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ALKALI-AGGREGATE REACTION IN NOVA SCOTIA
[Part] III. LABORATORY STUDIES OF VOLUME CHANGE

by

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ALKALI-AGGREGATE REACTION IN NOVA SCOTIA
III. LABORATORY STUDIES OF VOLUME CHANGE

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(Communicated by G. M. Idorn)

ABSTRACT

Studies of alkali-expansivity of Nova Scotia rock types included extensive length change tests of mortar bars and concrete prisms, and also rock cylinders immersed in alkali solution. The effects of such variables as alkali content, type of alkali, temperature, wet and dry cycling, anisotropy, optimum proportion of rock type, and the influence of pozzolan and fly ash were studied. Results obtained were correlated with petrographic studies so that potentially expansive rock types in the province may be recognized. Preventive measures applicable to field use were determined from analyses of expansion data.

SOMMAIRE

Les études de la dilatation due aux alcalis de certains genres de roches en Nouvelle-Ecosse comprennent de nombreux essais de changement de longueur sur des barres de mortier et des prismes de béton, et aussi sur des cylindres de roche plongés dans une solution alcaline. On étudie également le rôle de variables comme la teneur en alcalis, les genres d'alcalis, la température, un cycle humide ou sec, l'anisotropie, la proportion optimale des genres de roches et l'influence de la pouzzolane ou de la cendre volante. Les résultats obtenus sont mis en corrélation avec les études pétrographiques afin que l'on puisse reconnaître, dans la province, les genres de roches susceptibles de subir une dilatation. L'analyse des données de la dilatation a permis d'établir des mesures préventives applicables in situ.

This is the third in a series of papers describing a five-year study of alkali-aggregate reaction in Nova Scotia. The first paper (1) described the general investigation, conclusions, and recommendations, the second (2) dealt with field studies and petrographic examinations; the present paper provides additional results of various laboratory tests.

As for other alkali-aggregate reactions, the identification of alkali-expansive rocks in Nova Scotia necessitated reproduction of expansions in the laboratory and petrographic analyses. Because the reaction was extremely slow, as demonstrated under normal conditions of test, accelerated test methods had to be used. In extreme cases these tended to reduce, to some degree, the reliability of results obtained from length change tests. Extensive testing was thus necessary to develop test combinations that could be applied with confidence in evaluating aggregate sources in the area. The critical values of time versus expansion that are intended to distinguish safe from deleterious aggregate were based on correlation of all test data from mortar bars, concrete prisms, and rock cylinders, as well as on field experience. Tests were carried out in triplicate with some exceptions, in which case duplicates were used.

Mortar Bars

Procedures for testing mortar bars for length change have been described (1). Modifications in ASTM test method C227 used in the present studies are noted in each set of data presented.

Table I shows length change results of mortar bars made with the low and the high alkali cements at four temperatures. A large increase in the rate of expansion was registered between 100°F (38°C) and 125°F (52°C) for nearly all cases of alkali-expansive rocks. With low alkali cement the expansions were not excessive at the higher temperatures although some increase did occur. Studies of this type aided in the development of accelerated test procedures.

Table II gives typical expansions under conditions of temperature, alkalinity and time selected for evaluating Nova Scotia aggregates. In general the correlation, and therefore the confidence, decreases with increasing acceleration of expansion.

