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TEST FOR DETERMINING THE POTENTIAL
ALKALI-EXPANSIVITY OF AGGREGATES

by P. E. Grattan-Bellew

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EVALUATION OF MINIATURE ROCK PRISM TEST FOR DETERMINING THE POTENTIAL
ALKALI-EXPANSIVITY OF AGGREGATES

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ABSTRACT

Expansion of miniature rock prisms sawn normal to the layering of the rock and stored in 2N NaOH was monitored with a Huggenberger gauge or a linear voltage differential transformer (LVDT). Owing to their thinness (3 mm) the samples become saturated quickly and expansion usually commences within the first week, compared with the long initiation period typical of the rock cylinder method ASTM C586. The miniature rock prism test was evaluated for alkali-carbonate, slowly expanding siliceous aggregates and classical alkali-silica reactive rocks. Rates of expansion generally correlated well with those of corresponding concrete prisms tested according to CSA A23.2 - 14A.

L'expansion de prismes de roches miniatures prélevés à angle droit des couches dans des spécimens de roche et déposés dans une concentration 2N de NaOH a été observée avec une jauge Huggenberger ou avec un capteur de déplacement. En raison de leur minceur (3 mm), les échantillons ont été saturés rapidement. L'expansion de l'alkali commence habituellement au cours de la première semaine, contrairement à la méthode d'essai ASTM C586 où il faut attendre souvent une longue période d'initiation. La capacité de déterminer l'expansion causée par l'alkali-carbonate, les granulats siliceux à expansion lente et la réaction classique alkali-silice de l'essai sur une prisme de roche miniature a été évaluée. Les taux d'expansion des prismes de roches miniatures placés dans une solution de NaOH entre habituellement bien en corrélation avec les taux correspondants d'expansion des prismes de béton NNC A23.2 - 14A.

Introduction

The miniature rock prism test is designed as an accelerated form of ASTM C586, the rock cylinder method (1), for determining the potential expansivity of carbonate rocks. It eliminates the long initiation period frequently required before the onset of expansion of rock cylinders. The thin samples used in the miniature rock prism test become saturated with alkali and expan-

sion begins after only a few days. Preliminary results from the miniature rock prism test reported by Grattan-Bellew and Litvan (2) indicate a given expansion in about one third of the time required for the same expansion with the rock cylinder method, ASTM C586. The objective of this paper is to assess the applicability of the miniature rock prism test to a number of rock types. The expansion of miniature rock prisms stored in 2N NaOH has therefore been compared with the expansion of mortar or concrete prisms made with the same aggregates and high alkali cement, and stored at 38°C and 100% RH.

Samples and Apparatus

Miniature Rock Prisms

Miniature rock prisms $3 \times 6 \times 30$ mm can be sawn from a slab or rock, or even cut from a large gravel pebble. To avoid the effects of the anisotropy of layered rocks, all prisms were cut normal to the layering. Length of prism is not critical, but 30 mm was selected because it is a convenient length for measurement with the Huggenberger strain gauge. If length is measured with a linear voltage differential transformer (LVDT), shorter prisms may be used; this is particularly important when testing gravels in which it may not be possible to find large enough pieces from which to cut 30 mm prisms normal to the layering. The effect of cutting the prisms normal and parallel to layering is shown in Table 1. Miniature rock prisms of green argillite cut normal to the bedding expanded by 0.11% compared to only 0.03% for prisms cut parallel to the bedding. The rates of expansion shown in Table 1 were determined from the slope of the graph of the percentage expansion during the main expansive phase of the reaction versus the square root of time in days. The use of the concept of rate of expansion was discussed in a recent paper (3).

Huggenberger Gauge

This strain gauge is capable of reading to 1 μ m. The measurements are made between two stainless steel pins cemented into holes drilled in the rock prisms 20 mm apart (Fig. 1a). The pins are machined from stainless steel with a spherical head (Fig. 1b) that permits accurate

readings. The points of the Huggenberger gauge with which the readings are made have conical holes that fit over the pins. A cement such as Hysol 2038*, which does not swell in water, was used.

