium hydroxide being present appreciably (5,8). Much guidance for avoiding or minimising ASR has been given, as exemplified in a U.K. Concrete Society report (9). In addition, it must not be forgotten that the mere presence of some alkali silicate gel is not in itself sufficient evidence that any observed expansion has been specifically caused by ASR (5). It may be a result of other phenomena, such as frost and/or sulphate attack (10–13). Before disruption of mortar or concrete from ASR ensues, substantial quantities of alkali silicate gel are normally required. Expansions resulting from the occurrence of ASR can be readily reduced by the inclusion in concrete of a small percentage of steel reinforcement, because the expansive force generated by the formation of the alkali silicate gel is itself relatively small (13).

It has also been shown, in experimental simulations of mechanisms involved in the building up of stresses in concretes subjected to ASR, that the sole presence of calcium, reactive silica, alkali, and hydroxide ions can generate sufficient pressure to cause concrete cracking. For the concrete to crack, it is not necessary to initiate defects which require high pressures, but only to propagate the cracks that need much lower pressures for this to happen (14).

In practice, the risk of ASR needs to be minimised by lowering the level of available alkali content in the concrete by employing a low-alkali cement, or by diluting the cement with mineral additions, such as pulverised fly ash, ground granulated blast furnace slag, or natural pozzolan, as in the authors' own experiments (1), so as to reduce the effective reactive alkali levels in the cement. Also, there needs to be a judicious choice of aggregate, to remove or at least to ameliorate the sensitivity to alkalis and, importantly, to lower the water/cement ratio as far as is practicable to hinder or thwart moisture migration within the structure. Good mix design is essential.

All this means that the technical limits for alkali contents in mortars and concretes should not be regarded as absolute for all situations, but as approximate guidelines that are effective in some situations but not always necessarily so in others. The real technical limits for a given situation will, of course, vary depending upon the precise cement compositions, the actual mineral addition compositions and amounts utilised, and the actual sources of the aggregates employed. Only in this way, by taking real situations into account, can the most appropriate technical limits for a given set of circumstances in which construction is undertaken (not forgetting the actual site conditions either), allow ASR to be effectively minimised or prevented. It needs emphasising that universal guidelines will not work satisfactorily in all real situations, and that good mix design and adequate pretesting of the design mixes are essential. Poor mix design, such as unduly high water/cement ratios, may not only cause ASR but other undesirable phenomena as well, such as the frost and sulphate attack mentioned above and unsightly efflorescence (15,16). It is important that the alkali silicate gel is not confused with efflorescence, which is not often structurally damaging per se, because both phenomena may sometimes coexist in a given structure.

Thus the work undertaken by Prof. Monteiro et al. (1) is a very useful study which has shed more light on the important practicalities of avoiding damage to mortars and to concretes by ASR in particular, which is after all the most commonly experienced form of AAR, in quantifying that not all alkali silicate gels are equally expansive but that significant variations in expansion may arise. In addition, they have noted how the mineral admixtures that they used have actually changed the compositions of the alkali silicate gels. Their paper is a valuable contribution to our further understanding of the complexities of AAR.

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