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S252

THE EFFECTIVENESS OF MINERAL ADMIXTURES IN REDUCING EXPANSION DUE TO ALKALI-AGGREGATE REACTION WITH MALMESBURY GROUP AGGREGATES

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SYNOPSIS

The paper describes the effect of adding mineral admixtures to mortar and concrete made with known expansive materials in order to see how effective they were in reducing expansion due to the alkali-aggregate reaction. Several admixtures reduced expansion effectively when they replaced a certain quantity of high alkali cement but other factors should be taken into account before the admixtures are used in practice.

SAMEVATTING

Die referaat beskryf die uitwerking van die byvoeging van minerale bymengsels by mortel en beton om vas te stel hoe effektief dit uitsetting as gevolg van die alkali-aggregaatreaksie kon verminder. Verskeie bymengsels, as vervanging van 'n sekere hoeveelheid hoë alkali-sement, het die uitsetting doeltreffend verminder maar ander faktore moet in ag geneem word voordat die bymengsels in die praktyk gebruik word.

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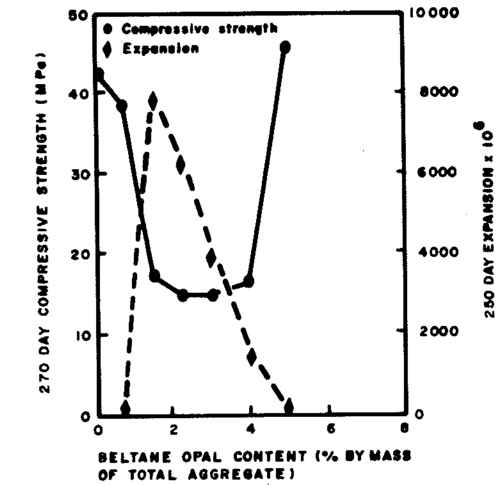
DISCUSSION

Prof S Diamond (Purdue University, USA) began his questions for Dr Hobbs by asking about the validity of initial crack formation as an indication of failure. Delegates had heard that, under some circumstances there was a significant tendency for early cracks in particular to fill up and heal by one process or another. Had he noticed whether the cracks that formed in his mortar bars followed such a tendency or did they remain open indefinitely. Was it his feeling that they really did constitute an unacceptable state of affairs if they were to appear in concrete.

Dr D W Hobbs replied that in their tests, they used Beltane opal in a size range (150 to 300 μm) in which they got very little gel formation on the surface. The cracks that they had seen were relatively free of gel. In some of their tests with increased Beltane opal content, the expansive reaction appeared to be over in as little as 10 days. These cracks appeared to remain as they were at 10 days, relatively free of gel.

At this point Dr Hobbs presented the slide shown on this page on which he had plotted compressive strength against Beltane opal content. The specimens, he said, had had a water/cement ratio of 0,59, and an aggregate/cement ratio of 4,5. The expansion was that measured at 250 days, and the compressive strength at 270 days. In the case of the higher Beltane opal content, the expansion ceased after about a month because of the excess of opaline type material which reduced the hydroxyl ion concentration to a threshold level. When they had measured the compressive strength at 270 days it had gone down enormously. There had been no healing. That did not mean to say that in a real concrete healing would not take place but it had not happened in their laboratory specimens.



Influence of reactive aggregate content upon compressive strength and expansion. w/c 0,59, a/c 4,5, reactive particle size 150 to 300 μm. Acid soluble alkali content of the cement, (Na_2O) = 1,04%

1. INTRODUCTION

The most effective, but not necessarily the most economical and practical precaution against expansive alkali-aggregate reaction is to use a low alkali cement to reduce the total alkali content of the concrete below the critical limit for a particular aggregate at which deleterious expansion can take place. Another alternative is to use an aggregate that will not react with the cement alkali in such a way as to produce excessive expansion. Where neither of these is possible an approved mineral admixture that will prevent deleterious expansion due to alkali-aggregate reaction can be interground or blended with the high alkali cement.

In 1976 it was established that alkali-aggregate reaction was the cause of the cracking and deterioration of many concrete structures in the Cape Peninsula and its environs[1]. Consequently priority was given to research into the use of mineral admixtures as one of the options for the prevention of the alkali-aggregate reaction in that area.

Previous research had shown that mineral admixtures that could be used to reduce expansion due to alkali-aggregate reaction were pozzolans[2, 3] and milled granulated blastfurnace slag[4].

The Pyrex glass mortar prism test, ASTM C441-69[5], was used for the provisional screening of admixtures and blended hydraulic cements to determine their effectiveness in reducing expansion due to alkali-aggregate reaction. In addition the pozzolans were also examined in accordance with ASTM C618-78[6] and blended hydraulic cements in accordance with ASTM C595-79[7] and the requirements of SABS 831-1971[8].

Admixtures and blended hydraulic cements that have been found to comply with the applicable requirements of the aforementioned three specifications and that have been found to be effective according to ASTM C441-69[5] cannot be accepted as suitable without reserve. It is essential to confirm the findings of the Pyrex glass mortar prism test with mortar prisms, concrete prisms and cubes in which the pariticular natural aggregate is used, and with the cement and the admixutes in the proportions envisaged in practice. Ideally the results of the laboratory investigation should be confirmed by the results of the long term performance of concrete beams, cubes and pavements made under controlled conditions and exposed to the natural environment.