TABLE 1

Expansion of Miniature Rock Prisms Cut
Normal and Parallel to the Bedding of
an Alkali-Expansive Argillite

Sample Argillite	Rate of Expansion $\text{days}^{-\frac{1}{2}} \times 10^{-3}$	% Expansion at 145 days
Green, normal	10	0.11
Green, parallel	2.6	0.030
Blue grey, normal	6.6	0.070
Blue grey, parallel	1.4	0.019

Linear Voltage Differential Transformer (LVDT)

For measurement with an LVDT the rock prism is clamped in a frame made of invar; at the lower end a nut is provided so that the LVDT can be adjusted to read zero with the sample in place (Fig. 2). The LVDT is capable of reading to 0.1 μ m, but a gauge that can read to 1 μ m would be adequate for measuring length changes. The output from the LVDT is connected to an amplifier and a strip recorder. The frame containing the prism is placed in 2N NaOH and left

* Hysol Canada Ltd., Don Mills, Ontario

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FIG. 1a

Huggenberger strain gauge with miniature rock prism in position

FIG. 1b

Stainless steel pins cemented into holes in the miniature rock prism

undisturbed for the duration of the experiment. To obtain realistic results, several prisms should be measured from each sample.

Experimental Technique

For quick results the prisms were vacuum saturated in the preliminary experiments, but subsequent tests showed that they become saturated after only a day or two in water at one atmosphere pressure. At the start of the experiment the length of the dry prism is measured. It is then placed in water and its length monitored until a constant value is obtained. This is taken as zero value for expansion in alkali. The samples are then placed in 2N NaOH. This normality was selected to maximize the rate of expansion.

If the Huggenberger gauge was used to monitor the length change of the prisms, or if an LVDT was used without a recorder, readings were taken every two or three days so that the trend of the expansion curve could be established. Later readings were taken at longer intervals, the exact time determined by the rate of expansion of the sample; rapidly expanding samples were read more frequently to pick up any changes.

Comparison of Expansions of Rock Prisms Recorded by Huggenberger and LVDT Methods

Expansions of prisms of an expansive carbonate rock, recorded in separate experiments using a Huggenberger gauge and an LVDT are shown in Fig. 3. The sample measured with the Huggenberger expanded much more than that measured with the LVDT. Similar disparities were invariably found with prisms of other reactive rock types, indicating that this is unlikely to be due to variations in composition of prisms of any one rock sample. Calibration of both measur-

ing instruments eliminated instrument error as the source of the difference. A direct comparison of the two instruments was also made by mounting a sample prepared for the Huggenberger gauge in the LVDT apparatus. The length of the sample was read with the Huggenberger at the beginning and at the end of the experiment. Expansion of the sample in NaOH was monitored by the LVDT for 30 days. Both instruments indicated the same expansion, and when non-expansive samples were tested, both methods gave the same results. From this it was clear that the difference observed in the expansion of prisms of reactive rocks measured by Huggenberger gauge and LVDT is due in some way to their reactivity. In another set of experiments the change in Young's modulus of 1 mm thick discs of reactive rock stored in 2N NaOH was monitored; it showed a decrease with time of storage. If the expansive samples are weakened by the NaOH, then stress applied to the samples by frequent readings with the Huggenberger gauge probably accounts for the excessive strain it recorded.

The LVDT system is the best method for recording length change of miniature rock prisms in alkali because the readings are accurate and there is no risk of breaking the sample as sometimes happens while prisms are being measured with the Huggenberger gauge. If a large number of samples are to be tested, the cost of LVDT apparatus may, however, become prohibitive.

The Huggenberger method of measurement from pins embedded in the rock has a major advantage over alternative types of strain gauges in that reaction deposits do not readily accumulate on the pins. Even if this were to occur, the pins can be readily cleaned without affecting the readings.

Application of Miniature Rock Prism Test to Selected Aggregates

Alkali-Carbonate Aggregate

The rock cylinder test, ASTM C586, was designed to test alkali-carbonate expansive aggregates. The expansion recorded by this method was compared with the expansion measured by the miniature rock prism test in an alkali-expansive carbonate aggregate from the Pittsburgh quarry in Kingston. Sample A6'-7' used by Swenson and Gillott (4) was tested first. Expansions recorded by Swenson and Gillott for rock cylinders were compared with those of miniature rock prisms in an LVDT apparatus. The rates of expansion determined from the slope of the line fitted to the points on the graph were 17×10^{-3} days $^{-1}$ for the rock cylinder method, ASTM C586, and 18×10^{-3} days $^{-1}$ for the miniature rock prism method. The correlation of expansions is shown in Fig. 4. The correlation coefficient for the lines fitted to the points on the graphs by the method of least squares is 0.9998, indicating that the results obtained with the miniature rock prism test correlate very well with those obtained

FIG. 2

Apparatus for measuring expansion of miniature rock prisms using LVDT (shown at the top). A sample is clamped into the apparatus. The knurled knob at the bottom is used to adjust the LVDT to read zero at the start of the experiment

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FIG. 3

Comparison of expansions measured on miniature rock prisms of expansive rock in 2N NaOH by Huggenberger gauge and LVDT apparatus

r = correlation coefficient for fit of least squares line to points on the graph

R = rate of expansion expressed as $\text{days}^{-\frac{1}{2}} \times 10^{-3}$

with the rock cylinder method. The advantage of the miniature rock prism method is that a given expansion is obtained in a shorter time.

