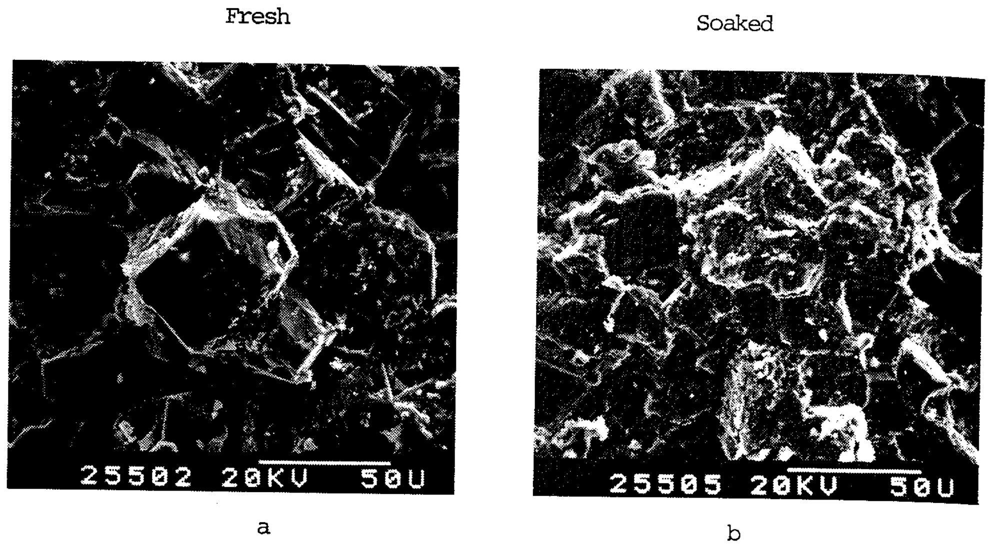


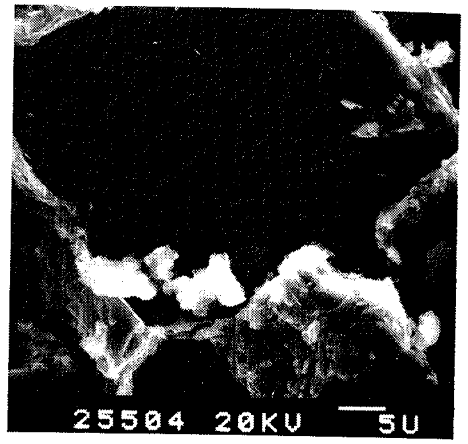
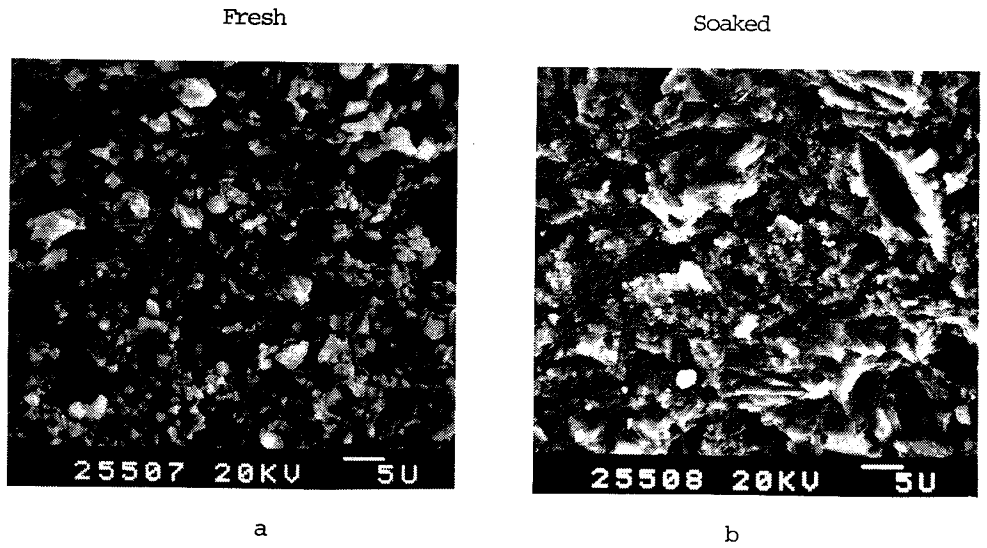


Plate 3 (above): Electron microphotograph of fresh and soaked dolomite.

