EVALUATION OF TEST METHODS FOR ALKALI-AGGREGATE REACTIVITY

P.E. Grattan-Bellew
Division of Building Research, National Research Council Canada
Ottawa, Canada K1A 0R6

ABSTRACT

Test methods for alkali-aggregate reactivity can be divided into those that determine the potential reactivity of an aggregate (the chemical test and the proposed petrographic method for determining the undulatory extinction angle of quartz) and those that purport to measure the expansivity of an aggregate in concrete (concrete prism, mortar bar, and rock cylinder methods). Several modifications have been developed for the chemical method, ASTM C289, to take into account regional variations in aggregates. The main disadvantage of the methods measuring expansion is that they take a long time. To try to overcome this problem, various methods of acceleration have been proposed, varying from immersion of the samples in salt solution at an elevated temperature to autoclaving. Autoclaving methods must be regarded with some caution, however, because at elevated temperatures and pressures hydrothermal reactions occur that do not take place at atmospheric pressure.

KEY WORDS: Evaluation, Tests, Alkali, Aggregate.

1. INTRODUCTION

The ideal method of determining the potential alkali expansivity of an aggregate in concrete should be applicable to all rock types, should be rapid, taking no more than a few days to complete, and must give reliable results. The quest for this test has kept a number of researchers busy for many years, but like that of the alchemists before them it will not succeed. Diversity in the composition, grain size, and porosity, and the presence or absence of secondary cementing minerals in rocks predicates against the development of a universally applicable, rapid test method. Some tests, for example the concrete prism method, are applicable to all rock types but may take so long that the structure will be built before the test is complete. Other tests, like the mortar bar and the chemical methods, are suitable for aggregates exhibiting classical alkali-silica reactivity but not for reactive carbonate aggregates. As a result, a number of different test methods have been, and continue to be, developed. This review will examine the effectiveness and limitations of existing and proposed test methods.

2. CHEMICAL TEST

The chemical method, ASTM C289 /1/, was developed as a rapid means of differentiating between potentially reactive and non-reactive silica-bearing aggregates. The criteria for evaluation were developed from the results of parallel sets of mortar bar and chemical tests on many aggregates from the United States /2/. The rocks tested included some containing opal, chert or chalcedony as the reactive component and others in which volcanic glass was the reactive component. As the two main reactive components, opal and volcanic glass, consist of cryptocrystalline SiO_2 and an aluminosilicate glass, respectively, it is surprising that one set of criteria were found to be appropriate for evaluation of both types.

The problem of obtaining meaningful values for the dissolved silica (Sc) and the reduction in alkalinity (Rc) are complicated if carbonates or sulphates, e.g., gypsum /3/, are present in the aggregate because they react with NaOH to reduce its alkalinity. The values of Sc and Rc are also very susceptible to operator influence. For example, if the sample is not properly sized and a significant amount of -150 µm material is included in the test, the value of Sc will be markedly increased. Grinding quartz to sizes less than about 100 µm greatly increases its solubility (Figure 1).

The phenolphthalein indicator does not give a sharp end point and the value of Rc determined is thus, to some extent, dependent on the judgement of the operator. Some of the problems inherent in the chemical test were discussed by Dent Glasser and Kataoka /4/. Their main conclusion is that the value of Rc, as currently determined, is rather meaningless since it includes reductions in both OH^- and the concentration of Na^+ in the solution. They suggested that the method should be altered so that OH^- can be determined by a pH meter and Na^+ by a spectroscopic method.

The question arises as to the need to determine the reduced alkalinity, Rc; is determination of Sc alone sufficient for predicting the potential reactivity of an aggregate? To investigate this, test results for a series of quartz sands containing varying amounts of opal /2/ were plotted in Figure 2; it is evident that expansion of mortar bars correlates better with the factor Rc/Sc than with Sc alone, indicating that for these aggregates it is better to determine both Rc and Sc.

It has been established that the criteria given in C289 are not adequate for the evaluation of Icelandic sands containing volcanic glass or of Danish flint gravels, for which low values of the amount of dissolved silica are indicative of potential reactivity. New criteria were developed for their evaluation as follows (personal communication, Hakon Ôlafsson):

Icelandic sands:
- non-reactive - Sc <100 mmol/L
- potentially reactive - Sc 100 to 200 mmol/L
- reactive - Sc >200 mmol/L

Danish gravels:
- non reactive - Sc <50 mmol/L
- potentially reactive - Sc 50 to 200 mmol/L
- reactive - Sc >200 mmol/L

In contrast, in Britain the Thames Valley flint gravels yielded values of Sc in excess of 100 mmol/L yet caused no problems in concrete /3/. It appears that separate sets of criteria need to be developed on a regional basis, even for evaluation of what are nominally the same rock types.