2. PROVISIONAL SCREENING

Materials and methods. The following materials were provisionally screened for use as admixtures, viz:

(i) Burnt clay bricks (BR)
(ii) Shale ex de Hoek (JCS) calcined at 1200 °C for 2 hours
(iii) Hornfels (P5) from the Tygerberg Formation
(iv) Pulverised fuel ash (PFA) ex Grootvlei power station
(v) Silica flour (SI) ex Pietersburg
(vi) Kieselguhr (KG) ex Postmasburg
(vii) Molererde (ME) ex Aalborg Portland Cement, Denmark
(viii) Milled granulated blastfurnace slag (Slagment) (SL) ex Pretoria.

In addition a blended portland cement I (1,05) (values in brackets indicate the percentage Na_2O equivalent of a cement) which contains 15 per cent calcined shale was also examined.

Cement F (1,02) was used as a high alkali cement for blending with the admixutres in the Pyrex glass mortar prism test and cement A (0,16) was used as a control cement with a low alkali content. Cement H (0,97) was used in the investigation that followed the preliminary screening tests.

Pyrex glass No 7740 was used for the mortar prism test ASTM C441[5].

The chemical analysis of the cements and admixtures was carried out in accordance with ASTM C114-77[9] and the available alkalis were determined as described in ASTM C311-77[10] except that for the cements A(0,16), F(1,02), H (0,97), and I(1,05) no $Ca(OH)_2$ was added.

The physical properties of the cements and admixtures were determined in accordance with the relevant SABS and ASTM methods.

The mineralogical properties were examined by X-ray diffraction analysis, and where required, with a petrographic microscope.

Results. The results of the chemical analysis are given in Table 1, page 2.

All the pozzolanic admixtures comply with the requirements for minimum content of (SiO_2 + Al_2O_3 + Fe_2O_3); maximum content of SO_3; maximum content of MgO and maximum percentage of available alkalis. Kieselguhr has a higher loss on ignition than the maximum specified limit. With regard to SABS 831-1971[8] the burnt clay brick, hornfels, P5, pfa and silica flour do not comply with the requirement of a maximum value of 3,0 for the ratio per cent Al_2O_3/per cent Fe_2O_3. However, for pfa the Al_2O_3 is present mostly as mullite which should not be susceptable to sulphate attack and in the case of silica flour the total Fe_2O_3 content is only 0,72 per cent.

Both cements F(1,02) and H(0,97) are high alkali cements according to ASTM C150-78a[11]. Blended cement I(1,05) complies with the compositional requirements of both ASTM C595-79[7] and SABS 831-1971[8].

The slagment complies with the chemical requirements of ASTM C595-79[7]. However, it is obvious that a mixture of 50 per cent slagment and 50 per cent opc would not com-

TABLE 1 : Results of chemical analysis

Property	Admixture								Cement			
	BR	JCS	P5	PFA	SI	KG	ME	SL	A	F	H	I
Composition, %												
SiO_2	70,10	64,10	65,80	45,62	94,06	76,66	72,50	33,38	23,00	20,86	20,7	27,1
Al_2O_3	20,49	20,35	19,77	40,79	0,72	3,77	10,80	14,43	5,76	6,00	5,62	5,75
Fe_2O_3	6,75	9,43	6,33	2,99	0,08	1,35	5,70	0,31	2,04	3,33	3,29	6,42
MgO	0,65	1,23	2,12	1,63	0,47	1,78	1,67	15,40	1,36	1,35	1,31	0,95
CaO	0,28	0,36	0,70	2,19	0,13	1,25	1,00	31,14	63,4	62,6	62,6	55,5
Na_2O	0,58	0,56	2,92	2,92	0,23	0,44	1,88	1,90	0,04	0,24	0,23	0,36
K_2O	2,33	4,48	3,45	1,30	0,38	0,60	1,53	1,15	0,18	1,18	1,13	1,05
SO_3	0,11	0,08	0,16	0,81	0,42	0,07	0,00	0,16	1,65	2,53	2,67	1,66
MnO	0,02	0,25	0,08	0,04	0,02	0,01	-	0,73	0,07	0,07	0,07	-
$S^{=}$	-	-	-	-	-	-	-	1,14	-	-	-	-
Ignition loss	0,28	0,13	2,02	1,49	2,43	11,70	3,30	1,66	1,02	1,02	1,10	1,07
Na_2O equivalent	2,11	3,51	5,19	3,78	0,48	0,83	2,89	2,60	0,16	1,02	0,97	1,05
Water soluble alkalis, %												
Na_2O	0,003	0,004	0,01	0,01	0,02	0,03	0,03	0,006	0,01	0,09	0,09	0,03
K_2O	0,01	0,01	0,02	0,002	0,02	0,01	0,02	0,006	0,05	0,86	0,75	0,24
Na_2O equivalent	0,01	0,01	0,02	0,01	0,03	0,04	0,04	0,01	0,04	0,66	0,58	0,19
Available alkalis, %												
Na_2O	0,05	0,11	0,11	0,33	0,09	0,05	0,12	0,10	0,04	0,21	0,20	0,15
K_2O	0,65	1,07	0,07	0,25	0,07	0,01	0,26	0,16	0,10	0,93	0,89	0,32
Na_2O equivalent	0,47	0,81	0,16	0,49	0,14	0,06	0,29	0,21	0,11	0,82	0,79	0,36

ply with the West German guidelines of a maximum Na_2O equivalent of 1,1 per cent. (Sprung, private communication 1980).

From the physical properties given in Table 2, page 3, it can be seen that only the pfa and the silica flour comply with the minimum value of 5,5 MPa required for lime reactivity index, while the water requirement of silica flour, kieselguhr and molererde is higher than the maximum value given in ASTM C618-78[6]. In regard to the percentage reduction in mortar expansion after 14 days, the pfa, silica flour, kieselguhr and molererde comply with the minimum of 75 per cent required by ASTM C441-69[5]; the pfa, however, does not comply with the alternative requirement of a maximum of 0,02 per cent expansion for mortar after 14 days in combination with cement F(1,02).