Table 1

LINEAR EXPANSIONS OF MOIST CURED MORTAR BARS MADE WITH LOW AND HIGH ALKALI CEMENTS AT FOUR TEMPERATURES

LA = 0.34% and HA = 0.88% ALK., Calculated as Na_2O
W = TIME, WEEKS

AGGREGATE DESCRIPTION	CURE TEMP. °C	LINEAR EXPANSION, PERCENT								EXP'N POTENTIAL, ALL TESTS
		LOW ALK. CEMENT				HIGH ALK. CEMENT				
		12W	16W	24W	48W	12W	16W	24W	48W	
BEACH SAND	23	0.011	0.013	0.016	0.020	0.016	0.018	0.020	0.025	HIGH
	38	0.018	0.012	0.020	0.021	0.017	0.020	0.028	0.047	
	52	0.015	0.018	0.021	0.026	0.037	0.049	0.066	0.102	
	64	0.015	0.017	0.021	0.024	0.054	0.062	0.076	0.114	
PYRITIFEROUS PHYLLITE	23	-	-	-	-	0.013	0.015	0.017	0.022	MODERATE
	38	0.019	0.021	0.023	0.026	0.019	0.024	0.032	0.050	
	52	-	-	-	-	0.065	0.077	0.089	0.110	
	64	-	-	-	-	0.054	0.063	0.083	0.135	
MICACEOUS QUARTZITE	23	-	-	-	-	0.017	0.019	0.019	0.023	BORDERLINE
	38	0.011	0.012	0.015	0.016	0.017	0.019	0.022	0.025	
	52	-	-	-	-	0.036	0.040	0.044	0.062	
	64	-	-	-	-	0.048	0.059	0.082	0.124	
CALCAREOUS ARGILLITE	23	0.008	0.010	0.009	0.014	0.015	0.016	0.016	0.024	HIGH
	38	0.012	0.014	0.017	0.015	0.016	0.019	0.025	0.041	
	52	0.010	0.011	0.012	0.045	0.054	0.072	0.095	0.173	
	64	0.012	0.015	0.024	0.034	0.059	0.070	0.088	0.156	
IMPURE FELDSPATHIC QUARTZITE	23	0.011	0.012	0.011	0.017	0.013	0.014	0.011	0.022	HIGH
	38	0.013	0.013	0.016	0.014	0.018	0.021	0.029	0.037	
	52	0.009	0.011	0.013	0.029	0.058	0.072	0.092	0.182	
	64	0.014	0.017	0.022	0.026	0.080	0.097	0.124	0.198	
META-GREYWACKE	23	-	-	-	-	0.014	0.015	0.017	0.020	MODERATE
	38	0.013	0.013	0.016	0.015	0.018	0.021	0.025	0.029	
	52	-	-	-	-	0.040	0.043	0.048	0.058	
	64	-	-	-	-	0.053	0.061	0.073	0.143	
INLAND SAND	23	-	-	-	-	0.017	0.019	0.022	0.027	BORDERLINE
	38	0.010	0.012	0.016	0.020	0.021	0.024	0.028	0.036	
	52	-	-	-	-	0.045	0.047	0.051	0.067	
	64	-	-	-	-	0.045	0.050	0.055	0.067	
GREYWACKE	23	0.010	0.011	0.011	0.015	0.013	0.014	0.014	0.021	HIGH
	38	0.018	0.017	0.014	0.014	0.022	0.024	0.025	0.027	
	52	0.008	0.011	0.018	0.031	0.043	0.057	0.077	0.114	
	64	0.020	0.024	0.029	0.049	0.064	0.073	0.089	0.134	
PHYLLITE	23	0.013	0.015	0.017	0.024	0.018	0.020	0.022	0.026	HIGH
	38	0.019	0.021	0.018	0.018	0.021	0.023	0.025	0.032	
	52	0.010	0.012	0.014	0.020	0.032	0.048	0.078	0.169	
	64	0.014	0.016	0.020	0.023	0.060	0.075	0.106	0.202	
BANDED GLASSY RHYOLITE	23	-	-	-	-	0.013	0.015	0.016	0.021	HIGH
	38	0.003	0.009	0.013	0.017	0.016	0.020	0.030	0.044	
	52	-	-	-	-	0.047	0.052	0.062	0.143	
	64	-	-	-	-	0.053	0.061	0.088	0.177	
PINK GRAPHIC GRANITE	23	0.009	0.010	0.012	0.017	0.012	0.014	0.014	0.016	NONE
	38	0.005	0.010	0.015	0.014	0.020	0.022	0.026	0.035	
	52	0.007	0.009	0.014	0.024	0.021	0.027	0.032	0.039	
	64	0.015	0.018	0.024	0.029	0.031	0.036	0.042	0.046	
FELDSPATHIC QUARTZITE	23	-	-	-	-	0.017	0.020	0.020	0.026	HIGH
	38	0.008	0.010	0.017	0.019	0.020	0.022	0.029	0.042	
	52	-	-	-	-	0.077	0.087	0.104	0.142	
	64	-	-	-	-	0.085	0.101	0.115	0.155	