In the late-expansive aggregates of the Malmesbury Formation in the Cape Peninsula of South Africa, in which strained quartz is the reactive component, the criteria specified in C289 are effective for differentiating reactive and non-reactive aggregates; but in the Tygerberg Formation from the same region lower values of Sc were obtained from reactive aggregates. The results of the chemical test on these aggregates, reported by Brandt, Oberholster and Westra /5/, are replotted in Figure 3. It is evident that the dividing line between reactive and non-reactive aggregates must lie at a value of Sc between 35 and 50 mmol/L.

In Serbia the chemical method, ASTM C289, used by Mitrović and Dučić /6/ indicated that the aggregates are potentially reactive (as did the mortar bar test), although no problems have been observed in concrete. There appears to be some doubt concerning the validity of both methods for evaluating these particular aggregates.

In Australia, the criteria specified in C289 are evidently satisfactory; they have been adopted as an Australian standard, AS 1141 Section 39, 1974.

2.1 Discussion

The chemical test is the only rapid, currently available method, that has been thoroughly evaluated. With some modification of the criteria used to define reactive aggregates, and in conjunction with a petrographic examination, it can be used to evaluate the potential reactivity of a wide range of siliceous aggregates. Improvements might be made in the analytical procedures so that the reductions in OH^- and in Na^+ are determined separately. There is some evidence that determination of dissolved silica alone is sufficient to differentiate between reactive and non-reactive aggregates. Owing to the wide diversity in the composition grain size and permeability of rocks, it is most unlikely that universally applicable criteria can be developed to differentiate between reactive and non-reactive aggregates; instead, criteria applicable to specified rock types should be developed.

2.2 Modified chemical test

A modified chemical test was developed for evaluating the potential reactivity of aggregates in the Schleswig-Holstein region of Germany. The aggregate is divided into two size fractions: 1-2 mm and 2-4 mm. These are digested in NaOH solution for 60 min at 90°C. The samples are washed, dried, and weight loss determined; this represents the amount of silica dissolved out by NaOH and gives, in principle, a measure of the potential reactivity of the aggregate. The limitations of this test have been discussed by Jensen, Chatterji, Christensen, Thaulow and Gudmundsson /7/. It would be applicable only to aggregates containing reactive silica, i.e., opal, chert or chalcedony and possibly also to aggregate composed of volcanic glass.

3. MORTAR BAR METHOD

The mortar bar test, ASTM C227-8 /8/, is the most widely used method of evaluating the potential alkali-reactivity of aggregates. A number of variations in the method of evaluating the test results are in use by different organizations. Despite the almost universal acceptance of the mortar bar method, it has several shortcomings: It usually takes from six months to a year to complete, except with some opal-bearing aggregates that can be evaluated in about three months. Such long lead times frequently do not exist before construction is started, even in major structures for which the durability of the concrete is of critical importance.

The evaluation of the reactivity of concrete aggregate by the mortar bar method assumes that expansion of concrete in the field correlates with expansion of test mortar bars. Although this holds true for some aggregates, there are exceptions. The carbonate aggregate from Kingston, Ontario, for example, shows much greater expansion in concrete prisms than in mortar bars, as do late-expansive quartz-bearing aggregates such as Malmesbury aggregate from the Cape Peninsula in South Africa and a greywacke from Nova Scotia, Canada /9/ (see Figure 4, #73-50).

3.1 Interpretation of observed expansion

Recommended criteria for evaluation of the results of the mortar bar test are given in ASTM C33-82, Appendix XI.1.3 /10/. It must be stressed that these are recommendations, not a mandatory part of the standard. Although they are frequently interpreted as "limits," this is incorrect.

According to C33, expansions are to be considered excessive if they exceed 0.05% at three months or 0.10% at six months; the three-month data should only be used, however, when a six-month test is not possible. The alkali content of the cement should be 0.6%, or preferably 0.8%. With the high alkali cements now commonly in use, an alkali level of 1.0% or greater would be more appropriate. The problem with these recommended maximum permissible expansions is that they assume a fast rate of expansion with a short initiation period. A slowly expanding aggregate may show mortar bar expansions well below the values considered to be deleterious, according to C33, but the continuing slow expansion will eventually lead to excessive stress and cracking.

A typical example of expansion of a mortar bar made with Malmesbury aggregate and a cement containing 0.82% alkali is shown in Figure 5 (personal communication, R.E. Oberholster). This aggregate is known to cause deleterious expansion in concrete made with a high alkali cement. The problem of evaluating the results of expansion of mortar bars made with late-expansive aggregates has also been discussed by Kennerly et al. /11/ and by Sims /3/.

