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A CONTRIBUTION TO THE DETERMINATION OF THE POTENTIAL ALKALI REACTIVITY OF TYGERBERG FORMATION AGGREGATES

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SYNOPSIS

The potential alkali reactivity of a number of aggregates from quarries on the Tygerberg Formation were evaluated by means of the chemical test ASTM C289-71, the mortar prism test ASTM C 227-71, the concrete prism test and the rock cylinder test ASTM C586-69. Investigations into the Nova Scotia aggregates, which are similar to the Tygerberg Formation aggregates, are fully considered. The results obtained are interpreted in terms of methods with their associated criteria as suggested by ASTM and several researchers.

SAMEVATTING

Die potensiële alkalireaktiwiteit van 'n aantal aggregate van groewe op die Formasie Tygerberg is geëvalueer m.b.v. die chemiese toets ASTM C289-71, die mortelprismatoets ASTM C227-71, die betonprismatoets en die rotssilindertoets ASTM C586-69. Die oorsese ondersoek van die Nova Skotia aggregate, wat soortgelyk is aan die Formasie Tygerberg aggregate, word ook deeglik in ag geneem. Die resultate wat verkry is, word volgens metodes en gepaardgaande kriteria wat deur ASTM en verskeie navorsers voorgestel is, geïnterpreteer.

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1. INTRODUCTION

Surveys of concrete structures in the Cape Peninsula and its immediate vicinity, carried out by the NBRI, have shown that about half the structures built with aggregates from the Tygerberg Formation are cracking.[1]

It is significant that among the structures examined, 83 per cent of those built during the period 1958-1962 were damaged and that during this period cements having alkali contents of up to 1,3 per cent Na_2O equivalent were produced. The surveys, also showed that structures containing Tygerberg Formation aggregates have been standing for thirty years or more with no damage whatsoever caused by the alkali-aggregate reaction.

Cores taken from cracked structures show clear signs of alkali-aggregate reaction which correspond to observations made by inter-alia Duncan[2], Gillot[3] and Dolar-Montuani[4] in Nova Scotia where the aggregates are similar to Tygerberg Formation aggregates.

A considerable number of methods, each having its own criteria, have been suggested to evaluate aggregates or aggregate-cement combinations for harmful alkali-aggregate reactions.

Apart from the chemical test, ASTM C289-71[5], the mortar prism test (ASTM C227-71[6]), modifications of the mortar prism test ASTM C227-71[6], the rock cylinder test (ASTM C586-69[7]) and a concrete prism test as suggested by Duncan[2] and Duncan et al[8, 9] to examine the Nova Scotia aggregates, were also used for the evaluation of the Tygerberg Formation aggregates for potential alkali reactivity.

2. AGGREGATES EXAMINED FOR POTENTIAL ALKALI-REACTIVITY

For the investigation, nine aggregate samples were taken from four quarries on the Tygerberg Formation. Approximately 500 kg of each aggregate was collected. The material was selected in the quarries mainly on the basis of colour and texture.

Five samples, i.e. P1, P5, A1(a), A2(a), and A6(b) were identified as hornfels and four, P4, A1(b), A2(b), and A6(a) were identified as greywackes. Sample P4 also contained small amounts of quartzite, quartz-albite-epidote-hornfels and mylonite. X-ray diffraction analysis showed that K-vermiculite was present in all these samples; P4, however, contained very little. No swelling clay minerals were observed in the samples. The physical properties of the samples were also examined, e.g. drying shrinkage, soundness, 10 per cent fines aggregate crushing test (FACT) value, water absorption and relative density. It was found that all samples complied with the applicable requirements of the standard specification SABS 1083-1976[10].