Cement I(1,05) and a blend of 50 per cent of cement F(1,02) and 50 per cent slag, comply with the requirement of ASTM C595-79[7] for maximum expansion of mortar after 14 days.

The mineralogical composition of the admixutres is summarised in Table 3, page 4.

3. MORTAR PRISM TESTS WITH MALMESBURY GROUP AGGREGATE

The provisional screening tests showed that some materials hold promise as pozzolanic admixtures and also as admixtures for reducing expansion due to alkali-aggregate reaction. These materials were investigated further.

Materials and methods. Based on the results of the provisional screening tests, it was decided to investigate further the following admixtures, viz:

(i) Calcined shale, JCS
(ii) Fly ash, PFA
(iii) Silica flour, SI
(iv) Kieselguhr, KG
(v) Molererde, ME and
(vi) Slagment, SL.

Since a sufficient amount of cement F(1,02), which was used for the Pyrex glass mortar prism test, was not available for the additional investigations it was decided to select a cement on the basis of the Pyrex glass mortar prism test, the assumption being that a cement that gave an expansion of 0,1 per cent or more within 14 days would also give a useful rate of expansion for mortar prisms made with a natural reactive aggregate. Cement H(0,97), the properties of which are given in Tables 1 and 2, gave an expansion of 0,112 per cent after 14 days with the ASTM C441[5] test and was, therefore, used as the high-alkali cement with which the admixtures were blended. Cement A(0,16) was used as a control low-alkali cement. In addition, blended cement I(1,05) was also investigated.

TABLE 2 : Physical properties of admixtures and cements

Property	Admixtures								Cement				
	BR	JCS	P5	PFA	SI	KG	ME	SL	SL 50	A	F	H	I
Relative density	2,68	2,69	2,69	2,28	2,18	2,19	1,98	2,88	-	3,14	3,15	3,15	3,07
Specific surface, cm^2/g	6 082	6 148	6 367	4 721	37 000	18 350	18 750	3 571	-	3 183	3 661	3 055	4 644
Lime reactivity index, MPa	4,56	4,50	Nil	7,59	9,81	5,01	5,04	5,08	-	-	-	-	-
Water requirement, % of control	100	100	100	119	118	111	100	-	-	100	100	100	100
Reaction with cement alkalis after 14 days													
Mortar expansion, %	0,035	0,039	0,052	0,028	-0,008	0,000	0,000	0,046	0,014	-0,002	0,120	0,112	0,020
Reduction, % of F(1,02)	71	68	57	77	163	100	100	62	88	102	-	-	82
Compressive strength, MPa													
3 days										24,0	32,4	33,2	36,3
7 days										35,5	38,7	38,4	47,1
Setting times, minutes													
Initial										195	150	120	115
Final										365	245	235	215
Soundness (expansion)													
Le Chatelier, mm										1	1	1	1
Autoclave, %										+0,042	+ 0,018	-	-0,038

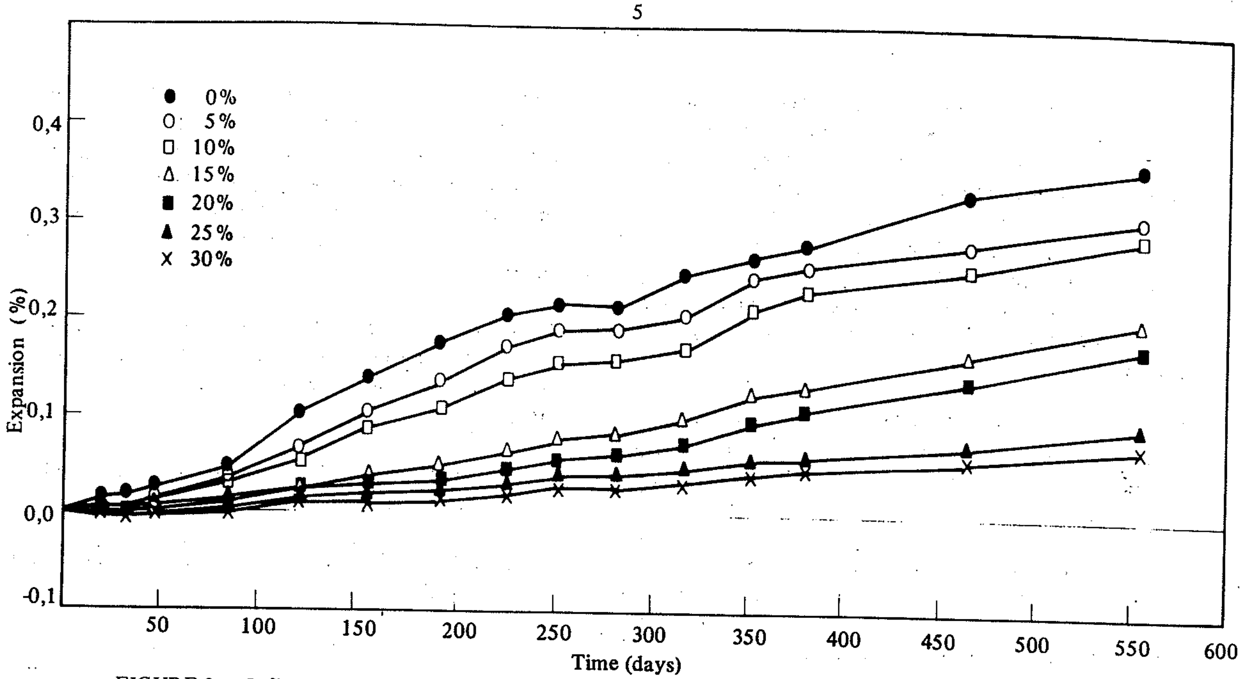


FIGURE 2 : Influence of different amounts of calcined shale JCS replacing high alkali cement H(0,97) on the linear expansion of mortar prisms stored over water in sealed containers at 38 °C. Aggregate, hornfels $P5_2$; a/c ratio 1,5

