

Results of an International Inter-Laboratory Test Program to Determine the Potential Alkali Reactivity of Aggregates by the ASTM C227 Mortar Prism Method

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ABSTRACT

Laboratories in Canada, New Zealand, Germany, Netherlands and South Africa have cooperated in a programme to determine the alkali reactivity of the same aggregate-cement combinations by the ASTM C 227 mortar prism method.

Four of the laboratories recorded similar, low expansions after one year, while significantly greater expansion was recorded in South Africa.

INTRODUCTION

After the Fifth International Conference on Alkali-Aggregate Reaction in Concrete held in Cape Town, South Africa in 1981, a number of scientists from different countries agreed to participate in an inter-laboratory test programme using ASTM Method C 227-81 to determine the potential alkali reactivity of cement-aggregate combinations.

PURPOSE

The ASTM C 227 criteria state that aggregate-cement combinations which produce excessive expansion should be regarded as potentially reactive. Expansion is considered excessive if it exceeds 0.05 per cent at 3 months or 0.10 per cent at 6 months. Expansion greater than 0.05 per cent at 3 months should not be considered excessive where the 6-month expansion remains below 0.10 per cent (ASTM C 33-81).

However, several researchers, among them Duncan et al (1973), Grattan-Bellew and Litvan (1976), Oberholster et al (1978), Grattan-Bellew (1981a, 1981b), Brandt et al (1981), Sims (1981) and Oberholster (1983), have reported expansions of less than 0.05 per cent within 3 months for aggregates such as greywacke, phyllite, hornfels, quartzite and granite when performing the ASTM C 227 mortar prism test, although they had service records which showed that they were deleteriously reactive. The result is that different laboratories have applied different criteria to distinguish deleterious from innocuous aggregates when using the same method. (Bredsdorff et al, 1960, Duncan et al, 1973 and Oberholster, 1983).

The purpose of the test programme using the ASTM C 227 test was firstly, to compare the results from different laboratories when using the same aggregate-cement combination, secondly to compare the variation in alkali reactivity of aggregates from different countries in combination with the same high-alkali cement and thirdly to compare the reactivity of cements from different countries in combination with the same reactive aggregate. The results of the first objective are reported here.

MATERIALS AND PROCEDURES

Aggregates

The aggregate used, P6, was 19 mm run-of-quarry aggregate from the Tygerberg Formation of the Malmesbury Group in South Africa which is known to be alkali reactive from its service record. It consists of a mixture of hornfels, quartzwacke and some quartzarenite.

Expansion data obtained for the aggregate in combination with cement J(1.10) (see Cements below) in experiments which commenced prior to the inter-laboratory test programme, are given below.

Mortar prisms, ASTM C 227	} 0.182%
3 sets of 3 prisms,	
after one year	
Concrete prisms, ASTM C 227 storage,	} 0.189%
after one year	
Concrete prisms, ASTM C 227 storage,	} 0.223%
22 °C, after two years,	
Concrete cubes, 300 mm, natural exposure,	} 0.089%
after four years	
	} 0.167%

For all the above concrete 350 kg cement per cubic metre was used and the Na₂O equivalent of the cement was 1.10 per cent.

A non-reactive natural sand, WS, was included as a control aggregate.

Cements

Cements were supplied for four different aggregate-cement combinations. The alkali content was as follows.

Cement	Na ₂ O equivalent, %		
	Water-soluble ¹	Available ²	Total ³
C(0.62)	0.12	0.48	0.62
D(0.85)	0.09	0.57	0.85
J(0.82)	0.66	0.80	0.82
J(1.10)	0.94	1.08	1.10

1. ASTM C 114, Section 17.2
2. ASTM C 311, Section 18: 7 g cement and 10 ml distilled water. Designated as active alkali content in South Africa.
3. ASTM C 114, section 17.1

Procedure

The aggregates were prepared and graded and the cement and aggregate for the different combinations weighed out in the correct mix proportions, as prescribed by ASTM C 227, by the NBRI in South Africa and sent to participating laboratories. In this way possible differences caused by variations in the preparation of the material by the different laboratories, were eliminated.

All the laboratories were required to follow as closely as possible both the procedures described in ASTM C 227 for the preparation of the mortar prisms and the requirements in respect of curing, storing and measuring.

RESULTS

The results obtained by the different laboratories for aggregate P6 in combination with each of the four cements, are presented graphically in Figure 1 and summarised in Table 1 together with results for the natural sand WS.

TABLE 1. Summary of linear expansions recorded after one year for aggregates P6 and WS with different cements.

Laboratory	Per cent linear expansion for							
	P6 with				WS with			
	C(0.62)	D(0.85)	J(0.82)	J(1.10)	C(0.62)	D(0.85)	J(0.82)	J(1.10)
South Africa	0.019	0.048	0.072	0.153	0.000	0.007	0.006	0.017
Canada	0.005	0.012	0.018	0.025	-	-	-	0.013
New Zealand	0.013	0.012	0.013	0.033	-	-	-	0.015
Germany	0.011	0.027	0.031	0.043	-	-	-	0.011*
Netherlands**	0.008	0.023	0.004	0.010	-	-	-	0.015
	0.024	0.034	0.006	0.030	-	-	-	0.021

* An expansion of 0.029 per cent recorded at 111 days, was disregarded because all values on this day seemed to be about double the previous and subsequent values.