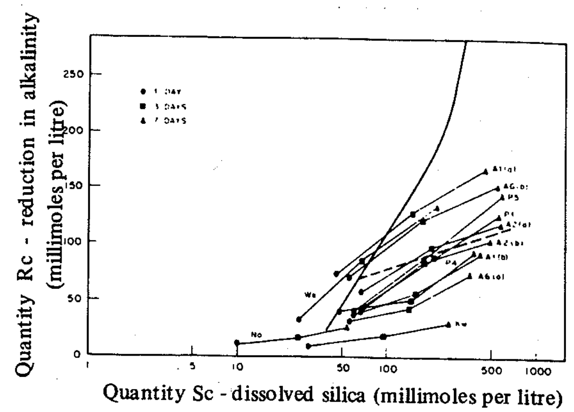

FIGURE 1: Increase in dissolved silica for 9 Tygerberg Formation aggregates as well as for norite, quartzite, and Witbank sand after treatment according to ASTM C289-71 for 1, 3 and 7 days.

Seven cements[11] were used for the mortar and concrete prism investigation, viz. A(0,16), B(0,82), C(0,62), D(0,85), G(0,58), F(1,02) and F(1,30). The figures in brackets represent the Na_2O equivalent of the cement.

3. THE QUICK CHEMICAL TEST ASTM C289-71

Little time is needed to carry out this test which entails the determination of the degree of reaction which takes place during 24 hours at 80 °C between Normal NaOH-solution and the aggregate. The sample is crushed and sieved to pass through a 300 µm sieve and the test specimen is that portion retained on a 150 µm sieve. The amount of silicon in solution and the decrease in alkalinity give an indication of the reactivity of the aggregate.

In the case of aggregates from the Tygerberg Formation, 4 kg of material were crushed and sieved until it all passed through a 300 µm sieve. The amount of material which was retained on the 150 µm sieve varied between 48 and 53 per cent (m/m).

All nine aggregates from the Tygerberg Formation as well as three control aggregates, viz. norite (No), quartzite (Kw) and a quartz sand (Ws) were examined by treating them for periods of 1, 3 and 7 days in 1N NaOH at 80 °C. The results are shown in Fig. 1. It is clear that for all samples, a reasonably linear relationship exists between silicon in solution (expressed as silica in Figure 1) and the treatment time. The increase in dissolved silica is higher for the Tygerberg Formation aggregates than for Witbank sand, quartzite and norite.

In order to determine the behaviour of smaller particles, the minus 150 µm plus 75 µm fraction and the minus

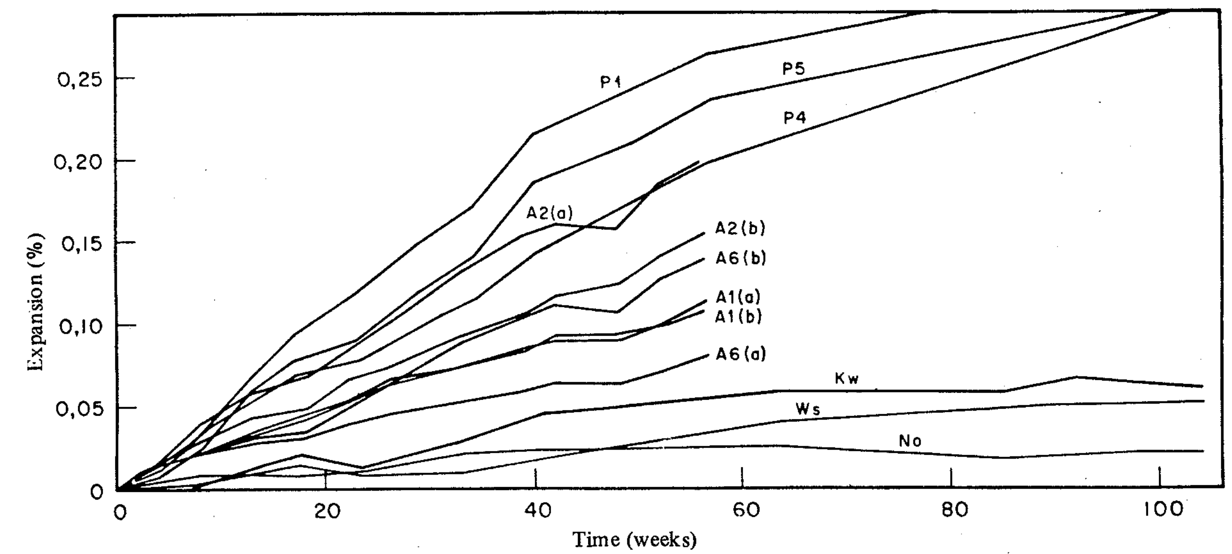

FIGURE 2 : Linear expansion of mortar prisms made with various Tygerberg Formation aggregates and cement F(1,30)

75 µm fraction were also treated according to ASTM C289-71. Despite the increasing fineness of the samples, Tygerberg Formation aggregates showed practically no increase in dissolved silicon, in contrast to the control aggregates where the silicon in solution increased with the fineness. A possible explanation for this is that the reactive component of Tygerberg Formation is inherently fine-grained.