TABLE II

Typical Mortar Bar Expansion Data using the ASTM C227 Modified Test for Evaluation of Nova Scotia Aggregate

Rock Type or Sand	Percent Linear Expansion at different Alkali contents and temperatures						Exp'n Potential, All Tests
	°C 38	38	38	52	64	64	
	% Alk* 0.88	1.04	1.42	0.88	0.34	0.88	
	Weeks 144	72	36	24	48	16	
Greywacke	.036	.069	.078	.077	.049	.073	High
Meta-greywacke	.052	.038	.125	.048	--	.061	Moderate
Calcareous argillite	.078	.84	.173	.095	.024	.070	High
Phyllite	.055	.075	.045	.078	.023	.075	High
Impure feldspathic quartzite	.051	.102	.169	.092	.026	.097	High
Micaceous quartzite	.035	.042	.069	.044	--	.059	Borderline
Pink graphic granite	--	.038	--	.014	.017	.018	None

* calculated as Na_2O

Figure 1 shows the effect of total alkalinity of cement paste on 48-week expansions of mortar bars made with aggregates of varying type and reactivity. For the same aggregates, selected as typical examples, Figure 2 shows the variation of percent expansion with amount of test aggregate relative to neutral sand present. For the conditions 100°F (38°C) 100 percent relative humidity, total alkalinity of 1.00 percent calculated as Na_2O, and a 48-week duration, the proportions of alkali-expansive rock types for maximum expansion occurred at from 35 to 100 percent concentration, in 26 samples tested. The one exception was the cherty agate that showed maximum expansion at about 4 percent concentration.

Six alkali-expansive aggregates, as determined by correlation of all test data, were used with the low alkali cement with or without added

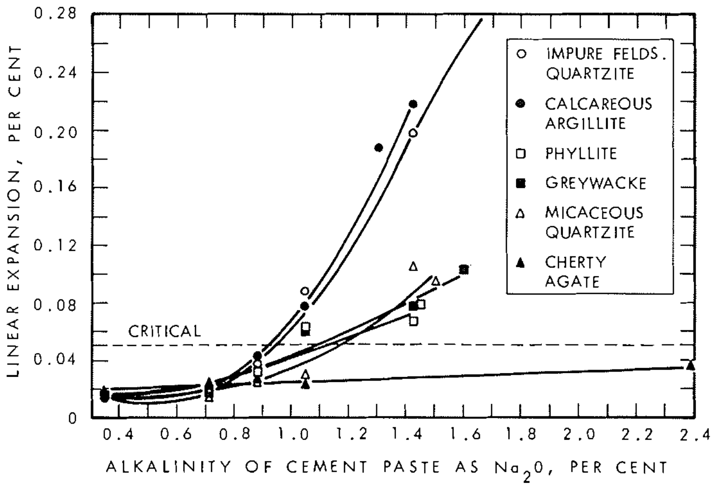

FIG. 1

The effect of cement paste alkalinity on the 48 week percentage expansions of mortar bars prepared from various aggregates and moist cured at 100°F (38°C) in sealed containers.

NaOH or KOH in the mixing water to obtain various total alkalinities calculated as Na_2O. In the mortar bar expansion data shown in Table III it is seen that very little difference, if any, exists between the relative aggressiveness of these two alkalis usually present in portland cement. This conflicts with results of alkali-expansive rock cylinders immersed in alkalis, where the NaOH was much more aggressive than the KOH.

