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RECENT PROGRESS IN DEVELOPMENT OF THE OSMOTIC CELL TO DETERMINE POTENTIAL FOR ALKALI–SILICA REACTIVITY OF AGGREGATES

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ABSTRACT

Preliminary research has shown the osmotic cell apparatus can identify potentially alkali-reactive siliceous aggregates intended for use in concrete. More recent efforts have focused on standardization of the apparatus, establishment of a data base, correlation with other test methods, applicability of the test in identifying slowly reactive rock types, and assessment of aggregate removed from structures exhibiting evidence of alkali-silica reaction. Results of these studies are presented.

INTRODUCTION

The osmotic cell test was developed more than 30 years ago by Verbeck and Gramlich at the Portland Cement Association.(1) The purpose of initial research using the osmotic cell was to interpret the mechanism(s) causing expansion resulting from alkali-aggregate reaction and to identify factors that affect the reaction. Verbeck and Gramlich also recognized that the osmotic cell procedure had the potential to be adapted as a rapid and acceptable method for evaluating potential reactivity of concrete aggregates.

Subsequently, Stark studied the viability of using the osmotic cell apparatus as a rapid test method to evaluate alkali reactivity of different aggregates.(2) Stark's data indicated favorable correlation of field service history and commercially available aggregates. Stark extended the applicability of the osmotic cell procedure by using it to aid in evaluation of alkali-silica reaction in several dams throughout the United States.(3,4)

Present studies are primarily concerned with refining and standardizing the test for use as a rapid method of evaluating aggregates for reactivity. Research is also underway to expand application of the test for use in assessing reactivity in existing structures.

TEST METHOD

In theory, the test was designed to simulate the interface between an aggregate particle and cement paste. The osmotic cell shown in Figure 1 is a box-like apparatus made of Lucite™ and containing a reservoir chamber and reaction chamber each filled with 1N NaOH solution. The chambers are separated by a cement paste membrane having a water-cement ratio of 0.55. Tops of the chambers have vertical capillary tubes attached which are filled with 1N NaOH solution. The reaction chamber is filled with 12.4 grams of test aggregate crushed to -50/+100 (-0.30/+0.15 mm) U.S. mesh sieve.

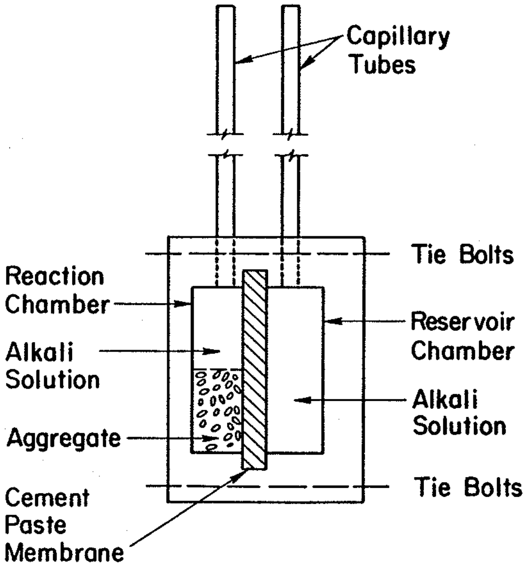

FIGURE I DIAGRAM OF OSMOTIC CELL

When reaction occurs, solution flows from the reservoir chamber through the cement paste membrane into the reaction chamber. This positive flow produces a height differential in capillary tubes of the two chambers. The differential as a function of time is a flow rate used to indicate reactivity. Flow in the opposite direction or negative flow, denotes no potential for reactivity. Based on past research, positive flow rates exceeding 1.5 to 2.0 mm per day indicate an aggregate has potential for deleterious reaction with alkalies in concrete.

A test period of 30 to 40 days is usually sufficient to identify potential for expansive reactivity when using a cell capable of evaluating 12.4 grams of test aggregate.

EVALUATION OF THE TEST METHOD

In order for a new reactivity test method to be accepted, it is necessary to establish: (1) precision of the test, (2) correlation with existing tests and field service history, (3) application to a wide variety of aggregate types, and (4) a standard methodology for commercial use. Standardization of the method by evaluation of many test variables has been reported by Verbeck and Gramlich(1) and Stark.(2) Test solution concentration, amount of aggregate, aggregate particle size, test length, flow rate criterion to determine reactivity, thickness and water-cement ratio of the cement paste membrane, and temperature of storage have been evaluated and optimized into a standard procedure based on this previous work.(1,2) Recent work has included evaluation of use of a larger test apparatus than the one originally developed.