The results in Figure 1 for the 24 hour treatment indicate that they are so close to the dividing line that the classification of aggregates as deleterious or innocuous becomes difficult. Repeated tests showed that the reproducibility of the values for reduction in alkalinity and the amount of silicon in the solution are not always as desired.

When interpreting the results obtained with the ASTM C289-71 chemical test, it should be kept in mind that the test was originally developed to determine the alkali reactivity of certain siliceous rocks, minerals and glasses with which alkali-silica reaction takes place. At this stage it is still not clear which mineral or minerals of Tygerberg Formation rocks react with alkali hydroxide solution.

4. MORTAR AND CONCRETE PRISM TESTS

Mortar prisms were made with the Tygerberg Formation aggregates P1, P4 and P5 and seven cements, and with A1(a), A1(b), A2(b), A6(a) and A6(b) and the two cements F(1,02) and F(1,30). They were made and stored according to ASTM C227-71[6]. Concrete prisms[2, 9]

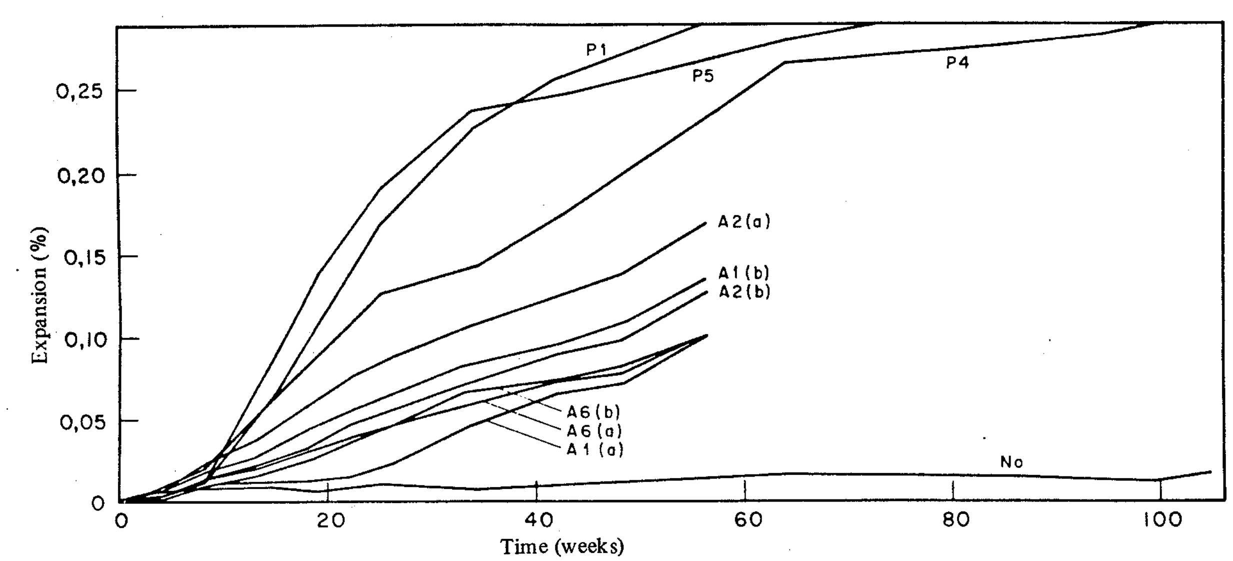

FIGURE 3 : Linear expansion of concrete prisms made with various Tygerberg Formation aggregates and cement F(1,30)

measuring 75 mm x 75 mm x 300 mm and having an aggregate/sand/cement/water ratio of 3,38:1,87:1,0:0,5 were also made, and stored in sealed containers over water at 38 °C. A non-reactive quartz sand from the Witbank area in the Transvaal was used. This sand complied with the requirements of Standard Specification SABS 1090-1976[12] and 1083-1976[10].