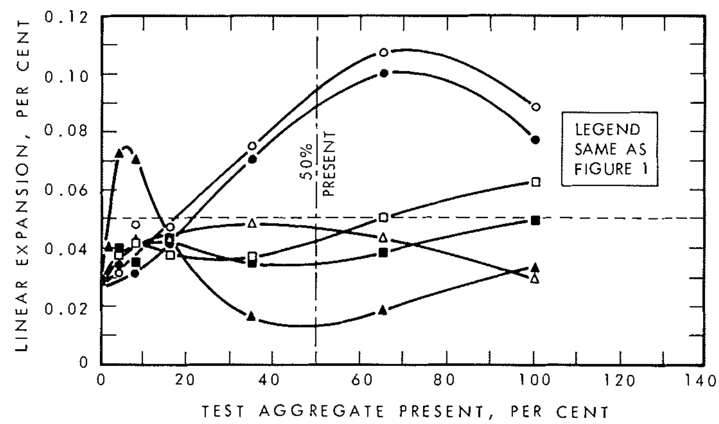

FIG. 2

Variation of percentage linear expansion with the amount of various aggregates present for 48-week-old mortar bars moist cured in sealed containers at 100°F (38°C). (Alkalinity of cement paste 1.00% as Na_2O).

TABLE III

EXPANSIONS OF MORTAR BARS MADE WITH ADDED NaOH OR KOH. 100°F (38°C) IN SEALED CONTAINERS. SELECTION OF 6 ALKALI-EXPANSIVE AGGREGATES.
L.A. Cement = 0.14% Na_2O + 0.20% K_2O calculated as Na_2O
H.A. Cement = 0.27% Na_2O + 0.61% K_2O calculated as Na_2O

Aggregate	Equiv. Na_2O % →	Percent linear expansion at 48 weeks						Concrete Prisms at 96 weeks
		Low Alkali Cement					H.A. + NaOH to 1.04	H.A. + NaOH to 1.00
		0.34	+ KOH to 0.71	+ NaOH to 0.71	+ KOH to 1.00	+ NaOH to 1.00		
Beach sand		.022	.033	.038	.055	.052	.068	
Calcareous argillite		.020	.041	.068	.070	.094	.077	.098
Feldspathic quartzite		.022	.043	.042	.075	.063	.088	.104
Greywacke		.020	.029	.030	.036	.053	.051	.157
Phyllite		.022	.032	.024	.038	.039	.075	.186
Greywacke		.025	.027	.028	.042	.046	.069	.075

Concrete Prisms

The concrete mix was of nominal 3500 psi design and typical of job mixes except that no chemical admixture was used. Further description is given in the first paper (1) which also gives characteristic expansion curves for the 3- by 3- by 11-inch prisms used (75- by 75- by 275-mm).

Some relationships between expansion of concrete, modulus of rupture, Rp, (ASTM C293-68), and the modified cube strength, Cp, (ASTM C116-68) after nearly two years moist curing at 100°F (38°C), are shown in Table IV. In nearly all cases when expansion becomes excessive the modulus drops from its 28-day value. When a pozzolan is substituted for 25 percent of the cement, by weight, and still using a high alkali cement, the modulus generally continues to increase. This is expected because of the effect of the pozzolan in decreasing expansion (Table V). Compressive strengths at 100 weeks (at 100°F, (38°C)) did not show as good correlation with the expansion.

Table IV

Expansion, Modulus of Rupture (Rp), and Compressive Strength (Cp) of 3 x 3 x 11 in. (75 x 75 x 275 mm) Concrete Prisms Cured at 38°C for Nearly Two Years. Rp = ASTM C293-68; Cp = ASTM C116-68. H. A. = High Alkali Cement. Rp in psi (and kgf/cm^2) and Cp in psi (and kN/m^2)