3.2 Corps of Engineers

The Corps of Engineers criteria for evaluation of the results of the mortar bar test are possibly more appropriate than those recommended in C33. EM 1110-2-2000 /12/ states that expansion of 0.10% or more at any age should be considered deleterious. An expansion of 0.05% or more at six months may also be considered deleterious. When expansions close to these limits are recorded, the trend of the time-expansion curve should be taken into account. This is in line with the concept of determining the rate of expansion proposed by Grattan-Bellew /9/. Cracking of mortar bars is generally observed when expansion exceeds about 0.04%; if cracking is accepted as evidence of deleterious reaction, expansions of less than 0.10% must indicate potential alkali-aggregate reactivity. The problem is that at present not enough information on the correlation between expansion of mortar bars and field concrete exists to set realistic safe limits of expansion for mortar bars.

3.3 Canadian Standards Association

The Canadian standard (CAN3.A23.1-M77, Appendix B3.4 /13/) states that expansions in excess of 0.04% at any age are to be considered deleterious. It also notes that the shape of the expansion curve is often of importance in making a judgement. The 0.04% limit for expansion is in agreement with frequent observations of cracking when this level of expansion is exceeded; the limit may, however, be too restrictive for some aggregates for which expansion may just exceed this value and then level off.

3.4 Accelerated Danish mortar bar test

This test, described by Jensen et al. /7/, is an accelerated version of the mortar bar method C227 and is used for Danish flint gravels. The mortar bars are made in the usual way and cured in a fog room at 23°C for 27 days. They are then placed in saturated NaCl solution at 50°C and expansion is monitored with time. No limits have been proposed. This method is reported to be satisfactory for the aggregates tested in Denmark, but there are no reports of its use elsewhere.

3.5 Chinese autoclaved mortar bar test

This is another accelerated mortar bar test. Mortar bars 1 × 1 × 4 cm are prepared and cured for one day in a fog room. Following this, they are steam cured at 100°C for 4 h and then immersed in 10% KOH solution and autoclaved at 150°C for 6 h. Expansions are recorded after each phase of the curing cycle. A large number of alkali-silica reactive aggregates were tested in this way by Ming-shu, Su-fen and Shi-hua /14/, who concluded that the method is capable of differentiating between reactive and non-reactive aggregates. More testing should be carried out to evaluate its effectiveness for a wider variety of rock types. Hydrothermal tests must, however, be regarded with some caution

because of the possibility that the observed expansion might be distorted by hydrothermally induced reactions that would not occur in concrete under normal conditions.

3.6 Discussion

No firm limit of expansion can be specified that is applicable to all rock types. Cracking of mortar bars is frequently observed when expansion exceeds about 0.04%, and this value might be considered indicative of potentially deleterious expansion. In some cases, however, this could result in classification of some aggregates that perform satisfactorily in concrete as deleterious. It would be desirable to have a time limit for the mortar bar test; owing, however, to wide divergences in initiation periods and in rates of expansion it is not possible to establish a universally applicable time limit. It is possible that regionally applicable time-expansion limits such as those proposed in C33 may be established for some suites of aggregates. Accelerated tests have so far not been evaluated for a wide enough range of aggregates to permit conclusions to be drawn as to their applicability.

4. CONCRETE PRISM TEST

The concrete prism test (CSA A23.2-14A /15/) was developed in Canada for evaluating the expansivity of reactive dolomitic limestones that do not cause significant expansion in mortar bars. The test has also been used successfully for late-expansive siliceous aggregates and limestones containing reactive silica. Similar tests have been used in New Zealand and South Africa. The criteria for evaluation of the test results are specified in CSA A23.1.M77, Appendix B3.5. Linear expansions of more than about 0.03% indicate potentially deleterious expansion. Appendix 3.5 concludes that some aggregates expand beyond the three-month period and that, where possible, the test should be continued until expansion has virtually ceased. This is sound advice, but it may often not be practical since with some late-expansive aggregates it may take up to two years for expansion to taper off. The use of the rate method of evaluating expansivity of aggregates /9/ may help in evaluating the expansivity of concrete prisms before expansion tapers off. It is very desirable to carry out a petrographic examination in conjunction with the concrete prism test so that the type of reactivity to be expected can be determined; this helps in the correct evaluation of early test results if it is not possible to wait until the expansion has tapered off.

The concrete prism method may be the most reliable test for all types of aggregate. In it, the aggregate is tested in the same size range and with the same cement:aggregate ratio that is used in field concrete. For some late-expansive siliceous aggregates and for carbonate reactive aggregates such as those from Kingston, Ontario, the concrete prism test is the only satisfactory method since these aggregates do not cause significant expansion in mortar bars. Expansion can be significantly accelerated by storage of the prisms at 38°C and 100% RH instead of at 23°C as specified. A few preliminary experiments to try and accelerate expansion by immersion of the prisms in NaCl solution, after the method of the Danish accelerated mortar bar test, were not very successful, but more research is needed before any firm conclusions can be drawn.