Plate 4 (right): Electron microphotograph of a dolomite crystal in soaked specimen exhibiting calcitic centre and dolomitic periphery.

Plate 5 (below): Electron microphotographs of fresh and soaked limestone.



OSMOTIC CELL TEST TO IDENTIFY POTENTIAL FOR ALKALI-AGGREGATE REACTIVITY

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1. ABSTRACT

1.1.1 An osmotic cell procedure for evaluating potential for deleterious reactivity of aggregates is described. A test criterion relating flow rate in the test to known performance in concrete is developed The test is relatively rapid and inexpensive to run, and is not labor-intensive. Additional work is underway to further extend applicability of the procedure.

KEYWORDS: Alkali-silica reactivity, concrete, osmotic cell, rapid test.

2. INTRODUCTION

2.1.1 The durability of many concrete structures depends on the adequacy of tests to detect potential for alkali-silica reactivity. In the United States, the most widely accepted test procedures used for this purpose are:

1) ASTM Designation: C227-81 Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)

2) ASTM Designation: C289-81 Standard Test Method for Potential Reactivity of Aggregates (Chemical Method)

3) ASTM Designation: C295-79 Standard Practice for Petrographic Examination of Aggregates for Concrete.

2.1.2 These tests have been used sucessfully for many years, either alone or in combination, to judge the suitability of an aggregate for use in making durable concrete. However, they all have certain limitations. In particular, many slowly reactive aggregates have been found to be innocuous in mortar bar tests that have been run for more than one year.(1) In addition, the tests can be labor-intensive and require the services of technically skilled personnel. They also can have limited applicability because of the particular mineralogical make-up of the aggregate sample.

2.1.3 It would therefore be useful to have a simple, relatively rapid, and inexpensive procedure that can identify deleteriously reactive materials without the limitations noted above. Exploratory work indicates that an osmotic cell procedure shows promise of fulfilling this need. Studies thusfar have been carried out primarily on homogenous materials known to be either deleteriously reactive or non-reactive in field and laboratory concretes and mortars. A description of the procedure and interim results are given below.

3. TEST METHOD

3.1.1 The apparatus used for this test procedure is known as an osmotic cell. It was developed more than 25 years ago by Verbeck and Gramlich at the Portland Cement Association Laboratories.(2) The cell was used in their work primarily to elucidate the mechanism of expansion resulting from alkali-silica reactivity, and to identify factors that determine whether expansive or non-expansive reactions will occur. Most of their tests were run using opal as the reactive material. However, they also recognized that the same apparatus might be useful for identifying potential for deleterious reactivity of different aggregates.

3.1.2 The osmotic cell, in effect, partially simulates the interface between an aggregate particle and surrounding hydrated cement paste. A schematic diagram of the cell is shown in Fig. 1. The cell is made of Lucite and consists of a reaction chamber and a reservoir chamber which are separated by a cement paste membrane of 0.55 water-cement ratio. Both chambers are filled with 1N.NaOH solution, but the reaction chamber also contains 12 grams of the test aggregate crushed to the -No. 50 + No. 100 sieve size. Attached to the top of both chambers are vertical capillary tubes which are filled to the same height with the 1N.NaOH solution. When reaction occurs, solution flows from the reservoir chamber, through the cement paste membrane, and into the reaction chamber. The flow produces a height differential between menisci in the two capillary tubes. This differential is taken as a measure of reactivity.

3.1.3 In the work of Verbeck and Gramlich, different alkalies and solution concentrations were studied. Also, membranes with different water-cement ratios, and the presence of solid calcium hydroxide, were evaluated. Temperature variations, as well as particle sizes of aggregates were studied. Although several of these alternative combinations more closely simulate actual conditions in concrete as compared to those used in the present investigation, they were found only to slow the rate of reaction, or to introduce other complexities into the system. Thus, the cell conditions described above were deemed to be satisfactory for evaluating reactivity potential of different aggregates.