Aggregate	96 week H. A.	28-day H. A.	100 weeks			
			H. A.		H. A. and Pozzolan	
	% Exp.	Rp	Rp	Cp	Rp	Cp
Pyritiferous Phyllite	.038	720 (50.4)	1002 (70.1)	6100 (42090)	---	6200 (42780)
Calcareous Argillite	.098	763 (53.4)	548 (38.4)	5685 (39227)	---	6050 (41745)
Meta-sub Greywacke	.045	633 (44.3)	901 (63.1)	5988 (41317)	1122 (78.5)	6257 (43173)
Feldspathic Quartzite	.104	687 (48.1)	532 (37.2)	5285 (36467)	880 (61.6)	4750 (32785)
Meta-grey-wacke	.044	754 (52.8)	1040 (72.8)	6400 (44160)	1140 (79.8)	4740 (32706)
Heterogeneous	.018	511 (35.8)	977 (68.4)	6333 (43698)	---	6078 (41938)
Quartzite	.069	691 (48.4)	760 (53.2)	5900 (40710)	1120 (78.4)	5150 (35535)
Meta-grey-wacke	.153	675 (47.3)	390 (27.3)	5350 (36915)	1080 (75.6)	5300 (36570)
Greywacke	.158	679 (47.5)	608 (42.7)	5444 (37564)	1129 (79.0)	5830 (40227)
Meta-grey-wacke	.140	709 (49.6)	503 (35.2)	5122 (35342)	1041 (72.9)	5455 (37640)
Phyllite	.186	628 (44.0)	500 (35.0)	4320 (29808)	990 (69.3)	4800 (33120)
Rhyolite I	.066	622 (43.5)	572 (40.0)	6285 (43367)	1140 (79.8)	5825 (40193)
Rhyolite II	.026	750 (52.5)	793 (55.5)	5592 (58585)	1103 (77.2)	6127 (42276)
Rhyolite III	.031	686 (48.0)	824 (57.7)	5537 (38205)	1148 (79.0)	5551 (38302)
Pink granite	.015	660 (46.2)	786 (55.0)	6175 (42608)	1010 (70.7)	5817 (40137)
Feldspathic quartzite	.030	669 (46.8)	716 (50.1)	6550 (45195)	930 (65.1)	4940 (34086)
Meta, feldsp. quartzite	.121	564 (39.5)	572 (40.0)	5560 (38364)	910 (63.7)	5950 (41055)
Feldspathic quartzite	.066	787 (55.1)	---	6800 (46920)	940 (65.8)	6100 (42090)
Quartzite and argillite	.060	808 (56.6)	782 (54.7)	5540 (38216)	940 (65.8)	5600 (38640)
Greywacke	.075	770 (53.9)	750 (52.5)	6410 (44229)	1080 (75.6)	5950 (41055)
Gr. and silt-stone	.138	742 (51.9)	570 (39.9)	5100 (34190)	775 (54.3)	5500 (37950)
Reference OHC	.014	845 (59.2)	974 (68.2)	6625 (45713)	960 (67.2)	5700 (39330)
Reference F C	.016	674 (47.2)	955 (66.9)	6229 (42980)	1103 (77.2)	5353 (36936)

TABLE V

Percentage Linear Expansion of Concrete Prisms after 96 Weeks Moist Curing in Sealed Containers at 100°F (38°C). The Effect of Partial Substitution of Cement by Pozzolan or Fly Ash

Alkalinity of H. A. cement 1.00% (as Na_2O) except where extra Alkali added, as shown, to compensate for reduced cement content. L. A. Cement 0.34% (as Na_2O)

Description	L. A. Cement Only	H. A. Cement Only	With Pozzolan		With Fly Ash	
			H. A. Cement	H. A. + NaOH	H. A. Cement	H. A. + NaOH
Calcareous Argillite	.006	.098	.009	.008	-	.004
Feldspathic Quartzite	.009	.104	.005	.015	.013	.006
Meta-Greywacke	.006	.044	.012	.008	.008	.012
Meta-Greywacke	.003	.153	.016	.021	.021	.021
Greywacke	.027	.158	-	.024	-	-
Phyllite	.011	.186	.023	.013	.011	.004
Banded, Glassy Rhyolite	.012	.066	-	.005	-	-
Feldspathic Quartzite	.009	.030	.006	.009	.005	.003
Meta-Feldspathic Quartzite	.010	.121	.016	.021	.014	.011
Quartzite and Argillite	.045	.060	.018	.020	.011	.016
Pink Graphic Granite	.011	.015	-	.012	-	-
Siliceous Ballast	.006	.016	-	.006	-	-