5. CONCRETE CUBE TEST

This test was developed in Germany /16/, and cracking is the criterion used to determine whether a cement-aggregate combination is reactive. There are two versions of it. In the first, 30-cm cubes are made and expansion is accelerated by storage in a fog room at 40°C. Other exposure conditions are also used, for example, storage on the roof of the research laboratory. In the second version of the test, 10-cm cubes are stored at 65% RH, with the bottom 1 cm immersed in water at 20°C. In some samples containing reactive aggregate marked cracking was observed just above the waterline.

In Britain, at the Cement and Concrete Association, a modified version of the 10-cm cube test is being investigated (D.W. Hobbs, personal communication). Cubes are immersed in a water bath at 23°C and crack formation is observed. A temperature of 23°C is reported to be the optimum for solubility of silica.

In South Africa, 30-cm cubes are used at outdoor exposure sites where they may be submitted to various moisture and weather exposure conditions.

Tests involving the observation of cracking have a major advantage over tests requiring acccurate measurement of length change in that no elaborate apparatus is required. This means that the concrete cube test could readily be carried out by pit, quarry or ready-mix operators. The disadvantage is that unless rapidly expanding aggregates are being evaluated it would take an unacceptably long time for visible cracks to develop. From laboratory observations by the author it is known that a considerable amount of expansion can frequently be observed before cracks become visible to the unaided eye.

6. ROCK CYLINDER METHOD

The rock cylinder method (ASTM C586-69 /17/) was designed to evaluate the potential reactivity of alkali reactive carbonate aggregates, but it has also been used with varying degrees of success to evaluate the reactivity of alkali-silica reactive aggregates /5, 10, 18, 19/. Paragraph 9.3 of C586 states that expansive behaviour of aggregate (carbonate) in concrete is qualitatively predicted by the results of the rock cylinder test. Grattan-Bellew /19/ found moderate correlation between expansion of concrete made with six samples of Kingston aggregate and expansion of miniature rock prisms made with the same aggregates. Much poorer correlation was observed for expansion of concrete prisms and that of miniature rock prisms made with late-expanding siliceous aggregates. Kennerley et al. /11/ found that some prisms of New Zealand greywacke expanded excessively in NaOH, but that the same rock caused no expansion in concrete.

It is concluded that the rock cylinder test, or variations of it, can only be used to evaluate the reactivity of certain rock types. Its optimum use would probably be for evaluating the potential expansivity of individual horizons in a quarry containing a rock type for which correlation of expansion of rock cylinders and that of concrete prisms has previously been demonstrated.

6.1 Accelerated rock prism test

An accelerated rock prism test for evaluation of the potential reactivity of carbonate aggregates has been developed by Kazimir /20/ and adopted as Czechoslovakian standard CSN 72 1160. Rock prisms 1 × 1 × 3 cm are prepared and autoclaved in NaOH solution at 215°C and 2.1 MPa for 6 h. This test is reported to be successful in differentiating between expansive and non-expansive carbonate aggregates. Some research was conducted by the author on the applicability of this test to late- expanding siliceous aggregates, but it was discontinued after a feldspar-like phase was found to have formed in the prisms. Expansions occurred, but as reactions were taking place (these do not occur at one atmosphere) it seemed most unlikely that the observed expansions would correlate with expansions of the same prisms under atmospheric conditions. More research should probably be done at various temperatures and pressures to see whether an accelerated test could be developed for late-expansive siliceous aggregates.

7. GEL PAT TEST

This test was developed in England as a rapid method of identifying potentially deleterious minerals such as opal or chert in mortar samples. It does not give any indication of the expansivity of the aggregate. As reported by Sims /3/, a smoothed, sawn surface of the mortar is prepared and immersed face down in alkali for three days. Gel forms on the reactive particles, which can thus be readily identified and counted to yield a measure of the percentage of reactive component in the aggregate.

A somewhat similar test, CSN 72-1162 /21/, is used in Czechoslovakia to accelerate rim development around prisms of siliceous aggregates embedded in mortar. It is useful for preliminary screening of potentially alkali-silica reactive aggregates, but additional tests would be necessary to obtain a measure of the expansivity of the aggregate in concrete.