Size of Osmotic Cell Apparatus

Due to concern as to whether testing 12.4 grams of aggregate is a truly representative sample of a source, a large cell apparatus was developed. The large cell is identical in all respects to the smaller apparatus except that the reaction and reservoir chambers have been enlarged to accommodate between 600 and 800 grams of test aggregate. Data collected for the larger apparatus and comparisons to results from the small apparatus for various reactive materials are given in Table 1.

TABLE 1
Test Results for Reactive Material
Tested in the Large and Small Osmotic Cells

Material	Test Condition	Final Test Age	Flow Rate
Crushed Opaline Sandstone Coarse Aggregate	Large Cell	4	71
Crushed Opaline Sandstone Coarse Aggregate	Small Cell	12	17.3
Pyrex Glass	Large Cell	7	30.1
Pyrex Glass	Small Cell	29	9.2
Crushed Basalt	Large Cell	7	5.0
Opal	Large Cell	9	11.3
Opal	Small Cell	26	12.4*

*Average of two tests

Preliminary data indicate the large cell apparatus provides data on reactivity approximately 3 to 4 times sooner than the small test apparatus, although both types of cells give similar results regarding potential for reactivity. Additional experimentation is being concentrated on standardization of the large cell apparatus for commercial use.

Remaining discussion and test results refer to work done with the smaller test apparatus.

Correlation of the Osmotic Cell with ASTM C 227 Mortar Bar Test and Service History

Several reactive and nonreactive aggregate types from various sources in North America have been tested in the osmotic cell apparatus to establish validity of the method. The aggregates were also tested by the standard ASTM C 227 mortar bar procedure for comparison. Service history of many of the aggregates tested is known. Replicate osmotic cell tests were performed on many of the aggregates to evaluate precision of the method for a single operator.

Table 2 presents results of osmotic cell and mortar bar tests along with service history data for selected reactive aggregates.

TABLE 2
Comparison of Service Record, Osmotic Cell Test and Mortar Bar Test Results for Several Reactive Rock Types

Material	Composition	Service Record	Osmotic Cell Flow Rate$^{(1)}$ (mm/day)	Three Month Mortar Bar Expansion$^{(2,4)}$ (%)	Six Month Mortar Bar Expansion$^{(3,4)}$ (%)	Comments
BL-3 Sand	Volcanic	Reactive	1.5 to 2.7	0.069	0.061	No deleterious mortar bar expansion with 0.82% alkali cement. Five replicate tests performed.
267 Sand	Volcanic	Unknown	3.7	0.054	0.094	0.118% expansion at 9 months.
CO Coarse Aggregate	Obsidian	Unknown	1.6 to 2.4	0.134	0.219	Three replicate tests.
CS Coarse Aggregate	Opaline Sandstone	Reactive	27.3 to 34.8	0.036	0.050	No deleterious mortar bar expansions with 0.20% alkali cement. Two replicate tests performed.
WF Sand	Volcanic	Reactive	1.1 to 1.2	0.071	0.123	No deleterious mortar bar expansions with 0.54% alkali cement. Two replicate tests performed.
WF-1-1/2	Volcanic	Reactive	1.5 to 2.0	0.190	0.325	As above. Four replicate tests performed.
RTM Crushed Stone	Basalt	Unknown	1.8 to 2.9	0.016	0.018	Three replicate tests performed.
PB Gravel	Volcanic	Unknown	2.2	(5)	(5)	
RG Sand	Volcanic	Reactive	1.8 to 1.9	.415	0.480	Two replicate tests performed.
Crushed Opal	--	Not Applicable	6.5 to 12.8	0.206	0.212	Five replicate tests performed.

Notes:
(1) Threshold flow rate for potential reactivity is 1.5 to 2.0 mm/day.
(2) Expansions of 0.05% at three months test age are considered capable of causing deleterious reactivity.
(3) Expansions of 0.10% at six months test age are considered capable of causing deleterious reactivity.
(4) Mortar bars made with either 0.92 or 1.09% alkali content cements. Alkali content expressed as equivalent Na_2O.
(5) Not yet available.

Although flow rate criteria indicating reactivity for the osmotic cell are based on correlation to field service history, there is fairly good agreement between deleterious mortar bar expansivity and deleterious flow rates in the osmotic cell. One exception is the RTM crushed stone, which is glassy basalt of unknown service record. This material appears reactive by the osmotic cell test, but nonreactive according to mortar bar expansion criteria. Therefore, the osmotic cell, when used to evaluate some glassy volcanic materials, appears to be highly sensitive to the glass phase. Generally, however, the method can differentiate between reactive and nonreactive materials from a wide range of locales.

Additionally, some mortar bar tests were repeated using different alkali level cements to establish a correlation between cement alkali level and potential for reactivity in the osmotic cell. Data suggest no strong correlation to a particular alkali level exists, except that the cell simulates reaction generally with high alkali cement.