The results for the mortar prisms are shown in Figure 2 and for the concrete prisms in Figure 3, (both using cement F(1,30)). The Figures show that there is a great variation in the expansion of the prisms made with the various aggregates. There is close agreement between the results obtained for the mortar prisms and for the concrete prisms.

The criteria of 0,05 per cent or more expansion within 3 months and 0,1 per cent or more winthin 6 months for mortar prisms, as given in ASTM C227-71 to distinguish between deleterious and innocuous aggregates, cannot be applied unreservedly to the Tygerberg Formation aggregates for the following reasons:

a) A cement with a known reactivity is not specified; since Tygerberg Formation aggregates show no pessimum effect, they could be compared in respect of alkali reactivity if examined in combination with a cement of which the reactivity is specified.
b) The test was developed for siliceous rocks, minerals, and glasses where alkali-silica reaction takes place;
c) It is uncertain at this stage whether alkali-silica reaction or another type of reaction is the reason for the expansion with Tygerberg Formation aggregates.

An expansion of 0,05 per cent can be regarded as a critical expansion limit because both concrete prisms stored under laboratory conditions and concrete cubes stored under field conditions show clear cracks at this expansion.

Duncan et al[9] and Duncan[2] reporting on Nova Scotia aggregates, suggest that an expansion of 0,05 per cent after 72 weeks for mortar prisms made with a cement of 1,0 per cent Na_2O-equivalent and of 0,05 per cent after 120 weeks for concrete prisms made with a cement with an Na_2O-equivalent of not less than 0,9 per cent, indicate a harmful aggregate.

At this stage doubt exists about the reproducibility of 0,05 per cent expansion within 72 or 120 weeks for aggregate cement combinations made with Tygerberg Formation aggregates and South African cements. It is not quite certain that an expansion of 0,05 per cent after 72 or 120 weeks is attributable to alkali-aggregate reaction only. Over and above the alkali-aggregate reaction, the cement paste itself[11, 13] can expand to a certain extent, and the variation in the results of repeated experiments over a period of 72 or 120 weeks is relatively large. Matters are further complicated because the reactivity[11] of cements with the same total alkali content can vary. It has, in fact, been found that these factors can influence the expansion by more than 0,05 per cent within 72 or 120 weeks. The interpretation of data is made difficult because the mortar prisms, especially those containing control aggregate, also expand by about 0,05 per cent after 72 weeks.

It has also to be taken into account that criteria are generally determined empirically for certain aggregates which, in practice, cause damage under certain conditions. The criteria mentioned in ASTM C227-71 or which are reported for Nova Scotia aggregates can therefore not merely be related to conditions in the Cape Peninsula. The stage at which deterioration with a specific reactive

