The Effect of Mineral Admixtures on the Alkali-Silica Expansion of Concrete Under Outdoor Exposure Conditions

R.E. Oberholster and G. Davies

National Building Research Institute
CSIR, Pretoria, South Africa

ABSTRACT

The results of experiments to establish the effects of different mineral admixtures on the expansion of concretes, made with alkali-reactive greywacke/hornfels aggregate and high-alkali cement, are discussed. The concrete specimens were exposed outdoors and the results should be applicable to concrete structures in practice.

INTRODUCTION

The effect of different mineral admixtures on the expansion caused by the alkali-silica reaction has previously been investigated and reported by Oberholster and Westra (1981). However, these experiments were done under laboratory conditions designed to speed up the alkali-silica reaction and mostly involved specimens of mortar, rather than concrete. Results from such experiments are difficult to translate into practice since the relationship between experimental and practical conditions is not known.

This paper deals with results obtained using different admixtures in concretes which were made with high-alkali cement and reactive quartz-bearing aggregate, and exposed outdoors. The work was undertaken on commonly used concrete mixes, so that the results could be practically applied to the design of concrete structures. In this way, the amounts of the different mineral admixtures required to prevent deleterious alkali-silica reaction could be specified with greater confidence.

MATERIALS AND METHODS

Materials

The following mineral admixtures were used: milled granulated blast-furnace slag (MGBS), fly ash (FA), calcined shale (CS) and condensed silica fume (SF). The chemical and physical properties of the materials used in the concrete beams and cubes are presented in Table 1. Details of the concrete from which the beams and cubes were made are presented in Table 2.

TABLE I : Chemical and physical properties of materials used in the concrete beams and cubes

Property		Cement M(B)	Cement J(C)	Aggregate P6(C)	Mineral admixture MGBS(B)	FA(B)	CS(B)	SF(C)	MGBS(C)
SiO_2	%	20.3	20.2	68.5	34.0	45.1	64.6	94.06	33.38
Al_2O_3	%	5.66	4.59	16.33	13.19	36.2	24.41	0.72	14.43
TiO_2	%	–	0.23	–	–	–	–	–	–
Fe_2O_3	%	3.56	3.77	5.39	0.43	2.58	5.23	0.08	0.31
MgO	%	1.44	1.40	0.56	17.26	1.43	0.13	0.47	15.40
CaO	%	62.9	63.2	0.09	31.2	8.42	0.50	0.13	31.14
SO_3	%	2.63	2.60	–	0.01	0.87	0.03	0.42	0.16
S	%	–	–	–	1.19	–	–	–	
Na_2O	%	0.25	0.18	2.36	0.24	0.67	0.11	0.23	1.90
K_2O	%	1.05	0.98	3.32	0.76	0.97	2.50	0.38	1.15
P_2O_5	%	0.18	0.16	–	–	–	–	–	–
Mn_2O_3	%	0.18	0.20	–	1.42	0.09	–	0.02+	0.73
LOI	%	1.39	1.30	1.78	2.48	3.04	1.60	2.43	1.66
Total	%	99.54	98.81	98.33	102.18	99.37	99.11	98.94	100.26
Na_2O equivalent									
Total	%	0.94	0.82	–	0.74	1.31	1.76	0.48	2.66
Active*	%	0.82	0.80	–	0.16	0.66	0.64	0.14	0.21
Relative Density		3.19	3.15	2.74	2.91	2.25	2.81	2.27	2.88
Specific surface (cm^2/g)		3285	3280	–	3882	4557	11000	37000	3620
Pozzolanicity**									
with $Ca(OH)_2$, MPa		–	–	–	5.93	6.94	5.24	9.81	5.08
with OPC, MPa		–	–	–	21.52	25.49	20.16	–	–
Index % of control		–	–	–	88.45	104.77	82.86	–	–

(B) Used in making the beams   +   Determined as MnO
(C) Used in making the cubes   *   Determined according to ASTM C311: Section 18
–   Not analysed   **   Determined according to ASTM C311: Sections 29-32 and 34