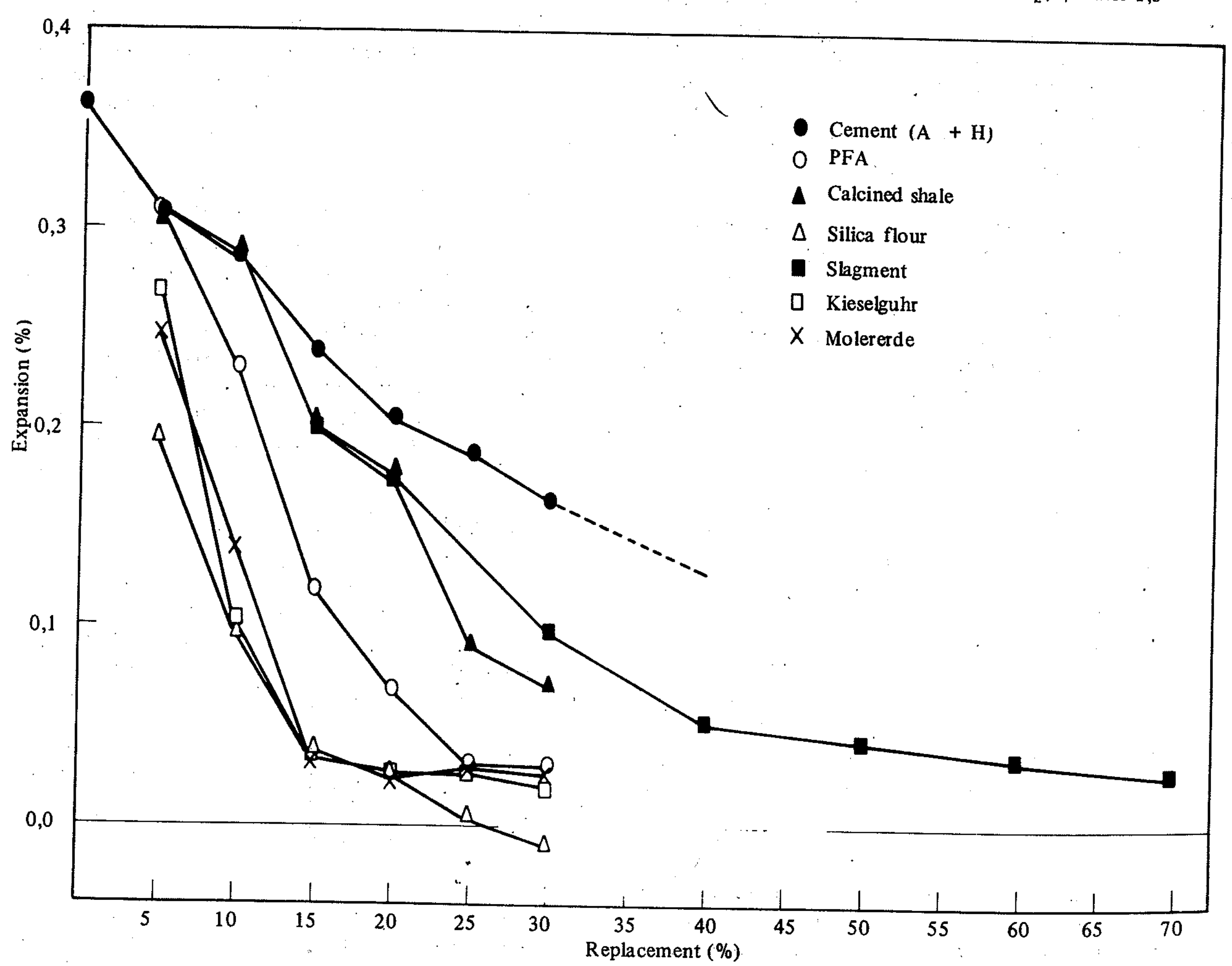


FIGURE 3 : Effect of replacing cement H(0,97) with increasing amounts of cement A(0,16) or various mineral admixtures, on the linear expansion of mortar prisms stored over water in sealed containers at 38 °C for 555 days. Aggregate, hornfels $P5_2$; a/c ratio 1,5.

TABLE 3 : Summary of mineralogical composition of the admixtures

Admixture	Mineralogy
Burnt clay brick, BR	Quartz, mullite, cristobalite
Calcined shale, JCS	Quartz, mullite
Hornfels, P5	Quartz, feldspar, illite/sericite, vermiculite
Pulverised fuel ash, PFA . . .	Quartz, mullite, CaO, glass
Silica flour, SI	Amorphous material
Kieselguhr, KG	Quartz, calcite, amorphous material
Molererde, ME	Quartz, amorphous material
Slagment, SL	Glass, spinel

As a natural reactive aggregate a hand selected hornfels, P5, from the Tygerberg Formation of the Malmesburgy Group was chosen. Since it was envisaged that admixtures that showed promise would have to be tested on a large scale in the long-term in concrete, it was decided also to use run of quarry aggregate, P6, from the same source as P5. This batch of quarry aggregate was found to consist of a mixture of hornfels and greywacke.