8. PETROGRAPHIC EXAMINATION

Petrographic examination, ANSI/ASTM C595 /22/, has been changed from a technique for determining the mineralogical composition of a rock to a semi-quantitative method of determining the potential reactivity of certain rock types by Dolar-Mantuani's development of a technique for determining the undulatory extinction angle, UE, and relating it to the expansivity of aggregate /23/. Following on earlier work /24-26/, describing the development of the technique for measuring strain in the quartz lattice by means of the undulatory extinction angle, Dolar-Mantuani suggested that aggregates with undulatory extinction angles of less than 15 deg may be characteristic of non-reactive aggregates.

Recent unpublished results obtained by the present author show that some South African aggregates (a quartzite from the Witwatersrand, a greywacke, and a spotted slate from the Malmesbury Formation in the Cape Peninsula, all of which cause excessive expansion in concrete) have UE angles of 36, 36 and 43 deg, respectively, indicating that there is some correlation between high UE angle and the reactivity of the aggregates. More research into this method should be carried out. It has great potential as a rapid method of evaluating the potential reactivity of quartz-bearing aggregates, particularly the late-expansive types common in Precambrian terrains. It would be useful to conduct a series of interlaboratory measurements of UE angles on reference samples so that participants could adjust their measuring techniques to ensure results consistent with those of other operators. In a limited test carried out in Ottawa, a variation of 10 deg was found among measurements made by three participants on the same quartz grains in a thin section. Such a wide variation may have resulted because one or more of the participants measured the extinction range, ER, rather than the undulatory extinction angle, UE, as defined by Dolar-Mantuani.

8.1 Use of scanning electron microscope

Use of the scanning electron microscope (SEM) to extend the scope of the petrographic method by permitting characterization of texture and composition of fine argillaceous rocks may, in due course, make it possible to distinguish between expansive and non-expansive horizons in a particular deposit. Figure 6 shows micrographs of two rocks from the Pittsbury quarry near Kingston, Ontario. Figure 6a shows the highly expansive dolomitic limestone characterized by isolated dolomite rhombs in a matrix of calcite; Figure 6b shows a dolostone, which is non-expansive. This sample is composed almost entirely of a more coarse grained dolomite. Electron probe analysis showed that the Ca/Mg count rate ratio was different in the two samples (6a: Ca/Mg = 3.6; 6b: Ca/Mg = 3.0), indicating a higher percentage of Ca in the reactive dolomite; it is, therefore, a metastable protodolomite /27/. The SEM has one great advantage over other techniques, (e.g., petrographic microscopy), that is, the speed with which observation and analysis can be done; in about half an hour a chip of rock can be coated, examined, and analysed by an experienced operator.

9. CONCLUSION

There is a definite trend towards modification of the standard ASTM tests for use in certain regions and for specified types of aggregate. This has come about as a result of inadequacies in the standard test methods, either because they fail to predict correctly the reactivity of an aggregate or because the test takes too long to complete. The test methods have been modified in two ways: expansion has been acccelerated, as in the Chinese autoclaved mortar bar test; the criteria for the chemical test, as recommended, have been modified to predict the reactivity of local aggregates more accurately, as in Iceland and Denmark where specific limits on the dissolved silica have been proposed.

Modified criteria for existing test methods may be limited to specified aggregates in certain regions. For example, the proposed Danish criteria for evaluating the results of the chemical test of flint aggregates, that Sc values between 50 and 200 mmol/L are indicative of potential reactivity, would be quite unsuited for the evaluation of Thames Valley flints, which are non-expansive in concrete despite having Sc values in excess of 100 mmol/L.

There is still a great need for better, more rapid methods of diagnosing potentially reactive aggregates. For reasons already outlined the new tests will probably be developed for the evaluation of certain aggregates in specific regions. The most promising for future development are the chemical method, in conjunction with improvements in techniques for petrographic evaluation, and possibly some type of autoclave acceleration for mortar or concrete expansion tests.

Acknowledgement

The author is indebted to P.J. Lefebvre for his enthusiasm for the work and the precision with which he carried out the experiments reported in this paper. This is a contribution from the Division of Building Research, National Research Council Canada, and is published with the approval of the Director of the Division.

References

/1/ ASTM C289-81, Potential Reactivity of Aggregates (Chemical Method), Annual Book of ASTM Standards, Part 14, Concrete and Mineral Aggregates. American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103, U.S.A., 1982, 198-205.

/2/ MIELENZ, R.C., GREENE, K.T. and BENTON, E.J., Chemical Test for Reactivity of Aggregates with Cement Alkalis; Chemical Processes in Cement-Aggregate Reaction. Journal of the American Concrete Institute, 19(3), 1947, 193-221.

/3/ SIMS, I., The Application and Reliability of Standard Testing Procedures for Potential Alkali Reactivity. Proc., 5th International Conference on Alkali-Aggregate Reaction, Cape Town, S252/13, 1981, 12 p.