TABLE 2 : Details of beams and cubes

Beam/cube Code Number	Aggregate Number	Cement or cement plus admixture comb. Na$_2$O equivalent % Total	Active	Cement + admixture (kg/m³)	Concrete Na$_2$O equiv. kg/m³ Total	Active	Compressive strength (28 days), (MPa)
A22 M(1.3) 370 kg	A22	1.30	1.18	370	4.81	4.37	42.3
A22 M(1.3) + 50% MGBS**	A22	1.02	0.67	370	3.77	2.48	46.3
A22 M(1.3) + 15% FA**	A22	1.13	1.10	370	4.85	4.07	47.2
A22 M(1.3) + 15% CS**	A22	1.37	1.10	370	5.07	4.07	42.3
P6 J(1.1) 350 kg	P6	1.12	1.10	350	3.92	3.85	–
P6 J(1.1) + 5% SF+*	P6	1.15	1.12	345	3.98	3.87	–
P6 J(1.1) + 10% SF+*	P6	1.19	1.14	340	4.03	3.88	–
P6 J(1.1) + 50% MGBS*	P6	1.69	0.52	335	5.69	1.74	–
P6 J(1.1) + 50% MGBS+*	P6	2.33	1.15	335	7.81	3.85	–
P6 J(1.1) 450 kg	P6	1.12	1.10	450	5.04	4.95	–
P6 J(1.1) + 5% SF+*	P6	1.15	1.12	444	5.12	4.97	–
P6 J(1.1) + 10% SF+*	P6	1.18	1.14	437	5.19	4.99	–
P6 J(1.1) + 50% MGBS*	P6	1.69	0.52	431	7.31	2.23	–
P6 J(1.1) + 50% MGBS+*	P6	2.33	1.15	431	10.03	4.95	–

–   Not determined   **   Substitution of cement done on a mass/mass basis
+   Alkali added to mix   *   Substitution of cement done on a volume/volume basis

Alkali was added to the mixing water to raise the active alkali content of the cement used in the beams and the cubes to 1.18 and 1.10 per cent Na_2O equivalent, respectively. The reason for this was so that the results would represent a 'worst case' (active alkali contents higher than 1.10 per cent Na_2O equivalent have rarely been recorded for South African cements).

Beams

A 19-mm nominal size, run-of-quarry, reactive Malmesbury greywacke/hornfels coarse aggregate was used. The fine aggregate was a Cape Flats dune sand with a fineness modulus of 1.69 and a shell content of 30 per cent; it is not alkali reactive. The mix proportions of coarse aggregate/sand/binder/water were 3.1/1.9/1.0/0.45. The mix had a cement content of 370 kg/m³ and a slump of 30 mm. Beams measuring 1 000 x 300 x 450 mm were cast. Compaction was by poker vibrator. The formwork was stripped two days after casting, and the beams were covered for a further five days before being placed in the final position for exposure. The long axes of the beams were orientated approximately east/west to maximise exposure to the sun. One set of extensometer targets at 900 mm centres, for expansion measurements, was fixed to the northern and southern longitudinal faces (approximately one-third of the way from the top), two on the upper face of the beam, and one set 200 mm apart, transversely at each end of the upper face.

Cubes

The cubes have an edge length of 300 mm. A 19-mm, graded, run-of-quarry Malmesbury greywacke/hornfels coarse aggregate was used. A non-reactive coarse quartz sand was used as fine aggregate. Two series of cubes were cast using cement contents of 350 and 450 kg/m³. The slump of the mix was 30 mm and compaction was by poker vibrator. Two sets of extensometer targets at 200 mm centres were fixed to each of the five exposed faces.

In the making of the cubes, the dilution of the available alkali content of the cement by the substitution of the admixtures was calculated and alkali hydroxide was added in the same proportion as the Na_2O and K_2O present in the cement, so as to keep the available alkali content the same, without regard to the amount of alkali provided by the mineral admixtures. For the 50 per cent slag replacement, cubes were also made without the dilution effect being compensated for.

The beams and cubes were exposed at the same site in Cape Town and the expansions discussed below represent the average of all the measurements made on a particular specimen of beam or cube.