The mortar prisms were made and stored as described in ASTM C227-71[12], except that an aggregate/cement (a/c) ratio of 1,5 was employed initially to expedite the investigation. At a later stage the investigation was repeated on a smaller scale with an a/c ratio of 2,25. Each of the pozzolanic admixtures was blended in quantities equal in volume to 5, 10, 15, 20, 25 and 30 per cent by mass of cement H(0,97) and for the slagment equal in volume to 15, 20, 30, 40, 50, 60 and 70 per cent cement by mass.

To determine to what extent a reduction in the alkali content due to dilution of the cement by replacement with the admixtures would influence the expansion of the mortar prisms, cement A(0,16) was blended with cement H(0,97) in proportions to obtain the same Na_2O equivalent as for the balance of the opc containing the various replacements of admixtures.

Results. The results obtained for aggregates P5 and P6 in combination with each of the three cements H(0,97), I(1,05) and A(0,16) are presented graphically in Figure 1. With cement H(0,97) the run of quarry aggregate expands 20 per cent less than the hand selected aggregate. With cement I(1,05) there is a reduction of about 77 per cent in expansion with both aggregates after 555 days. However, X-ray diffraction data revealed that cement I(1,05) consisted of a blend of sulphate resisting cement and calcined shale. If the alkali content of the calcined shale is taken as 3,6 per cent equivalent Na_2O and the percentage of shale blended with the portland cement is the maximum amount allowed by SABS 831*, viz 15 per cent, then the Na_2O equivalent of the cement would be in the region of 0,6 per cent; therefore the Na_2O equivalent of the blended cement would be equal to 1,05 per cent. The low alkali cement A(0,16) produces no expansion with either of the aggregates.

The effect of blending an admixture with cement H(0,97) on the expansion of mortar prisms is illustrated in Figure 2 which shows the results obtained for calcined shale. A similar series of curves was obtained for the other admixtures. Figure 3 compares the effectiveness of the various admixtures in reducing expansion after 555 days. The top curve shows the effect of mere dilution of cement H(0,97) on the reduction in expansion.

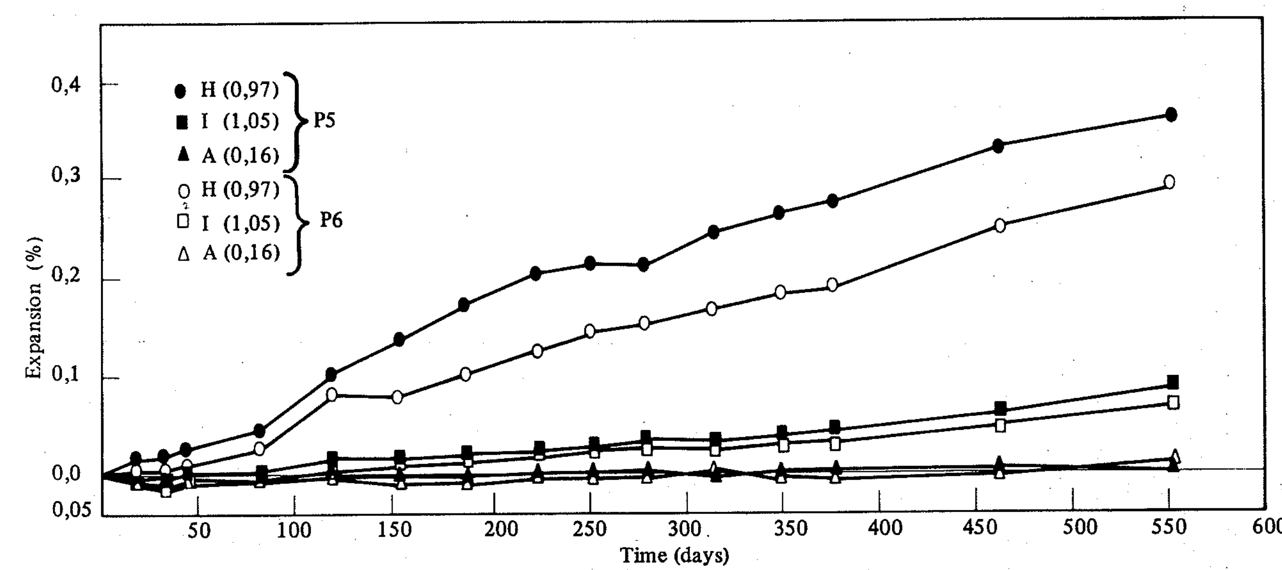


FIGURE 1 : Linear expansion of mortar prisms made with aggregates $P5_2$ and P6 and each of the cements H(0,97), I(1,05) and A(0,16). Stored over water in sealed containers at 38 °C; a/c ratio 1,5

The top curve shows that there is a proportional decrease in expansion as the Na_2O equivalent of the cement decreases from 0,97 per cent to 0,68 per cent at 30 per cent replacement. The line was extrapolated (dashed portion) to obtain an indication of the amount of expansion at 0,60 per cent Na_2O equivalent, i.e. at 38 per cent replacement. From the results it can be concluded that the hornfels aggregate does not show a pessimum effect. Therefore, the results obtained with the admixtures can be interpreted without considering a possible pessimum effect.

The results in Figure 3 also show that the reduction in expansion obtained by blending admixtures with the high alkali cement is greater than can be ascribed to a mere dilution effect.