/4/ DENT GLASSER, L.S. and KATAOKA, N., Some Observations on the Rapid Chemical Test for Potentially Reactive Aggregate. Cement and Concrete Research, 11, 1981, 191-196.

/5/ BRANDT, M.P., OBERHOLSTER, R.E. and WESTRA, W.B., A Contribution to the Determination of the Potential Alkali Reactivity of Tygerberg Formation Aggregates. Proc., 5th International Conference on Alkali-Aggregate Reaction, Cape Town, S252/11, 1981, 6 p.

/6/ MITROVIĆ, N. and DUČIĆ, V., Prilog, Zbornik, 1 MK-a, 10, 1981, 195-204.

/7/ JENSEN, A.D., CHATTERJI, S., CHRISTENSEN, P., THAULOW, N. and GUDMUNDSSON, H., Studies of Alkali-Silica Reaction - Part 1, A Comparison of Two Accelerated Methods. Cement and Concrete Research, 12, 1982, 641-647.

/8/ ASTM C227-81, Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar Bar Method). Annual Book of ASTM Standards, Part 14. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, U.S.A., 153-158.

/9/ GRATTAN-BELLEW, P.E., A Review of Test Methods for Alkali Expansivity of Concrete Aggregates. Proc., 5th International Conference on Alkali-Aggregate Reaction, Cape Town, S252/9, 1981, 12 p.

/10/ ASTM C33-82, Appendix XI. Methods for Evaluating Potential Reactivity of an Aggregate (Para. 1.2, Method C289). Annual Book of ASTM Standards, Part 14. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, U.S.A., 13-22.

/11/ KENNERLEY, R.A., ST. JOHN, D.A. and SMITH, L.M., A Review of Thirty Years of Investigation of the Alkali-Aggregate Reaction in New Zealand. Proc., 5th International Conference on Alkali-Aggregate Reaction, Cape Town, S252/12, 1981, 9 p.

/12/ ENGINEER MANUAL EM 1110-2-2000, Engineering and Design Standard Practice for Concrete, (Appendix B, 3C). Department of the Army, Office of the Chief of Engineers, Washington, D.C. 20314, 1971.

/13/ CSA CAN3-A23.1-M77, Appendix B3, Tests for Alkali-Aggregate Reactivity (3.4, ASTM Standard C227, Potential Alkali Reactivity of Cement-Aggregate Combinations (mortar bar method). 3.5, CSA Test Method A23.2-14A, Alkali-Aggregate Reaction, National Standard of Canada): CAN3 A23.2-M77, Concrete Materials and Methods of Concrete Construction, Methods of Test for Concrete. Canadian Standards Association, Rexdale Boulevard, Rexdale, Ontario, Canada, 1977, 122-123.

/14/ MING-SHU, Tang, SU-FEN, Han, and SHI-HUA, Zhen, A Rapid Method for Identification of Alkali Reactivity of Aggregate. Cement and Concrete Research, 13, 1983, 417-422.

/15/ CSA A23.2-14A, Alkali-Aggregate Reaction (Concrete Prism Test). National Standards of Canada, CAN3 A23.1-M77, CAN3 A23.2-M77, Concrete Materials and Methods of Concrete Construction. Methods of Test for Concrete. Canadian Standards Association, Rexdale Boulevard, Rexdale, Ontario, Canada, 1977, p. 183-185.

/16/ BONZEL, Von J. and DAHMS, J., Alkalireaktion im Beton, Herstellung Verwendung 23, 11, S495/500 und H.12, S597/554, 1973.

/17/ ASTM C586-69, Standard Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method). Annual Book of ASTM Standards, Part 14, Concrete and Mineral Aggregates. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, U.S.A., 1982, 357-360.

/18/ DUNCAN, M.A.G., SWENSON, E.G., GILLOTT, J.E. and FORAN, M.R., Alkali-Aggregate Reaction in Nova Scotia, Part I, Summary of a 5-Year Study. Cement and Concrete Research, 3, 1973, 55-70.

/19/ GRATTAN-BELLEW, P.E., Evaluation of Miniature Rock Prism Test for Determining the Potential Alkali-Expansivity of Aggregates. Cement and Concrete Research, 11, 1981, 699-711.

/20/ KAZIMIR, J., Možnosč Skratenia Skúšky Rozpinania Dolomitových Hornín s Alkáliami, Staveb. Cas. 25, c s. Veda Bratislava, 1977, 413-432.