Excellent correlation was found between expansion of miniature rock prisms in 2N NaOH and expansion of concrete prisms in a modified form of CSA 23.2-14A (5) in which samples are stored at 38°C and 100% RH. It is concluded that the miniature rock prism method gives a very good indication of the potential expansivity of carbonate aggregate. The main advantage of the miniature rock prism method is its speed. If, for example, expansion of 0.06% or greater is considered indicative of deleterious expansion, this amount is observed in 9 days with the miniature rock prism method but not until after 81 days with the modified concrete prism test (5). With the rock cylinder method, 0.06% expansion was observed after 36 days.

To evaluate the miniature rock prism method further, rock prisms and corresponding concrete prisms were made from samples taken from the top lift of the Pittsburgh quarry. Because of the number of prisms involved in the test (24), the Huggenberger gauge was used to make the measurements (there were not enough pieces of LVDT apparatus available). In Fig. 5 the rates of expansion of miniature rock prisms stored in 2N NaOH are plotted against rates of expansion of concrete prisms made with high alkali cement (1.08% Na₂O equivalent) and stored at 38°C and 100% RH. The correlation coefficient of the line fitted by the method of least squares to points representing samples 78-13, 78-14, 78-15, 78-17 and 78-18 is 0.8681, indicating only a moderate correlation. This is probably due to erratically high readings recorded with

FIG. 4

Graph showing percentage expansion of rock cylinder (ASTM C586) versus percentage expansion of miniature rock prisms measured with LVDT (Sample is A6'-7', Pittsburg quarry)

the Huggenberger gauge for expansive samples. Extrapolation from Fig. 5 indicated a rate of expansion for concrete prisms of $80 \times 10^{-3} \text{ days}^{-\frac{1}{2}}$, corresponding to the observed rate of expansion of rock prisms of $330 \times 10^{-3} \text{ days}^{-\frac{1}{2}}$. The observed rate of expansion of the concrete prisms was $56 \times 10^{-3} \text{ days}^{-\frac{1}{2}}$. Although the difference between the measured and extrapolated values is large, it is of little significance because both of these extremely high rates of expansion are indicative of an excessively expansive aggregate. It may be concluded that although the Huggenberger gauge does not give as accurate a value as may be obtained by an LVDT apparatus, there is reasonable correlation between rates of expansion of miniature rock prisms in alkali and concrete prisms made with high alkali cement and stored at 38°C and 100% RH.

Slowly Expanding Siliceous Aggregates

Duncan (6) and Dolar-Mantuani (7) applied the rock cylinder method of ASTM C586 to slowly expanding siliceous aggregates. Although the method works with these types of rock (greywacke, quartzite, argillite, phyllite), Duncan's results indicate that the correlation of expansion of concrete prisms and rock prisms is poor. The correlation coefficient was 0.5703.

The rock cylinder method is not a very practical method with either of these rock types for two reasons: it takes just as long to obtain results as the concrete prism method; and when expansive rocks are tested, gel-like material is frequently deposited on the surfaces from which measurements are made, causing erratically high readings. This problem does not occur with the miniature rock prism method; with the LVDT the sample is clamped in the apparatus for the duration of the run, and with the Huggenberger gauge measurements are made from the steel pins, which are readily cleaned. It was decided to test the miniature rock prism method on two samples that had shown deleterious expansivity in the field.

FIG. 5

Graph showing rates of expansion of rock prisms versus rates of expansion of concrete prisms made with carbonate aggregates from Pittsburg quarry. (Rates of expansions of miniature rock prisms are averages of sets of four prisms measured with Huggenberger gauge)

Argillite from Lady Evelyn Lake, Ontario

The petrology of this rock has been described (8). The mean expansion of all the rock cylinders measured by Dolar-Mantuani (7) and of five miniature rock prisms measured with the Huggenberger gauge is shown in Fig. 6. It is known from field and laboratory evidence to be deleteriously expansive. After 64 days in alkali the rock cylinders still showed no expansion, but the miniature rock prisms had expanded by 0.04%. The superiority of the miniature rock prism test over the rock cylinder method is evident. In Fig. 7 the expansion of miniature rock prisms is plotted against expansion of concrete prisms measured by the author and against expansion of mortar bars measured by Dolar-Mantuani (7).