4. TEST RESULTS

4.1.1 Results for twelve materials tested in the osmotic cell are shown in Figs. 2 through 4. These results are representative of a much larger body of data obtained on additional aggregate samples. In the figures, height differential between menisci in the capillary tubes attached to each chamber is plotted against time. Curves that show increasing height differential above zero indicate flow of alkaline solution from the reservoir chamber, through the cement paste membrane, and into the reaction chamber which contains the test material. This is considered positive flow. Height differentials due to positive flow of sufficient magnitude were used to indicate potential for deleterious alkali-aggregate reactivity in concrete.

4.1.2 Conversely, negative flow is possible and represents movement of alkaline solution from the reaction chamber into the reservoir chamber. As can be seen in the data, negative flow often occurs during the first several days of the test period, regardless of whether potentially reactive material is under test. This appears to represent, in part, equilibrium redistribution of alkaline solution among the porous solid components of the system, and does not necessarily reflect the tendency of the test material to react with the solution. However, prolonged negative flow is taken as evidence that the test material is non-reactive.

4.1.3 The curves in Fig. 2 show results for opal and two samples of Pyrex glass cullet, all of which are known to be highly reactive in concrete made with high alkali cement (Na_2O equivalent greater than 0.6%). Also shown are results for Ottawa sand, which is essentially pure unstrained quartz, and which is known to be non-reactive. The opal and both Pyrex samples show relatively high positive flow rates, which indicates a high rate of reaction. Of the three, opal developed the highest positive flow. It is noteworthy that significantly different reaction rates were recorded for the two Pyrex samples, since this material is used as a standard reactive aggregate in laboratory testing to determine the effectiveness of pozzolan to inhibit alkali-aggregate reactivity. Mortar bar expansion tests confirmed this difference. For Ottawa sand, the curve reflects a negative flow, which indicates, as expected, that this material is non-reactive in concrete.

4.1.4 In Fig. 3, results are presented for naturally occurring, commercially available, aggregates which have known service records in concrete. The dashed curves represent results for known reactive materials, while the solid curves are for non-reactive aggregates. Again, the reactive materials produced high flow rates compared with the non-reactive materials. Also, after an initial period of varying flow, rates remained constant for the duration of the test period. Curves for two of the materials, Andesite Nos. 2 and 3, showed reversals from negative to positive flow.

4.1.5 Figure 4 also presents test results for four materials that are known to be either non-reactive or slowly reactive in field concretes. All four show low flow rates in the osmotic cell. Among these materials, the mica schist and mylonite which first showed evidence of deleterious reactivity after more than ten years in field concretes, produced excessive (greater 0.10%) expansion in ASTM C 227 mortar bar tests only after four years.(3) The gabbro is known to be innocuous and produced the upper flow limit for all non-reactive aggregates thusfar tested.

4.1.6 The relatively close grouping of curves shown in Fig. 4 permits an estimate of flow rate above which a test aggregate can be judged to be deleteriously reactive. In Table 1, these rates are calculated, in millimeters per day, for 11 of the 14 materials for which data are represented in Figs. 2 through 4. The reactive and non-reactive classification shown in the tables is based on long-term field observations. As shown in the table, flow rates greater than 1.5 to 2.0 mm per day indicate potential for deleterious reactivity in concrete.

4.1.7 The flow rate criterion of 1.5 to 2.0 mm per day is based primarily on tests of individual rock and mineral types. However, it also may apply where as little as 1% of the total aggregate is known to be deleteriously reactive. This is shown in data presented in Table 2. In these test samples, 1, 2, 5, and 10% of otherwise non-reactive aggregate has been replaced by opal. As indicated, a 1% replacement produced a flow of 3.6 mm per day. More work is underway in this area of testing.

4.1.8 The significance of these findings is that they substantiate the known performance of these test materials in concretes and mortars, thus validating the possible use of this technique for detecting potential for deleterious reactivity of aggregates.