For completeness, Table 3 presents osmotic cell and ASTM C 227 mortar bar test results for known nonreactive materials.

TABLE 3
Comparison of Service Record, Osmotic Cell Test and ASTM C 227 Mortar Bar Test Results for Several Nonreactive Rock Types

Material	Composition	Service Record	Osmotic Cell Flow Rate(1) (mm/day)	Three Month Mortar Bar Expansion(2,4) (%)	Six Month Mortar Bar Expansion(3,4) (%)	Comments
BR Crushed Gravel	Siliceous	Nonreactive	2.3	0.017	0.021	Nonreactive by rock prism test.
BR Sand	Siliceous Limestone & Dolomite	Nonreactive	1.2	0.016	0.019	
GR Gravel	Volcanic	Nonreactive	3.0	0.015	0.020	
GR Sand	Volcanic	Nonreactive	2.4	0.015	0.017	
GLR Gravel	Siliceous Limestone	Nonreactive	-1.2	0.012	0.015	Nonreactive by rock prism test. Used 0.54% alkali cement in mortar bars.
GLR Sand	Siliceous Limestone	Nonreactive	-1.8	0.016	0.017	Used 0.54% alkali level cement in mortar bars.
TQ Coarse	Calcite Dolomite	Nonreactive	-0.1 to -0.3	(5)	(5)	Three replicate tests performed.
Ottawa Sand	Quartz	Nonreactive	-0.1 to +0.4	(5)	(5)	Eight replicate tests performed.
S J Sand	Volcanic	Nonreactive	-0.2	0.026	0.050	
SJ-1-1/2	Volcanic	Nonreactive	-0.3	0.018	0.023	
SQ Sand	Quartz	Nonreactive	-0.3	0.025	0.028	
CG Sand	Quartz, Granite, Feldspar	Nonreactive	0.1	0.020	0.023	
CG Gravel	Granite Gneiss, Schist	Nonreactive	-0.1	0.019	0.026	

Notes: (1) Threshold flow rate for potential reactivity is 1.5 to 2.0 mm/day.
(2) Expansions of 0.05% at three months test age are considered capable of causing deleterious reactivity
(3) Expansions of 0.10% at six months test age are considered capable of causing deleterious reactivity
(4) Mortar bars made with 0.83 to 1.09% alkali content cements. Alkali content expressed as equivalent Na$_2$O.
(5) Not yet available.

Again, with the exception of one slightly glassy volcanic aggregate (GR sand and GR gravel) osmotic cell test results correlate with mortar bar expansion and service record.

Data in Tables 2 and 3 show the test can effectively discriminate reactive from nonreactive rock types. Additional tests are underway to build a larger data base for acceptance purposes.

Precision

Many of the osmotic cell test results presented in Tables 2 and 3 were replicated several times by a single operator. Table 4 shows number of replicate tests; mean, minimum, and maximum flow rates; standard deviation; and coefficient of variation for 10 different aggregates.

TABLE 4
Statistical Data for Precision of the Osmotic Cell Test

Material	No of Tests(1)	Mean Flow Rate (mm/day)(2)	Minimum Flow Rate (mm/day)	Maximum Flow Rate (mm/day)	Standard Deviation (σ)	Coefficient of Variation (%)
BL-3 Sand	5	2.1	1.5	2.7	0.5	23.8
CO Coarse Agg.	3	1.9	1.6	2.4	0.4	21.0
CS Coarse Agg.	2	31.0	27.3	34.8	5.3	17.1
WF Sand	2	1.15	1.1	1.2	0.1	8.7
WF-1-1/2 Gravel	4	1.7	1.5	2.0	0.2	11.8
RTM Crushed Stone	3	2.5	1.8	2.9	0.6	24.0
RG Sand	2	1.85	1.8	1.9	0.1	5.4
Crushed Opal	5	10.7	6.5	12.8	2.5	23.4
Ottawa Sand(3)	8	0.1	-0.1	+0.4	0.4	400.0
TQ Crushed(3) Stone	3	-0.2	-0.3	-0.1	0.1	-50.0
					Weighted Avg.	12.5(4)

Notes:
(1) Performed by a single operator.
(2) Threshold flow rate for potential reactivity is 1.5 to 2.0 mm/day.
(3) Nonreactive aggregate.
(4) Weighted average based on calculated coefficients of variation for reactive aggregates shown.

Standard deviation and coefficient of variation shown for the limited data in Table 4 are reasonable for tests of this type, suggesting good reproducibility of the method by a single operator. Quantity of data presently available is inadequate for rigorous statistical interpretation of the test. Work is in progress for additional replicate testing using single and multiple operators.

Where standard deviations are large (CS coarse aggregate and crushed opal) flow rates have been very high and represent very highly reactive materials. Where coefficient of variation has been high (Ottawa sand and TQ crushed stone) flow rates and standard deviations have been very low. These latter two aggregates represent nonreactive materials.