It is not easy to decide what amount of expansion to take as being low enough to indicate an effective lowering by an admixture. In the ASTM C441[5] Pyrex glass mortar prism test a reduction of 75 per cent in expansion of the high alkali cement combination is taken as indicative of a suitable admixture for reducing expansion effectively. It is, however, clear that this criterion cannot be applied to decide at what level of replacement by an admixture an effective reduction in expansion is obtained since, for example, a 75 per cent reduction in expansion at 555 days would give for cement H(0,97) a vlaue of 0,090 per cent with aggregate P5 and 0,072 per cent with aggregate P6. Therefore, a maximum expansion should be a mandatory alternative.

From the dashed portion of the upper curve in Figure 3 it is seen that the expansion at an Na_2O equivalent of 0,6 per cent, ie 32 per cent replacement, is approximately 0,13 per cent. Therefore, if expansions less than this are regarded as acceptable and an expansion of 0,1 per cent maximum is taken as a criterion, then the following percentages of admixtures are suggested to ameliorate alkali-aggregate expansion with Malmesbury aggregate.

Admixture	Per cent, m/m cement replaced	Per cent, m/m admixture added*
Calcined shale	25	21
Pulverised fuel ash	20	14
Silica flour	10	7
Kieselguhr	15	10
Molererde	15	9
Slagment	30	27

* The amount in this column is equal in volume to the mass of cement replaced

Silica flour, molererde and kieselguhr were the most effective admixtures for reducing expansion. Silica flour has the highest surface area and the lowest alkali content of all the admixtures investigated. Molererde, a diatomaceous earth containing a considerable proportion of clay[13], and kieselguhr have surface areas equal to half of that of the silica flour but 4 to 6 times higher than those of the other admixtures.

With the exception of silica flour and kieselguhr, all the admixtures have higher total alkali contents than cement H(0,97). However, only the calcined shale has a higher available alkali content than cement H(0,97). This may be one explanation for the fact that the performance of the calcined shale was the poorest of the pozzolanic admixtures.

Based on the quantity of admixture needed to effectively reduce the expansion to less than 0,1 per cent, the admixtures can be arranged in the following order of effectiveness:

silica flour > kieselguhr > molererde > pfa > calcined shale > slagment.

The available alkali content of the admixtures in increasing order is as follows:

kieselguhr < silica flour < slagment < molererde < pfa < calcined shale.

From this it would appear that, although the available alkali content is a possible indicator of the usefulness of an admixture, other factors also play a role, eg surface area, as with silica flour compared with kieselguhr and pozzolanicity as with pfa and calcined shale compared with slagment.

Figure 4 represents the results obtained for calcined shale when an a/c ratio of 2,25 was used. The general trend for the various percentages of replacement is the same. However, the magnitude of the expansion is considerably less. This is understandable in terms of cement content and, therefore the total alkali content of the mortar prisms. The cement content is approximately 600 kg/m³ at an a/c ratio of 2,25 and approximately 770 kg/m³ at an a/c ratio of 1,5. Therefore, to obtain approximately the same magnitude of expansion at an a/c ratio of 2,25, a cement with an Na_2O equivalent of 1,24 per cent would have to be used.

4. CONCRETE PRISM AND CUBE TESTS

The investigation with concrete was carried out with the two admixtures that are commercially available in the Transvaal and that can be supplied to the South Western Cape, namely slagment and pfa, and with the calcined shale that can be produced in the South Western Cape.

Cement H(0,97) was used as a high alkali cement and cement A(0,16) as a low alkali cement. The reactive coarse aggregate was hornfels P5 and norite was used as a non-reactive coarse aggregate. A non-reactive quartz sand was used as fine aggregate.

Concrete prisms measuring 300 x 75 x 75 mm and concrete cubes with sides measuring 100 mm were cast from a mix with the proportions coarse aggregate/sand/cement/water equal to 3,38:1,87:1:0,5. The calcined shale and pfa replaced up to 30 per cent of the cement and the slagment up to 70 per cent of the cement. The prisms and cubes are