5 SUMMARY

5.1.1 Work conducted thusfar indicates that the osmotic cell is a useful tool for identifying individual rock and mineral samples that are potentially deleteriously reactive with alkalies in concrete. A flow rate criterion was found in the test, above which a material under test would be judged to be reactive when used with high alkali cements in concrete. Slowly reactive aggregates which pass existing ASTM tests but fail in field structures have been identified as potentially reactive in the osmotic cell.

6. ADDITIONAL RESEARCH

6.1.1 Additional research is underway to further extend the applicability of the osmotic cell procedure for aggregate evaluation. This includes testing of heterogeneous sands and gravels, evaluation for alkali carbonate reactivity, and extraction and testing of aggregates already in concrete in field structures. In the latter case, preliminary work, in which the particles of concern are sawed or drilled out of the concrete, crushed, and tested, shows promise of verifying potential for reactivity.

6.1.2 Work is also underway to evaluate effectiveness of pozzolan in inhibiting reactivity. Cells which will accomodate larger test samples, are also being evaluated. It is anticipated that the versatility of this device will serve to fill gaps in our present recommendations for testing of potential reactivity. The procedure itself is inexpensive and requires only minimum training to properly assemble the cell and run the test.

7. REFERENCES

1) Stark, D., "Alkali-Silica Reactivity: Some Reconsiderations," ASTM Cement, Concrete, and Aggregates, Vol. 2, No. 2, Winter 1980, pp. 92-94.

2) Verbeck, G.J. and Gramlich, C., "Osmotic Studies and Hypothesis Concerning Alkali-Aggregate Reaction," ASTM Proceedings, Vol. 55, 1955, pp. 1110-1128.

3) Stark, D., Unpublished data, Portland Cement Association.

TEST MATERIAL	CLASSIFICATION	FLOW RATE mm/DAY
Opaline Limestone	Reactive	58.0
Beltane Opal		26.0
Andesite No. 1		20.0
Pyrex Glass No. 1		19.0
Pyrex Glass No. 2		5.8
Mylonite		2.4
Mica Schist		2.3
Andesite No. 4		2.0
Gabbro	Non Reactive	1.5
Andesite No. 3		0.4
Quartz		-0.2