/21/ CSN 72 1162, Stanovenie Odolnostri Prirodného Stavebného Kameňa Proti Silicifikách. MDT 691.2.620.1 679.682.1, Československá Státna Norma Schválená: 24.10. 1981.
/22/ ANSI/ASTM 295-79, Standard Recommended Practice for Petrographic Examination of Aggregates for Concrete. Annual Book of ASTM Standards, Part 14, Concrete and Mineral Aggregates. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, U.S.A., 1982 218-229.
/23/ DOLAR-MANTUANI, L.M.M., Undulatory Extinction in Quartz Used for Identifying Potentially Alkali-Reactive Rocks. Proc., 5th International Conference on Alkali-Aggregate Reaction, Cape Town, S252/36, 1981, 6 p.
/24/ DEHILLS, N.S. and CORVALAN, J., Undulatory Extinction in Quartz Grains of Some Chilean Granitic Rocks of Different Ages. Geological Society of America, Bulletin 75, 1964, 363-366.
/25/ DOLAR-MANTUANI, L.M.M., Petrographic Aspects on Siliceous Alkali-Reactive Aggregates. Proc., Symposium on Alkali-Aggregate Reaction, Reykjavik, 1975, p. 87-100.
/26/ MATHER, K., Presentation at Symposium on Alkali-Aggregate Reactivity. Annual Meeting of Transportation Research Board, Washington, D.C., 1976.
/27/ SWENSON, E.G. and GILLOTT, J.E., Alkali-Carbonate Rock Reaction. Highway Research Record, No. 45, 1964, 21-40.

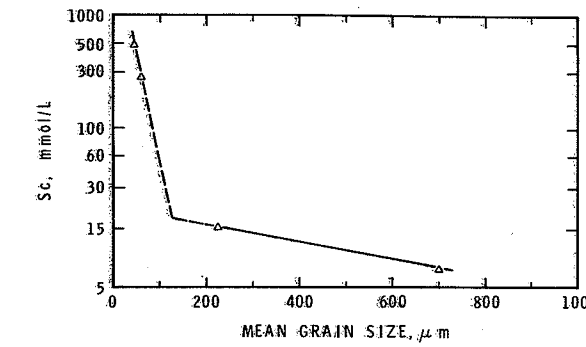


Figure 1 Effect of grain size of quartz on the amount of dissolved silica determined by the chemical method, ASTM C289

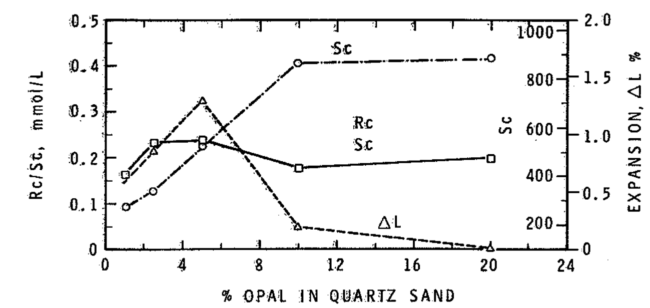


Figure 2 Plot showing variation in Sc and Rc/Sc determined by the chemical test, ASTM C289, and length change of mortar bars of quartz sand containing various amounts of opal

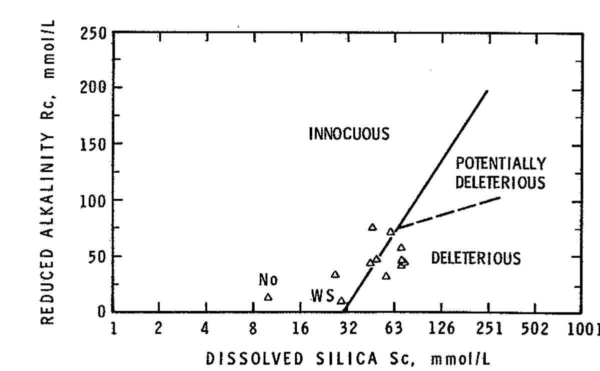


Figure 3 Results of chemical test, ASTM C289, for some reactive and non-reactive South African aggregates. Non-reactive: No (norite) and WS (quartz sand)

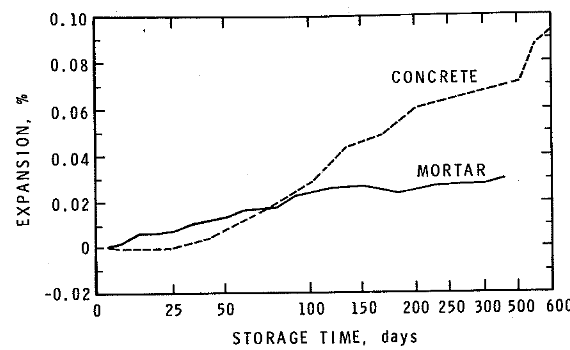


Figure 4 Comparison of expansions of mortar bars and concrete prisms made with greywacke #73-50 from Malay Falls, Nova Scotia /9/, and a cement containing 1.08% alkali