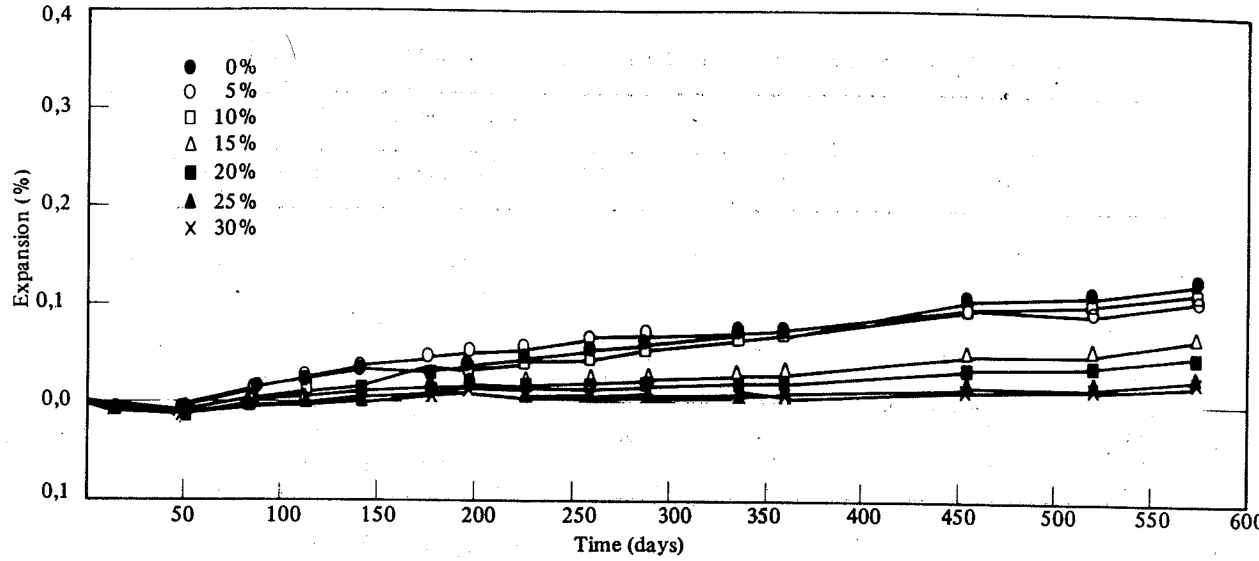


FIGURE 4 : Influence of different amounts of calcined shale (JCS) replacing high alkali cement H(0,97) on the linear expansion of mortar prisms stored over water in sealed containers at 38 °C. Aggregate, hornfels $P5_3$, a/c ratio 2,25

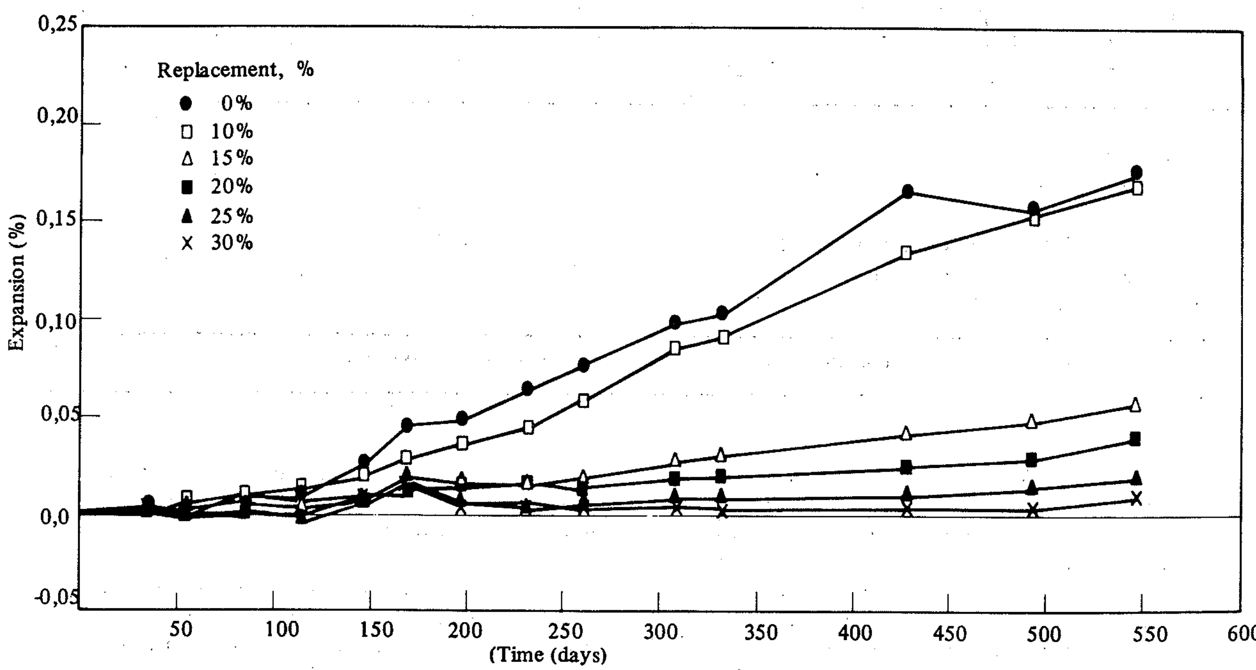


FIGURE 5 : Influence of different amounts of calcined shale replacing cement on linear expansion of concrete prisms stored over water in sealed containers at 38 °C, cement H = 0,97% Na_2O eq and 350 kg/m³; aggregate = hornfels $P5_3$.

being stored under ASTM C227-71[12] conditions. The compressive strength of the cubes is determined at ages of 7, 28 and 90 days and 1, 2 and 3 years.

Results. The results for calcined shale are presented graphically in Figure 5. The expansion curves follow very much the same trend as for the mortar prisms with an a/c ratio of 2,25. There is an abrupt decrease in expansion from 10 to 15 per cent replacement. However, at 15 and 20 per cent replacement there is still an upward trend in expansion but not at 25 and 30 per cent replacement.

With pfa, expansion of concrete is effectively suppressed at replacements of 20 per cent and more and for slagment at replacements of 30 per cent and more. Therefore, with concrete the percentage admixture replacements that were found by the mortar prism tests to effectively reduce expansion, were confirmed.

The results of the compressive strength tests are given in Table 4, page 8. Comparison of the results of the combination containing reactive aggregate plus low alkali cement with those of the combination with high alkali cement

(g) A result obtained with mortar prisms will be confirmed by the use of concrete prisms.

(h) Slagment added to a high alkali cement in sufficient quantities to reduce expansion effectively, did not reduce the compressive strength of concrete cubes; pfa and calcined shale, however, reduced the compressive strength.

(i) Up to an age of 1 year cubes made with the combination of reactive Malmesbury aggregate and high alkali cement showed no decrease in compressive strength when compared with the combination containing low alkali cement, even though distinct cracks were present.