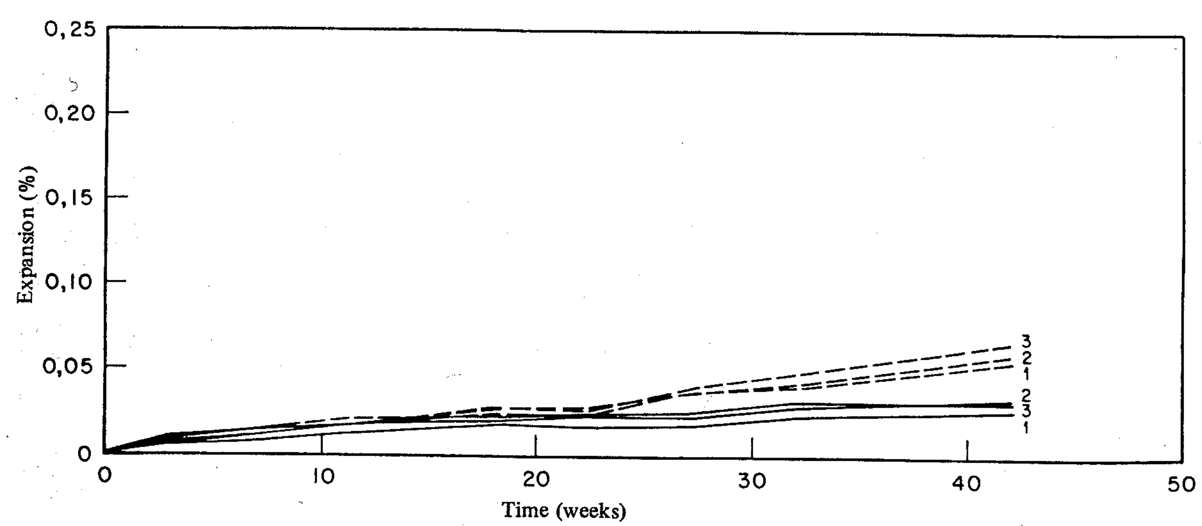

FIGURE 4:Linear expansion of rock cylinders of aggregate A1(b) drilled in three mutually orthogonal directions (1, 2 and 3) during treatment in 1N NaOH-solution (- - - - -) and water (———) at 38 °C)

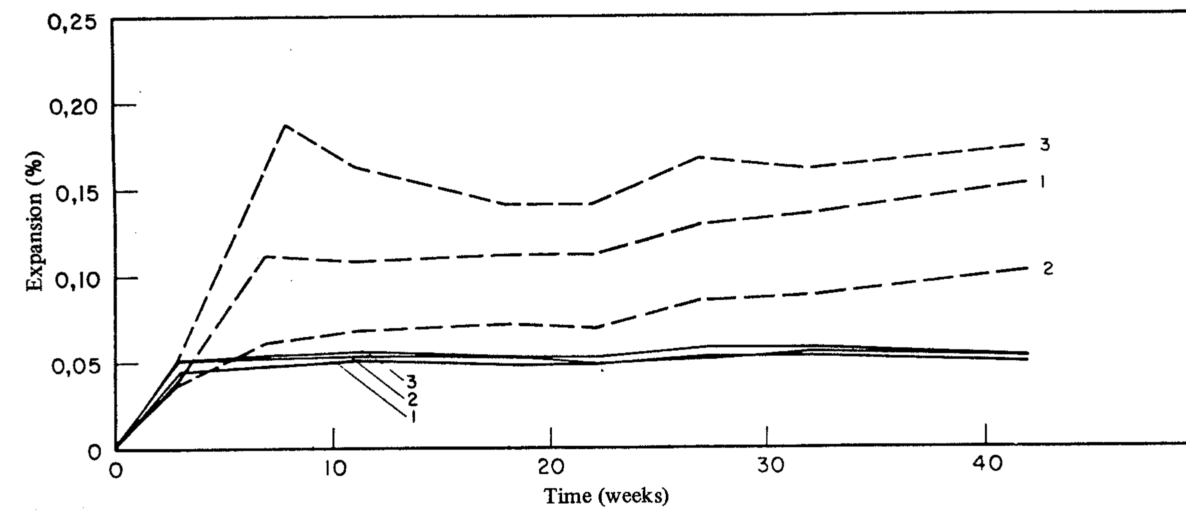

FIGURE 5 : Linear expansion of rock cylinders of aggregate A2(a) drilled in three mutually orthogonal directions (1, 2 and 3) during treatment in 1N NaOH-solution (- - - - -) and water (———) at 38 °C.

aggregate-cement combination will be noticable in practice depends on the way in which the reaction or the expansion mechanism is influenced, by factors such as the temperature, humidity, concrete design, reinforcing, the orientation of the structure, the cement content of the concrete, or the reactivity of the cement.

With a view to developing criteria for distinguishing between deleterious and innocuous aggregates as far as the alkali-aggregate reaction is concerned, and especially to bring laboratory results as far as possible in line with practice, 300-mm concrete cubes were made with Tygerberg Formation aggregate and seven cements. These are being exposed to natural environmental conditions in the South Western Cape.