RESULTS

Beams

The expansion measured for the beams is presented graphically in Figure 1. The control beam, containing no mineral admixture, after a dormant period of approximately 533 days, started expanding rapidly and steadily to exceed the 0.05 per cent expansion about 174 days later. The NBRI considers this value the dividing line between deleterious and non deleterious expansion. To date (2 100 days) the control beam has expanded by a substantial 0.260 per cent. The effectiveness of the fly ash and MGBS in preventing deleterious expansion is clearly demonstrated in Figure 1, with values that approximate to zero. The addition of calcined shale did not prevent deleterious expansion. However, the onset of expansion was retarded, the 0.05 per cent level being reached after 1 100 days (approximately one year later than the control
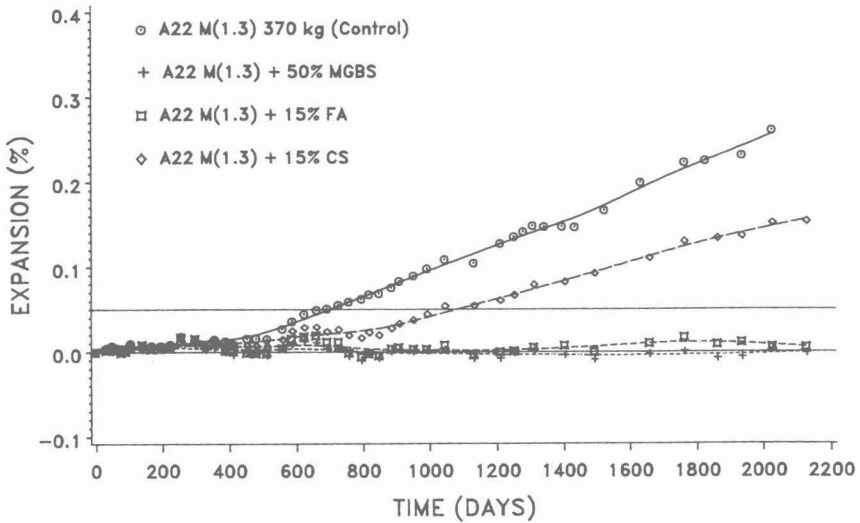
FIGURE 1:   Graph showing the effect of mineral admixtures on the dimensional
change of concrete beams containing alkali-reactive aggregate

beam). To date, this beam has expanded 0.153 per cent. It is clear from the flatter
slope of the curve for the beam made with calcined shale that its rate of expansion has
been slower than that of the control sample, but not sufficiently so to prevent
deleterious expansion.

Cubes

Results for the cubes made with 350 kg and 450 kg cement (plus admixture), per
cubic metre, are presented in Figure 2 and Figure 3, respectively.

Cubes made with 350 kg cement per cubic metre of concrete: The control sample
for this series started expanding approximately 670 days after commencement of
exposure and expansion exceeded 0.05 per cent 280 days later. To date (1 450 days), it
has expanded by 0.167 per cent. The addition of 5 per cent SF (volume/volume) to the
concrete delayed the start of expansion by 460 days compared to the control sample.
However, once expansion started, it continued at a rate similar to that found for the
control sample, and it exceeded 0.05 per cent approximately 270 days after expansion
started. The addition of 10 per cent SF and 50 per cent MGBS appears (thus far at
least) to have prevented deleterious expansion.

Cubes made with 450 kg cement per cubic metre of concrete: The cubes from this
series showed very similar trends to those found for the previous series. The only real
difference between the two series is that the control cube and the cube with 5 per cent
SF started expanding earlier. Expansion of the control sample exceeded 0.05 per cent
after approximately 860 days (this is only slightly earlier than for the control sample
containing 350 kg/m³ of cement, and is probably not statistically significant).
Expansion of the sample containing 5 per cent SF exceeded 0.05 per cent after 1 170
days, almost a year earlier than its equivalent in the series containing 350 kg/m³
cement. The reason for this difference is not immediately clear but it might be related
to the difference in total alkali content of the concrete.