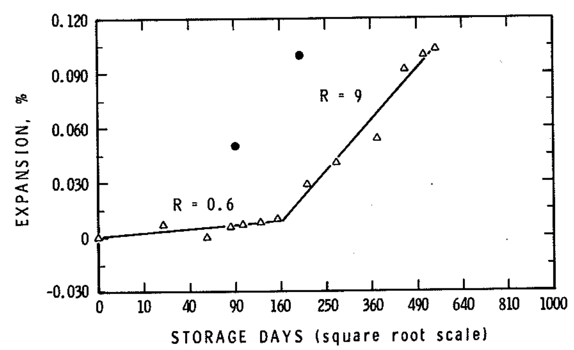
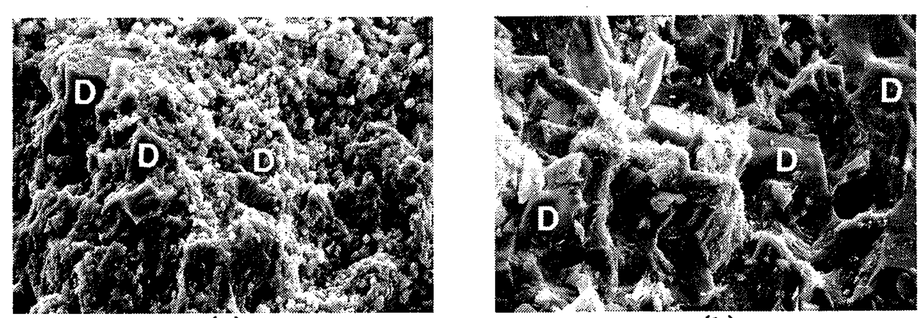


Figure 5 Expansion of mortar bars containing Malmesbury aggregate made with cement containing 0.82% alkalis stored at 38°C and 100% RH.
● - ASTM Limits, R - rate of expansion x 10^3



(a) (b)

Figure 6 SEM micrographs of carbonate rocks from Pittsburg quarry near Kingston, Ontario
(a) Highly expansive dolomitic limestone consisting of isolated dolomite rhombs (D) in a matrix of fine calcite
(b) Non-expansive dolostone consisting of larger dolomite crystals (D) with minor amounts of quartz and calcite

ALKALI-SILICA REACTIVITY OF VARIOUS DANISH FLINT TYPES

Preben Christensen, S. Chatterji,
N. Thaulow, Arne Damgaard Jensen

Teknologisk Institut, Byggeteknik
Gregersensvej, Taastrup, Denmark.

1. ABSTRACT

Measurement of expansivity of sand by the saturated NaCl-bath method in general gives 1 of 4 different expansion characteristics:

I. No expansion

II. No expansion in 8-12 weeks, then slow, but steady expansion over a long period.

III. Initial quick expansion followed by prolonged, slow expansion.

IV. Quick initial expansion followed by an asymptotic expansion.

Thin-section examination shows that the different expansion characteristics could be correlated with different rock types.

Type I occurs when either no reactive particles are present, or only dense, calcedonic flint is present in small amount.

Type II is caused by a somewhat poreous, microcrystalline, calcedonic flint.

Type III occurs in sand types containing small amount of opaline flint and small amount of poreous, microcrystalline calcedonic flint. When the expansion from the opaline flint ceases, the calcedonic flint comes into action.

Type IV occurs when opaline flint is the dominating, reactive rock type.

On the basis of these observations, it appears that most Danish flint types are reactive under appropriate conditions, when salt is added from external sources, but that the rate of reaction is markedly different.

Opaline flint reacts very quickly.

Calcedonic flint reacts slowly, provided it is somewhat poreous.

Dense, calcedonic flint reacts so slowly that the reactivity may be ignored in most practical purposes.

In the design of concrete constructions, the reactivity of the flint should be evaluated and specified using different "reactivity factors" for the different flint types.

2. INTRODUCTION

In Denmark the most common causes of the deterioration of concrete structures are alkali-silica reaction and the freeze-thaw cycles. Recently it has been realized that sand types containing alkali-reactive particles play a very important part in this breakdown. In view of this observation systematic study of Danish sand types has been conducted at the Teknologisk Institut. Some aspects of this investigation have already been published (1, 2, 3). Two different techniques are used in Denmark to evaluate the potential reactivity of sand types. One of these is the warm NaCl-bath technique, a functional technique which estimates the potential expansivity of the sand types under investigation (1). The second is the standard petrographic technique which gives information about the reactive particles, their type, amount, size, distribution, etc. Thus the two methods give related , but not identical information. In this investigation, well over 100 sand types have been studied using both methods to relate their time-expansion characteristics with their mineralogy.