This investigation, which included consideration of the criteria laid down for Nova Scotia aggregates, clearly shows that the Tygerberg Formation aggregates are potentially alkali reactive. It has further been discovered that concrete prisms (350 kg cement per m³) made with Tygerberg Formation aggregates and cements having a total alkali-

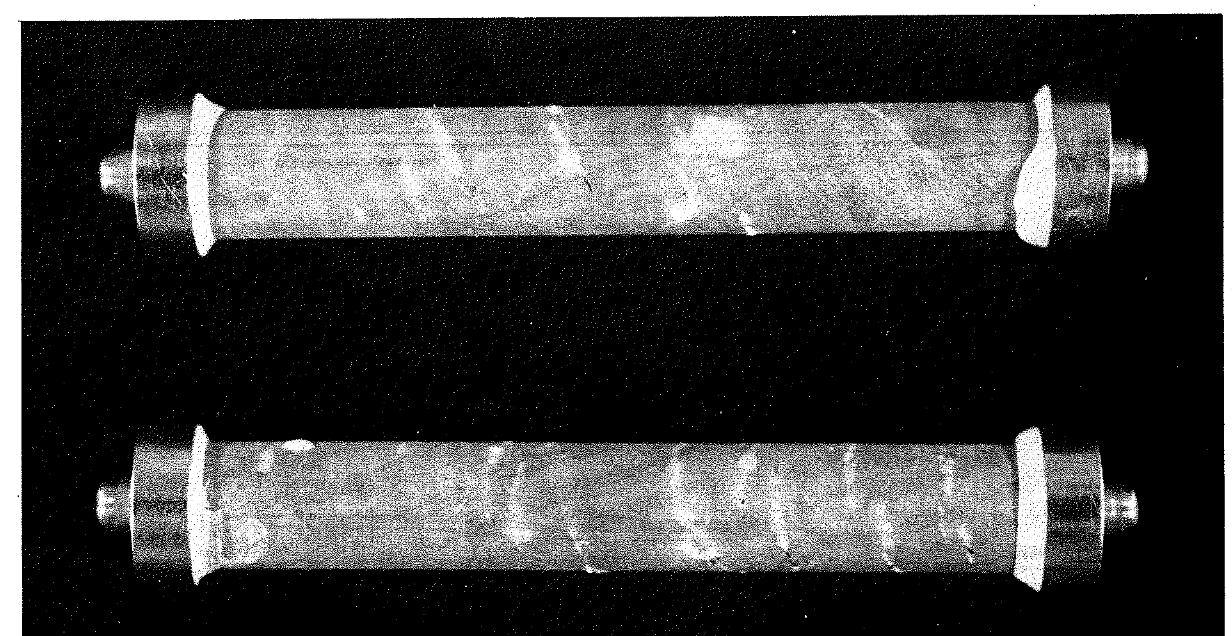

FIGURE 6 : Rock cylinders of hornfels P1 after treatment for 10 weeks in 1N NaOH-solution at 38 °C. Core dimensions are 70 ± 0,2 mm long and 10 ± 0,1 mm in diameter

content of less than 0,6 per cent Na_2O-equivalent (or available alkali content of less than 0,5 per cent Na_2O-equivalent) showed no significant expansion as a result of the alkali-aggregate reaction when stored at 38 °C for 120 weeks.

5. THE ROCK CYLINDER METHOD

Duncan et al[8] found that the ASTM C586-69[7] rock cylinder test in a modified form was also suitable for the examination of Nova Scotia rocks for alkali reactivity.

For the purpose of the examination, cores from each of the rocks P1, P4, P5, A1(a), A1(b), A2(a), A2(b), A6(a) and A6(b), were drilled in three mutually orthogonal directions and samples were stored in water and sodium hydroxide solution of 38 °C. The rock cores were 70 ± 0,2 mm in length and 10 ± 0,1 mm in diameter. Stainless steel caps attached with Tepicolle KB60 were used as reference points to measure the length of the three cores which were used for each treatment. The OH-concentration of the 1N NaOH-solution used for the treatment of the rock cylinders almost corresponds to the concentration of alkali in the pore fluid of a mortar prism made according to ASTM C227-71 (cement content approximately 122 g), with a cement which releases 0,82 per cent Na_2O-equivalent available alkali after 28 days.