Table V gives more detailed results of the effect of pozzolan and fly ash in suppressing expansion of concrete prisms made with alkali-expansive aggregate and high alkali cement. The pozzolan is a calcined volcanic tuff with a good performance record. Detroit-Edison fly ash was also used. In order that the effect of the mineral admixture should not be attributed merely to the reduction in total alkali resulting from decrease in cement content, a comparative series of tests was carried out in which total alkalinity was maintained at the high alkali cement level. Even in this case, as shown in Table V, the mineral admixtures were both very effective in reducing expansion to values considered acceptable. Use of a pozzolan or fly ash would require consideration of disadvantages as well as advantages.

Rock Cylinders

An adaptation of ASTM C586 was used in determining alkali-expansivity by immersing rock samples in alkali solution, (NaOH unless otherwise stated). Cylinders were cored measuring 0.375 in. (9.6 mm) in diam. by 1.38 ± 0.02 in. (35 ± 5 mm) long. They were drilled from three mutually orthogonal faces of each rock sample except in a few cases where this was not possible. After grinding the end faces parallel, the cylinders were cleaned in organic solvent and then dried to constant weight. Several saturation techniques were used during this test series. In some studies they were presoaked in water. In all tests reference specimens were continuously immersed in water at the requisite curing temperature. The expansion due to the water immersion was subtracted from the results of alkali immersion and the corrected value reported. The special comparator used to measure length changes over long periods of time was selected to eliminate wear on the cylinder, ensure a constant measuring pressure, and permit rapid measurement to reduce shrinkage effects.

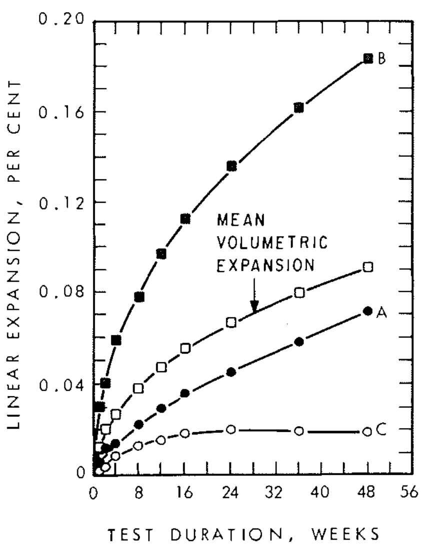

FIG. 3

Time-linear expansion relationships of cylinders taken from argillite, showing expansion in 3 mutually orthogonal directions, A, B and C. Cured in 2.67 M NaOH at 100°F (38°C)

The anisotropy exhibited by most of the rocks is demonstrated in Figure 3 for one of the argillites studied. A formula was used to obtain from these three length change results a percent mean volumetric expansion which would, for a given sample, always be the same regardless of the relative inclinations of cores to the bedding plane. Using this method and a derived critical volumetric expansion of 0.056 percent, a good correlation was obtained between the rock cylinder tests and those of the mortar bars and concrete prisms in distinguishing rocks that expanded excessively in the presence of alkali.

Typical volumetric expansion results on rock cylinders immersed in 1.0 molar NaOH at 73°F (23°C) are presented in Table VI. The rock types shown by the mortar bar and concrete prism tests to be alkali-expansive were

TABLE VI

TYPICAL VOLUMETRIC EXPANSION WITH TIME OF MAINLY ALKALI-EXPANSIVE ROCK CYLINDERS IN 1.0 MOLAR NaOH AT 73°F (23°C)