** Upper row for 20x20x160 mm and bottom row for 40x40x160 mm prisms.

From the expansion results the following can be seen:

- (i) South African researchers recorded expansions that were respectively 173, 177, 232 and 355 per cent more than those of the German laboratory where the next highest expansions were recorded.
- (ii) The South African results showed a significant and almost linear increase in expansion with the increase in per cent available Na_2O equivalent through the range C = 0.48, D = 0.57, J = 0.80 and J = 1.08.
- (iii) The South African results did not show a flattening off during the first year (nor did the curves flatten much between years 1 and 2).
- (iv) Neither the Canadian nor the New Zealand laboratories recorded expansions for alkali-reactive aggregate P6 in combination with cements C(0.62), D(0.85) and J(0.82) that were significantly different from the expansions they recorded for the non-reactive combination of sand WS and cement J(1.10).
- (v) The Netherlands' results, evaluated as a whole, appear erratic.
- (vi) According to ASTM C 227 criteria, aggregate P6 is not potentially deleteriously reactive in combination with any of the four cements based on results of any of the laboratories.

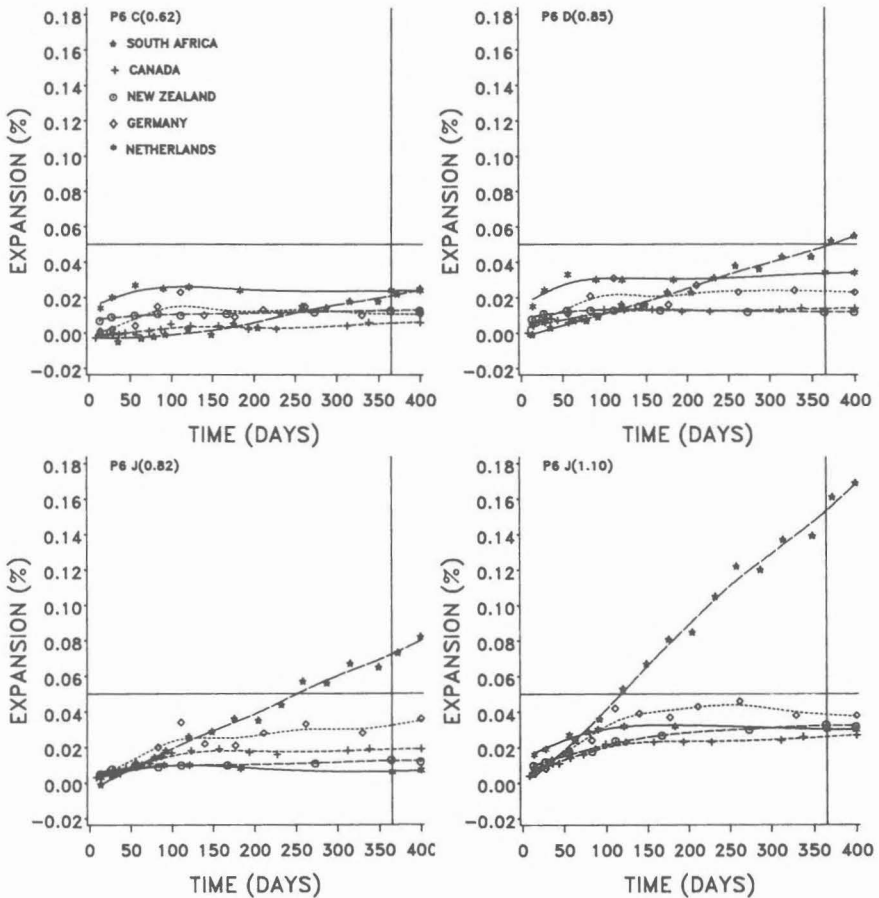


FIGURE 1: Linear expansions recorded with time for aggregate P6 in combination with four different cements, using ASTM C 227.

Photographs of the surface of the mortar prisms, supplied by the New Zealand researchers, did not show exudations of gel, with the exception of an isolated deposit on one of the prisms made with aggregate P6 and cement J(1.10). Surface mottling, possibly lime efflorescence, was evident on one pair of prisms made with cement D(0.85) and aggregate P6. All the South African prisms made with aggregate P6 in combination with the four different cements, showed gel exudations, the amount of which increased with an increase in available Na_2O equivalent of the cement. The other participants did not supply details of gel exudation or surface mottling.

DISCUSSION AND CONCLUSION

It is not clear why the South African researchers recorded expansions so much greater than those of the other participants. Some of the reasons which have been suggested are given below.

St John of New Zealand was of the opinion that the greater expansions recorded in South Africa were caused by cyclic wetting and drying as a result of lack of high humidity at all times in the storage vessels, and a failure to prevent drying during length measurements.

Bakker, Netherlands, suggested that shrinkage occurred in the South African prisms because of moisture loss which took place during the initial 14 days when the relative humidity inside the containers was less than 100 per cent. Fine cracks resulting from the shrinkage, allowed easier ingress of water at later stages. Because the cement minerals had already hydrated almost completely at the later age, water taken up by the prisms was then available for the alkali-silica reaction and the prisms could start expanding. At the later age, stresses set up by the expansion could not be taken up by the mortar and the prisms cracked, leading to the high expansion. Because the other laboratories maintained their samples at 100 per cent relative humidity, enough moisture was available at all times for hydration and the alkali-silica reaction, with the result that expansion occurred uniformly at an early age when the mortar was still plastic and the stresses could be taken up without damage to the mortar.

Lenzner, Germany, thought that a possible reason might be differences in the techniques for the preparation of the mortar.

Grattan-Bellew, Canada, considered several possible reasons and finally concluded that a plausible explanation for the higher expansion recorded in South Africa was the high humidity in the storage containers.

An important observation is that gel exudations and other clear signs of alkali-silica reaction were present in the South African mortar prisms that expanded.

It is clear that the reason for the difference in expansion can only be determined by conducting a new series of experiments in which the relative humidity is carefully monitored.

It is, however, evident that the ASTM C 227 criteria for distinguishing deleterious from innocuous aggregates, do not apply to reactive quartz-bearing aggregates.

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