The greater expansion observed for the mortar bars is thought to be related to the formation of a large amount of gel by the reaction of this aggregate and the alkalis in the cement. In reactions where gel formation and swelling are the major factors in the expansion of mortar or concrete, greater expansion is observed with finer grain sizes of the reactive component (9).

During the main reactive phase of the expansion of concrete or mortar prisms, the correlation between expansion of miniature rock prisms and concrete prisms and mortar bars is very good. This indicates that expansion of miniature rock prisms in 2N NaOH gives a good indication of the potential expansivity of concrete and mortar made with this type of argillite and high alkali cement. With this aggregate, the rock prisms in alkali took almost as long as the concrete prisms to reach a given percentage expansion. From the

FIG. 6

Expansion of miniature rock prisms and rock cylinders (ASTM C586, Dolar-Mantuani (7)) of argillite from Lady Evelyn Lake, Ontario (Points shown for the miniature rock prism are the average of five prisms measured with Huggenberger gauge)

R = rate of expansion expressed as $\text{days}^{-\frac{1}{2}} \times 10^{-3}$

point of view of time required for the test to be carried out with this type of rock there is little advantage in the miniature rock prism test over the concrete prism test.

Feldspathic Quartzite from Malay Falls, Nova Scotia

The composition of the aggregate, #73-50, is shown in Table 2. Severe deterioration of concrete made with it was reported by Duncan (10), and subsequent laboratory tests confirmed that the deterioration was due to alkali-expansivity. The mean expansion of four miniature rock prisms stored in 2N NaOH and the expansion of concrete prisms made with high alkali cement was determined. The rate of expansion of the concrete prisms, $24 \times 10^{-3} \text{ days}^{-\frac{1}{2}}$ (during the main expansive phase of the reaction), is much greater than the rate of expansion of miniature rock prisms in alkali, $7 \times 10^{-3} \text{ days}^{-\frac{1}{2}}$; but after 240 days the rate of expansion of the concrete prisms falls to $1.5 \times 10^{-3} \text{ days}^{-\frac{1}{2}}$. In Fig. 8 the expansion of miniature rock prisms is plotted against the expansion of concrete prisms. It is evident that during the main expansive phase of the reaction of the concrete prisms (64-240 days) the rate of expansion correlates well with the rate of expansion of miniature rock prisms in alkali. Using this type of aggregate, results are obtained in a shorter time with the miniature rock prism test than with the concrete prism method. For example, in 72 days the rock prisms expanded by 0.08%, while the concrete prisms expanded by only 0.008%.

Quartzites from Canadian Shield and Appalachian Regions

To conclude this evaluation of the miniature rock prism method, the

TABLE 2

Composition and Rates of Expansion of Miniature Rock Prisms Stored in 2N NaOH and Concrete Prisms Stored at 38°C and 100% RH. (Moderate correlation was found for the expansion of rock prisms and concrete prisms of the first nine samples, but it was poor or non-existent for the last five)

Sample No.	Rate of Expansion $\text{days}^{-\frac{1}{2}} \times 10^{-3}$		Composition of Rock %						
	Rock Prisms	Concrete Prisms	Clay Size Minerals	Quartz		Feldspar	Biotite	Accessory Minerals	
				<0.05 mm	>0.05 mm				
77-8	4.5	3.1	-	25	75	-	-	-	
76.1	3.7	5.3	-	39	9.4	-	50.0	1.6	
74-45	2	7.8	2	12	77	6	-	3	
74-54	5	8.1	14	9	77	-	-	-	
74-51	5	11.3	22	19	58	-	-	1	
74-46	6	11.9	55	27	13	2	-	3	
74-57	6	14.1	52	29	15	2	-	2	
72-92	8	23.0	27	10	62	-	-	1	
73-50	7	24	15	40	43	2	-	-	
74-56	6.2	2.6	13	10	62	6	-	9	
74-52	5	1.2	16	3	78	-	-	3	
74-50	8.5	5.5	20	18	58	4	-	<1	
74-47	14	10	31	17	45	6	-	<2	
74-46	6	11.9	55	27	13	2	-	3