Slowly Reactive Aggregates

Of concern in acceptance of new rapid test methods to assess potential reactivity is the capability of discerning slowly reactive rock types. Experimentation with the osmotic cell on slowly reactive rock types has shown mixed results. Osmotic cell data for five different slowly reactive types are presented in Table 5.

TABLE 5
Osmotic Cell Test Results for Slowly Reactive Aggregates

Material	Test Condition	Final Test Age (Days)	Flow Rate (mm/day)
RB Quartzite(1)	1N NaOH, 73°F test temperature	95	0.8
Unweathered Granite(2)	1N NaOH, 73°F test temperature	45	-0.1
Weathered Granite(2)	1N NaOH, 73°F test temperature	45	2.0
Mylonite	1N NaOH, 73°F test temperature	31	6.3
BG Quartzite(1)	1N NaOH, at 73°F test temperature	59 to 62	-0.1 to +0.9(3)
BG Quartzite(1)	1N NaOH, at 100°F test temperature	40 to 62	0.2 to 0.4(4)
Threshold flow rate indicating potential for deleterious reactivity		1.5 to 2.0	

Notes:
(1) Known to be reactive in field structures.
(2) No record of service history.
(3) Five replicate performed, $\underline{X} = 0.4$, $\sigma = 0.4$.
(4) Five replicate performed, $X = 0.3$, $\sigma = 0.1$.

Fine-grained, known reactive aggregates, such as mylonite, are easily distinguished as being reactive by the osmotic cell test. A weathered, slightly metamorphosed granite is also characterized as being potentially reactive. Coarse grained, known reactive quartzites (RB and BG quartzites) and an unweathered, slightly metamorphosed granite could not be discerned as being reactive in the osmotic cell, even at elevated test temperatures and extended test duration.

Although not shown in Table 5, changes in processed particle size to -100/+200 mesh sieve size and/or increased normality of the test solution, in combination with increased test temperature and extended test duration did not yield indications of reactivity for the BG quartzite. Additional experimentation with slow reactors is in progress.

Discrimination of Reactive Aggregate Taken From Distressed Field Concrete

Aggregate particles were sawed from concrete cores and tested in the osmotic cell. Structures from which the cores were taken had suffered distress as a result of alkali-silica reaction. Reactive aggregate particles were selected by examining the cores petrographically. Table 6 shows results for tests on aggregates sawn from cores taken from a bridge and three dams.

TABLE 6
Osmotic Cell Test Results for Aggregate Sawed from Cores of Distressed Field Concrete*

Material	Flow Rate (mm/day)
Chert & Quartzite Particles Sawed from a Column above ground line in a Bridge	0.5
Chert & Quartzite Particles Sawed from a Bridge Pier (below water line)	1.1
Chert Particles Sawed from a Bridge Pier (above water line)	2.6
Andesite Particles Sawed from Right Buttress of Coolidge Dam (3 to 5 in. depth)	0.0
Andesite Particles Sawed from Right Buttress of Coolidge Dam (1 to 3 in. depth)	7.3
Andesite Particles Sawed from Face of Friant Dam (15 to 19 in. depth)	0.6
Andesite Particles Sawed from Dry Stairway of Friant Dam (30 to 34 in. depth)	6.7
Quartzite Particles Sawed from Thrust Block of Stewart Mountain Dam (8-1/2 in. depth)	0.3
Granite Particles Sawed from Thrust Block of Stewart Mountain Dam (12 to 16 in. depth)	0.9
Andesite Particles Sawed from Face of Stewart Mountain Dam (26 to 30 in. depth)	10.2
Rhyolite Particles Sawed from Thrust Block of Stewart Mountain Dam (15 to 18 in. depth)	0.8
Threshold flow rate indicating potential for deleterious reactivity	1.5 to 2.0

*Cores were taken from dry and uncracked to moist and cracked areas of structures that exhibited distress due to alkali-aggregate reaction.

Data for companion aggregate particles tested from the same structure show the osmotic cell can indicate whether potentially reactive silica is still present in aggregate particles sawed from field concretes. Such information is helpful in evaluating the state of reactivity in a structure, as well as determining methods of remediation.

Although experimental, the osmotic cell can be applied to field concrete investigations, but should be used in conjunction with other tests, such as field relative humidity measurements and length change measurements on cores extracted from the structure under evaluation.

CONCLUSIONS

Recent development of the osmotic cell apparatus provides additional data indicating this rapid test method is capable of identifying potentially alkali-reactive aggregates. The test can discern between reactive and non-reactive rock types much quicker than the generally accepted ASTM C 227 mortar bar expansion test.

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