TABLE 1 FLOW RATES FOR TEST MATERIALS

PERCENT OPAL	FLOW RATE mm/DAY
100	26.0
10	13.0
5	10.0
2	5.4
1	3.6

TABLE 2 FLOW RATES FOR OPAL

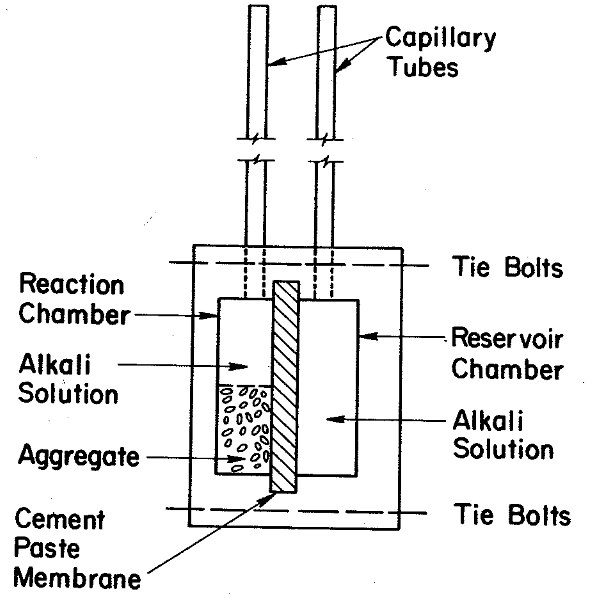

FIG. 1 DIAGRAM OF OSMOTIC CELL

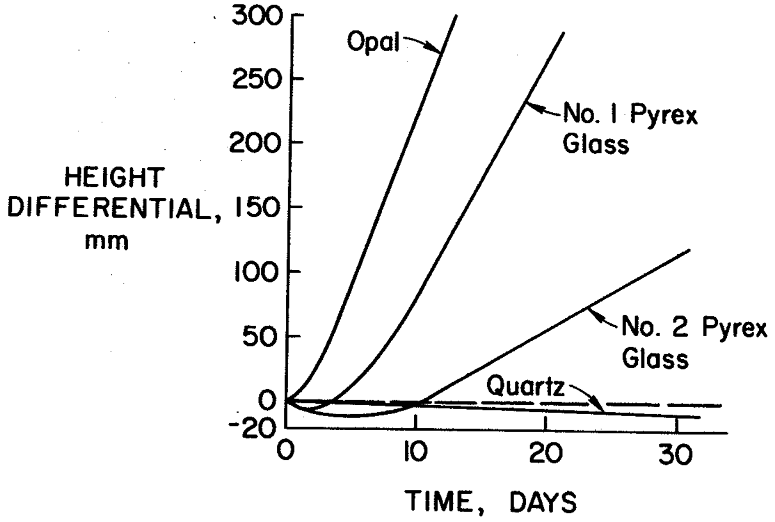

FIG. 2 RESULTS OF OSMOTIC CELL TESTS

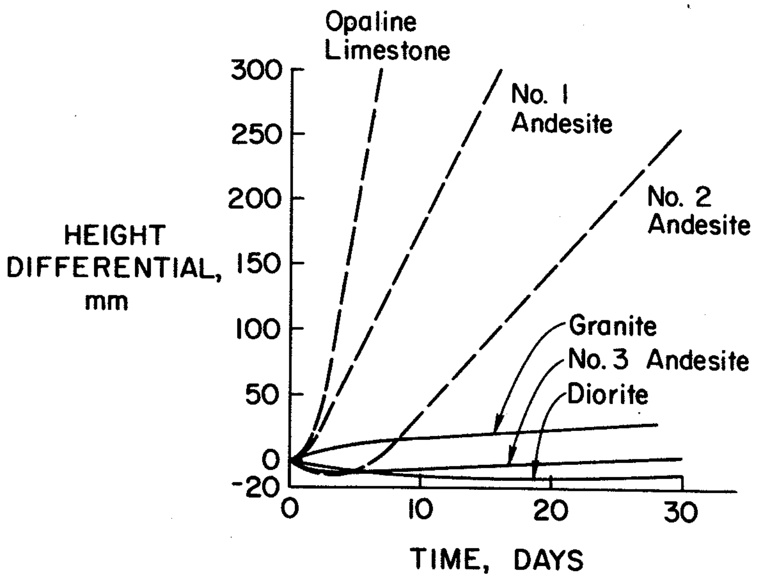

FIG. 3 RESULTS OF OSMOTIC CELL TESTS

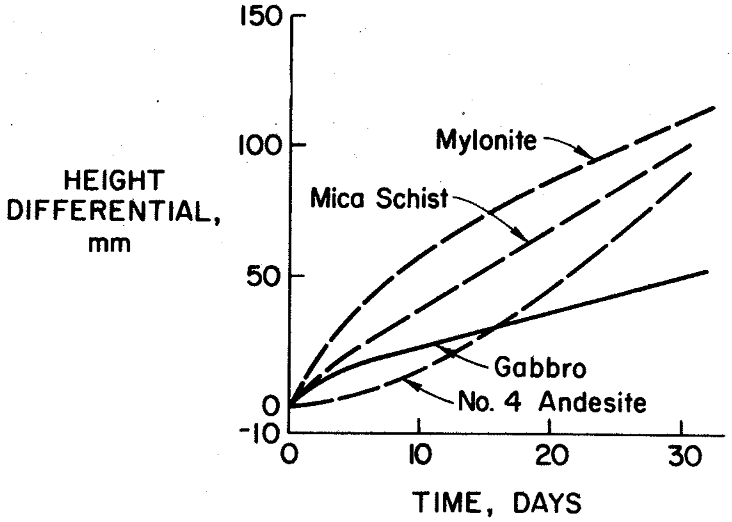

FIG. 4 RESULTS OF OSMOTIC CELL TESTS