The results provide a note of warning in that the sample with the 5 per cent SF
started expanding suddenly after 1 100 days at a rate that is very similar to that of the
control cube. It is possible that at some later stage the other concrete specimens could
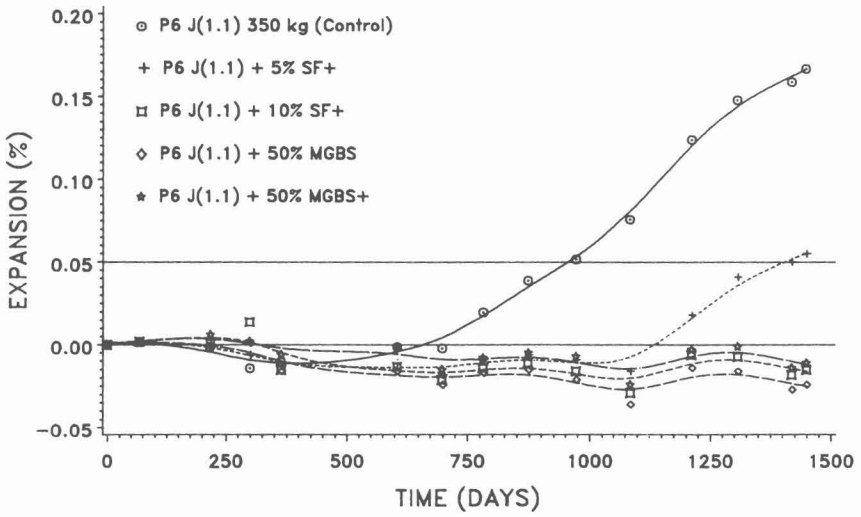also start expanding.

FIGURE 2 : Graph showing the effect of mineral admixtures on the dimensional change
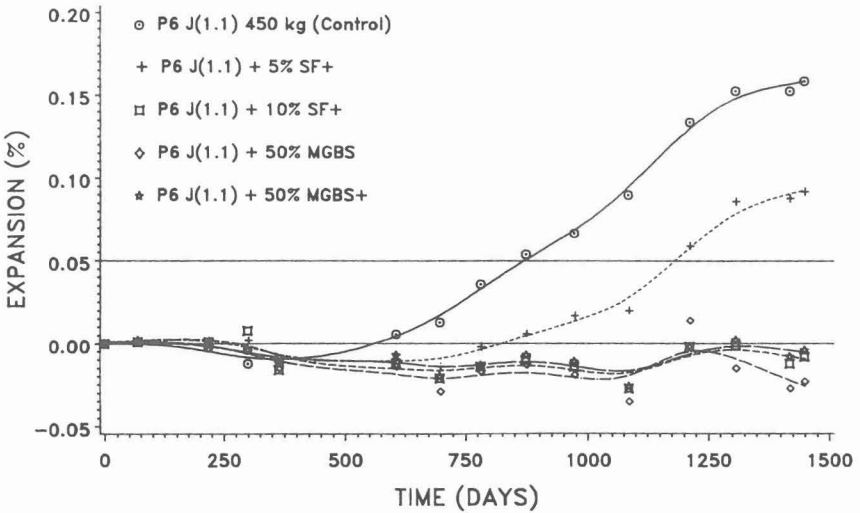of concrete cubes made with alkali–reactive aggregate

FIGURE 3 : Graph showing the effect of mineral admixtures on the dimensional change
of concrete cubes made with alkali–reactive aggregate

It is also obvious from Figure 3 that there is no difference at this stage, between the cubes made with MGBS, in which the effects of the dilution of alkalis were compensated for, and those in which it was not done.

CONCLUSIONS

Although the cubes and beams have only been exposed for 4 and 6 years respectively, it seems reasonable to conclude the following:

1. Replacement of cement by 50 per cent MGBS (on a volume/volume or mass/mass) basis appears to be effective in preventing the deleterious expansion due to the alkali–silica reaction even when the active alkali content of the concrete is as high as 4.95 kg/m³ Na_2O equivalent.
2. Replacement of cement by 15 per cent (mass/mass) of an approved fly ash appears to be effective in concrete with an active alkali content of up to 4.07 kg/m³ Na_2O equivalent.
3. Replacement of cement by 10 per cent (volume/volume) SF appears effective even when the active alkali content of the concrete is as high as 4.99 kg/m³ Na_2O equivalent.
4. Replacement of cement by 15 per cent (mass/mass) calcined shale or 5 per cent (volume/volume) SF is not effective in preventing deleterious expansion caused by the alkali–silica reaction in concrete with active alkali contents of up to 4.07 and 3.87 kg/m³ Na_2O equivalent, respectively.

REFERENCE

Oberholster, R.E. and Westra, W.B. 1981. The effectiveness of mineral admixtures in reducing expansion due to alkali–aggregate reaction with Malmesbury Group aggregates. In Fifth International Conference on alkali–aggregate reaction in concrete, ed. R.E. Oberholster pp S252/31. 1–10. Cape Town.