The expansion of rock cylinders for the aggregates A1(b) and A2(a) is shown in Figures 4 and 5, respectively. The mutually orthogonal directions of the rock cores are marked 1, 2 and 3.

The expansion of the rock cores of aggregate A1(b) in water does not significantly differ from that in 1N NaOH-solution whereas a relatively high expansion is reached with cores of aggregate A2(a) in 1N NaOH-solution compared to that in water. P1 has the same high expansion as A2(a) but the other aggregates performed in more or less the same way as A1(b).

Reactive materials are found to a certain extent in the rock cylinders of aggregates A2(a) and P1 in veins (petrographically identified as chert) which react with the sodium hydroxide solution and can cause expansion.

Figure 6 shows rock cylinders of aggregate P1 after 10 weeks of treatment in 1N NaOH-solution at 38 °C. The rock cylinders have veins and the reaction products that have formed in these veins are clearly visible. What is not clear at this stage is to what extent the expansion of mortar or concrete prisms is influenced by this phenomenon.

Rock cylinders from the Tygerberg Formation aggregates further display a strong, progressive loss of mass in 1N NaOH-solution of approximately 0,4 to 1 per cent over a period of 52 weeks while the mass increases slightly in water to begin with after which it remains constant. It is not clear at this stage whether the rock cylinder test can be adapted to determine the potential alkali reactivity of Tygerberg Formation aggregates.

6. CONCLUSIONS

At this stage a universally applicable test by which the Tygerberg Formation aggregates can be evaluated within a reasonable period, say 3 months, as being deleterious or innocuous in respect of the alkali-aggregate reaction cannot be proposed.

(a) The investigation showed that expansion as a result of alkali aggregate reaction between Tygerberg Formation aggregates and high alkali cement (> 0,8 per cent Na_2O-equivalent available alkali) takes place. It also showed clearly that no expansion occurred as a result of alkali-aggregate reaction with low alkali cement (< 0,05 per cent Na_2O-equivalent available alkali) and little or no expansion with medium alkali cement (0,5 to 0,8 per cent Na_2O-equivalent available alkali).

(b) The investigations carried out according to ASTM C227-71 and ASTM C289-71 showed that it is impossible to judge Tygerberg Formation aggregate meaningfully by means of these methods.

The criteria in ASTM C227-71 and ASTM C289-71 are applicable to certain siliceous rocks, minerals and glasses in which alkali-silica-reaction, which is coupled to specific environmental conditions where damage to concrete has been observed, takes place. The Tygerberg Formation rocks consist of silica and silicate minerals and it is not yet known which minerals are reactive and whether it is an alkali silica, alkali silicate or any other type of reaction.

(c) An expansion of 0,05 per cent after a specified time cannot be recommended as a criterion to distinguish between deleterious and innocuous aggregates at this stage since the reactivity of cements having the same total alkali content differs and up to this time no cement with a standard reactivity can be prescribed. The poor reproducibility of experiments and the expansion of the cement paste itself influence the results. Furthermore the expansions measured in the laboratory could not, up to now, be correlated with expansions in practice. It is also most impractical to have to wait 72 or 120 weeks to obtain results.

(d) The results obtained with the rock cylinder method show that only certain rock cylinders containing reactive material in veins expand in 1N NaOH at 38 °C. The results obtained with the rock cylinders cannot at this stage be related to expansions obtained for mortar and concrete prisms.

(e) For the present, a test method and criteria to distinguish between deleterious and innocuous aggregates within a reasonable period, say three months, cannot be proposed.

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DISCUSSION

Dr J Skalny (Martin Marietta Cement, Baltimore, USA) asked Mr Brandt to define what he meant by a 'cement with a standard reactivity'.

Mr Brandt replied that when two different laboratories did tests on the same aggregate they would use the cement with the highest alkali content available. Although both laboratories might use a cement with the same total alkali content of 1,02 per cent Na_2O equivalent, the expansion obtained for mortar prisms might differ by a factor of 3, because the active alkali content of the two cements was different. In the previous paper (S252/10) it had been shown that a good relationship was found to exist between expansion and available alkali content. He therefore proposed using the available alkali content as a parameter to standardise the reactivity of cements.