Rock Type	Percent Expansion at Weeks Shown					
	4	12	48	72	96	120
Meta-greywacke	.002	.009	.059	.100	.138	.161
Meta-greywacke	.004	.007	.042	.095	.162	.211
Quartzite greywacke	.002	.005	.047	.096	.159	.222
Quartzite greywacke	.002	.007	.011	.027	.058	.073
Calcareous argillite	.011	.016	.051	.060	.067	.074
Calcareous argillite	.001	.016	.128	-	-	-
Phyllite	.036	.037	.104	.159	.239	.286
Pyritiferous phyllite	.004	.008	.022	.044	.088	.115
Feldspathic quartzite	.005	-.001	.036	.062	.081	.070
Feldspathic quartzite	-.006	-.004	.008	.024	.046	.059
Micaceous quartzite	.004	.000	.014	.064	.138	.200
Micaceous schist	.001	.002	.051	.147	.255	.303
Chalcedony (Riversdale)	.013	.003	-.043	Disintegrating		
Agate (Brazil)	.036	.043	-.036	Disintegrating		
Flint (England)	.007	.002	.035	.022	-.013	-.237

generally those that reached the critical volumetric expansion in the rock cylinder test. Similar good agreement was found for non-expansive rocks. It is of interest that some rock types known to be alkali-silica reactive appeared to contract when subjected to this test, probably through partial dissolution.

Figure 4 shows typical curves in which rate of expansion of a phyllite increases with concentration of NaOH. In Figure 5 is shown the increase in

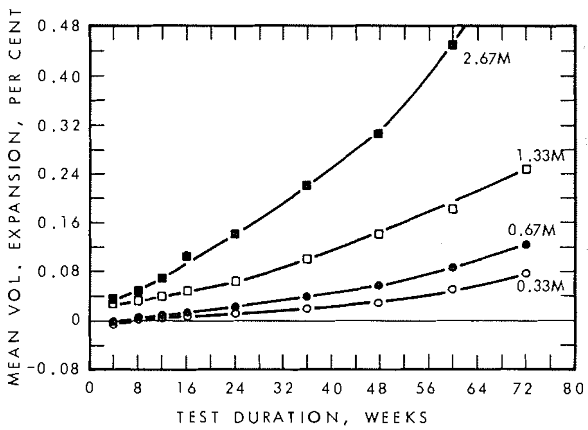

FIG. 4

The effect of NaOH concentration on the time-mean volumetric expansion relationship for phyllite at 100°F (38°C).

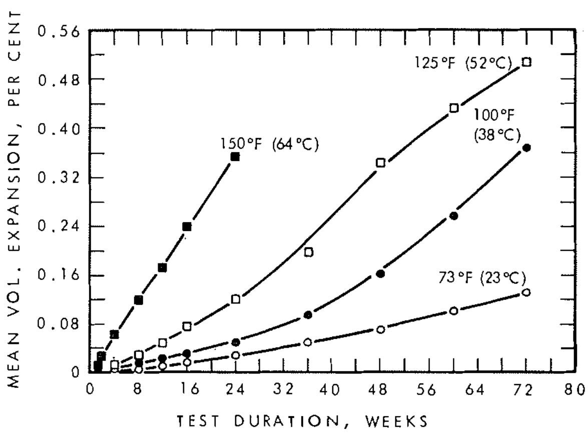

FIG. 5

The effect of temperature on the time-mean volumetric expansion relationship for greywacke cured in 2.67 M NaOH

rate of expansion of a greywacke with increase in temperature. These results are in agreement with those from mortar bar and concrete prism tests.

It was found in separate series of experiments that small axial loads of the order of 11 psi (76 kN/m^2) reduced the expansion rate. KOH and LiOH were found to produce small expansions relative to those of NaOH.

In one test series with alkali-expansive rocks, after 72 weeks immersion in various concentrations of NaOH, the samples were transferred to distilled water. The expansions continued at only a slightly slower rate.