FIG. 7

Expansion of concrete prisms and mortar bars versus expansion of miniature rock prisms in 2N NaOH, Lady Evelyn Lake argillite (Times required to attain various levels of expansion are also shown)

FIG. 8

Feldspathic quartzite from Malay Falls, N.S. Comparison of expansion of concrete prisms and miniature rock prisms in 2N NaOH - the correlation coefficient 0.9998 refers to the fit of the central part of the graph between 64 and 240 days

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FIG. 9

Expansion of miniature rock prisms of agate in 2N NaOH. Rates of expansion "R" expressed in $\text{days}^{-\frac{1}{2}} \times 10^{-3}$ for expansion and shrinkage phases of reaction are 4.4 and -26, respectively

expansion in alkali of 15 prisms of quartz-bearing rocks from these regions was compared with the expansion of corresponding concrete prisms made with high alkali cement. The results are shown in Table 2, which includes the composition of the aggregates as well. In most cases there was good correlation of expansion for the miniature rock prisms and concrete prisms made from the same rock. In the last six samples listed in Table 2, however, the correlation between expansion of rock prisms and concrete prisms was poor or non-existent. The reason for this is not clear, but it may be due in part to the selection of non-representative rock prisms or to erratic results from the Huggenberger gauge (used for all samples except #72-92). More testing will be necessary to evaluate the reliability of the miniature rock prism test for slowly expanding siliceous aggregates.

In the first nine rock prisms in Table 2, for which good correlation was found for their expansion and that of corresponding concrete prisms, the rates of expansion of the rock prisms were plotted against the rates of expansion of concrete prisms made with the same aggregates; the correlation coefficient of the line fitted to the points is 0.8126, indicating that the rates of expansion of the miniature rock prisms give a reasonable indication of the potential expansivity of the concrete prisms. It is possible that there would be better correlation if an LVDT instead of the Huggenberger gauge were used to monitor the length change of the rock prisms.

Classical Alkali Silica Rocks

A prism of agate, representing this group, was tested in an LVDT cell in 2N NaOH solution. For the first 170 days it expanded at a rate of $4.4 \times 10^{-3} \text{ days}^{-\frac{1}{2}}$ (Fig. 9); subsequently, it shrank as it started to dissolve in the alkali. After 400 days it disintegrated. Similar results were obtained with

Beltain opal (11). The expansion of concrete containing either opal or agate is due to the formation and swelling of a gel-like phase, not to the direct expansion of the aggregate, as is the case with the alkali-carbonate reactive aggregates. A correlation between the rates of expansion or contraction of miniature rock prisms of classical alkali-silica reactive aggregates and expansion of concrete made with these aggregates cannot therefore be expected. The expansion or contraction of a rock prism of this type of aggregate does, however, indicate in a general way that the aggregate is reactive.

Conclusions

The expansion in 2N NaOH of miniature rock prisms of carbonate aggregate corresponds well with the expansion of concrete prisms made with the same aggregate and high alkali cement stored at 38°C and 100% RH. Better results were obtained with the LVDT cell than with the Huggenberger gauge. This is thought to be due to erratically high values obtained with the Huggenberger gauge owing to weakening of the prisms as the reaction proceeds.

One of the major advantages of the miniature rock prisms test is its rapidity. The small size of the samples, $3 \times 6 \times 30$ mm, is also an advantage for storage during the test. It would be particularly useful in evaluating the potential expansivity of the horizons in a quarry containing thinly bedded carbonate rocks. The small size of the samples, down to 15 mm if an LVDT is used, permits evaluation of the potential expansivity even of pebbles from a gravel deposit.

For slowly expanding siliceous aggregates, quartzites, argillites, quartz-biotite gneiss, and greywackes, the miniature rock prism test results are not as promising. This may be due, in part, to the testing of non-representative samples. To overcome the problem it is recommended that four or five rock prisms tested from each sample be cut from different blocks of rock. Agreement of rates of expansion for miniature rock prisms and concrete prisms would probably be improved by use of an LVDT system of measurement in place of the Huggenberger gauge.

Miniature rock prisms made from classical alkali-silica reactive aggregates first expanded, then contracted and disintegrated. Although the rates of expansion or contraction do not give a measure of the potential expansivity of concrete prisms made with these aggregates, they do indicate that the rock is potentially deleteriously expansive in concrete.

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