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TABLE 4 : Compressive strength of concrete cubes stored under ASTM C227-71 conditions

Coarse aggregate/cement combination	Compressive strength, MPa, at				
	7 days	28 days	90 days	1 year	2 years
Norite + H(0,97)	34,0	40,8	46,3	55,1	57,6
P5 + 100% H(0,97)	31,6	39,1	41,2	48,2	47,2
P5 + 70% H(0,97) + slagment*	33,4	40,1	45,5	51,2	60,3
P5 + 60% H(0,97) + slagment*	31,7	38,4	40,0	46,4	49,8
P5 + 50% H(0,97) + slagment*	30,0	37,0	41,1	46,5	46,5
P5 + 40% H(0,97) + slagment*	30,4	36,5	37,3	42,3	45,3
P5 + 30% H(0,97) + slagment*	24,7	31,3	31,5	38,3	40,7
P5 + A(0,16)	27,0	35,7	41,3	47,4	
P5 + 100% H(0,97)	31,6	39,1	41,1	47,4	
P5 + 90% H(0,97) + PFA*	33,3	40,7	41,8	48,4	
P5 + 85% H(0,97) + PFA*	27,4	37,5	35,2	41,8	
P5 + 80% H(0,97) + PFA*	28,3	35,7	34,4	40,5	
P5 + 75% H(0,97) + PFA*	26,4	36,5	39,0	41,7	
P5 + 70% H(0,97) + PFA*	25,9	34,8	38,5	39,6	
P5 + 100% H(0,97)	31,6	39,1	41,1	47,4	
P5 + 90% H(0,97) + Calcined shale*	30,2	36,0	39,8	46,6	
P5 + 85% H(0,97) + Calcined shale*	25,0	33,0	38,0	41,3	
P5 + 80% H(0,97) + Calcined shale*	25,3	35,5	37,6	41,5	
P5 + 75% H(0,97) + Calcined shale*	27,8	35,0	40,7	42,3	
P5 + 70% H(0,97) + Calcined shale*	23,0	31,5	37,5	40,6	

* Cement replaced by a mass of admixture equal in volume to the volume of the mass of cement replaced.

shows that no deterioration in compressive strength occurs up to an age of 2 years, although the cubes of the combination with the high alkali cement were clearly cracked. It is, however, possible that a decrease would have shown up if strength tests had been carried out at more frequent intervals. Replacement of up to 30 per cent of cement H(0,97) with slagment does not result in a decrease in compressive strength. However, for pfa and calcined shale there is a marked decrease in compressive strength when more than 10 per cent cement is replaced.

5. CONCLUSIONS

(a) Several admixtures effectively reduced expansion due to alkali-aggregate reaction with Malmesbury aggregate when they replaced a certain amount of high alkali cement.

(b) With the Malmesbury aggregate a reduction in expansion to less than 0,1 per cent after 555 days for mortar prisms was taken as indicating an adequate reduction in expansion. This is less than the expansion obtained, by extrapolation, for mortar prisms made with Malmesbury aggregate and a cement with an Na_2O equivalent of less than 0,6 per cent.

(c) The reduction in expansion obtained by blending admixtures wth a high alkali cement is greater than can be ascribed to a mere dilution effect.

(d) Although the available alkali content of an admixture may be an important factor to take into account when considering it for the amelioration of alkali-aggregate expansion, other factors such as surface area and pozzolanic reactivity may be more relevant.

(e) Blends of the high alkali cement H(0,97) and more than 27 per cent, m/m, slagment effectively reduced expansion although the total alkali content of the resulting blend was more than the 1,1 per cent Na_2O equivalent given by the West German guidelines for a mixture of 50 per cent portland cement and 50 per cent granulated blast furnace slag.

(f) When evaluating admixtures for their effectiveness in suppressing expansion in combination with a natural aggregate one must ensure that the aggregate does not show a pessimum effect. The Malmesbury aggregate showed no pessimum effect.

DISCUSSION

Dr A B Poole (Queen Mary College, London) asked for an explanation of the statement that mineral admixtures were more than merely dilutents. Did Dr Oberholster think, he asked, that this was due to a pozzolanic reaction between the alkalis and the admixtures or was there an alkali-silica type of reaction between the finely ground admixtures and the alkalis in the cement at the time the concrete was mixed.

Dr Oberholster replied that he thought they were the same thing in the case of materials such as silica flour (fumed silica condensate.) As far as the slagment (granulated blast-furnace slag) was concerned it was well known that the alkalis could activate it in the same way that $Ca(OH)_2$ did.

Mr W R Barker (D & H Ash Resources, Johannesburg) asked for some clarification of the fact that in his conclusion Dr Oberholster had seemed to discount the value of fly ash (pfa) because the quantities required to produce an adequate reduction in expansion were associated with a loss in the compressive strength of the concrete. Mr Barker said he had looked at the mix proportions of the test specimens and it was evident that the material used had not been a very good fly ash since it had required substantially more water than the control specimens. Their experience with fly ash in this country had shown them where to go for materials with suitable water reducing characteristics and he wondered whether these would not be worth considering in the South Western Cape.

Dr Oberholster hastened to correct Mr Barker's wrong impression by affirming that he thought that pfa was a suitable material to use for reducing expansion due to alkali-aggregate reaction. As far as the results that they had obtained were concerned it had to be remembered that they had worked at a constant water:cement ratio in order to compare the results obtained from a variety of admixtures without introducing an additional variable. They had also stored the specimens under conditions which differed from normal practice in order to compare the results of adding different percentages of admixture. Now that they had established that certain admixtures were suitable for effectively reducing expansion due to alkali-silica reaction the concrete technologists should see what they could do to design the most suitable concrete mixes to use with the suggested admixtures.

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