A special rock cylinder study was carried out on a number of Nova Scotia rock types to determine the reliability of a selected test condition in relation to tests with mortar bars and concrete prisms made with high alkali cement. In this case the cylinders were vacuum saturated with distilled water and allowed to equilibrate for 28 days before initial measurement and immersion in alkali. The conditions were 2.67 molar NaOH at 125°F (52°C) for 16 weeks, using 0.056 percent volumetric expansion as the critical value. The degree of agreement with test results from mortar bars and concrete prisms in detecting rocks that are prone to excessive expansion is shown in Figure 6, (a) and (b). These and other experiments showed that the rock cylinder test is a good method for the initial evaluation of an aggregate source.

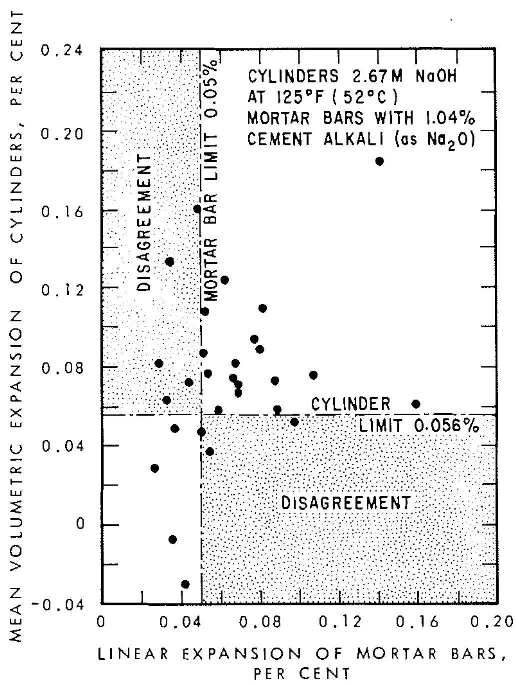

FIG. 6 (a)

Comparison of expansion of 16-week-old rock cylinders and 72-week-old mortar bars (Nova Scotia rock types).

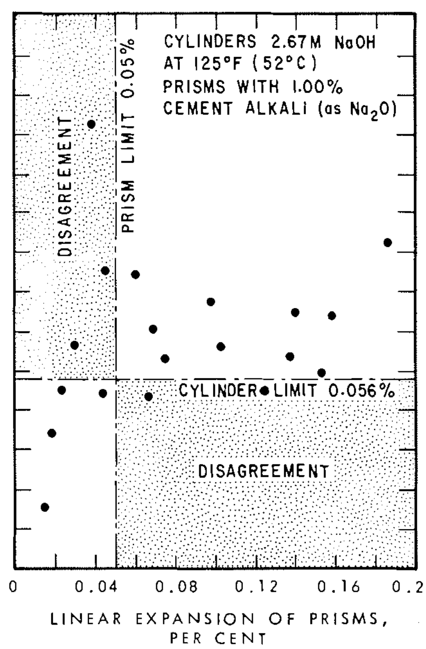

FIG. 6 (b)

Comparison of expansions of 16-week-old rock cylinders and 96-week-old concrete prisms (Nova Scotia rock types).

Summary

Good agreement was obtained between the various tests with mortar bars, concrete prisms, and rock cylinders in distinguishing potentially alkali-expansive rocks from non-expansive rocks. To some degree this was remarkable considering the heterogeneity of rock types and minerals in any given sample. Some correlation data and the recommended test conditions are outlined in the first paper (1). Further and detailed test data are to be found in the doctoral thesis of the first author (3).

As in other types of alkali-aggregate reactions which have been studied and reported, the mortar bar and concrete prism tests continue to be good direct methods for evaluation. The rock cylinder test, heretofore limited to the alkali-carbonate rock reaction, has been shown to be applicable to evaluation of the rocks in Nova Scota.

Interpretation of the experimental results given in this paper, and also in the two preceding ones, will be dealt with in the next and last paper in this series.

References

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3. M.A.G. Duncan. "Correlation of Field and Laboratory Evidence of Alkali-Silica Reactivity in Nova Scotia Concrete", Ph. D Thesis, Nova Scotia Technical College, 1970, p. 1 - 544.