NORWEGIAN EXPERIENCE WITH DIFFERENT TEST METHODS FOR ALKALI-AGGREGATE REACTIVITY

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Several types of aggregates with known field performance (both reactive and non-reactive) have been tested according to the methods: ASTM C227 mortar bar test, Canadien CSA A23.2-14A concrete prism test, South African NBRI mortar bar test, Danish TI-B51 mortar bar test and Japanese Fresh-Con GBRC concrete cylinder test.

Both the Canadien concrete prism test and the South African mortar bar test seem to be suitable for distinguishing between reactive and non-reactive Norwegian aggregates. These two methods have already been used for evaluation of potential alkali reactivity of several Norwegian aggregates with known an unknown field performances.

INTRODUCTION

The use of harmful amounts of alkali reactive aggregates has been prohibited by Norwegian Standards for the last 30 years. However, not much attention was paid to this prohibition until the problems with alkali reactive aggregates were seriously acknowledged a few years ago.

In 1989 a major research program was initiated. One of the major research tasks of this project was to identify the magnitude and the nature of AAR in Norwegian concrete structures. This work is presented in the paper of Jensen & Danielsen (1). Another major research task was to evaluate test methods adapted for prediction of reactivity in Norwegian aggregates. This paper gives an overview of the results from this work.

TEST MATERIALS

An ASTM type I neat Portland cement produced by NORCEM A/S at Dalen factory was used. The alkali content of this cement was 1.07 % Na_2O eq. This alkali content corresponds well to that of the most common cements that have been used in Norwegian concrete structures, at least since 1959 (1).

The potential reactive aggregates used were crushed rock samples of rhyolite, two sandstones, mylonite, quartzite and phyllite. They were all of types similar to aggregates which had caused AAR-damage in Norwegian concrete structures (1).

As potentially innocuous aggregates a crushed rock sample of greenstone and a natural granite sample of glaciofluvial origin were used. From concrete structures where these two aggregates have been used, no AAR-related damages have ever been observed.

ASTM C227 MORTAR BAR METHOD

Two mortar mixes were made, one with rhyolite - and one with granite aggregate. According to ASTM (2), combinations showing expansions exceeding 0.10 % after 6 months should be considered as potentially reactive. The granite mortar showed expansions less than 0.03 % during a 12 months test period, and could thereby, in good agreement with its field performance, be classified as non reactive. The rhyolite mortar however, also had to be classified as non reactive, as it showed a 6 months expansion of 0.065 %. This classification corresponds badly with the field performance of rhyolite concrete. No further tests were performed according to this method.

JAPANESE FRESH-CON GBRC CONCRETE CYLINDER METHOD

This method is based upon the fact that the modulus of elasticity is one of the concrete properties that is significantly affected by AAR-damage. Strong acceleration obtained by material composition and curing conditions, makes the method a most rapid one. By NaOH-addition the alkali content is increased to 9 kg Na_2O eq per m^3 of concrete. At an age of 2 days the dynamic modulus of elasticity is measured on three 10x20 cm cylinders, both before and after a 2 hours steam curing period at 111°C. According to Tamura et al. (3), the aggregate should be considered as potentially deleterious if the E-modulus is decreased by more than 20 % through the steam curing period, otherwise as innocuous.

Two concrete mixes were made. As coarse aggregates granite, respectively rhyolite, were used.

E-modulus reductions of 17 % and 30 % were measured for the granite- and the rhyolite concrete, respectively. Thereby the two aggregates were correctly classified. However, as the granite concrete came very close to the 20 % limit, further tests were performed by Barkenæs & Relling (4). Out of two parallel tests with natural granite concrete they found E-modulus reductions of 17 % and 21 %, respectively. Further, a test on concrete made with a non reactive greenstone, showed an E-modulus reduction of 22 %. Based on these and other test results (4), the method was judged as "not suitable" for the evaluation of Norwegian aggregates.

DANISH TI-B51 MORTAR BAR METHOD

Two mortar mixes were made with the aggregates, granite and rhyolite, respectively. Expansion measurements were performed during a 20 weeks period of storage in saturated NaCl solution at 50°C.

If expansions exceeding 0.10 % occur within 8 weeks, the aggregate should be considered as potentially reactive, otherwise as innocuous according to the Danish Basic Concrete Specification for Building Structures (5). After 20 week expansions of 0.022 % and 0.043 % were measured for the granite- and the rhyolite concrete, respectively. Consequently, neither this method seemed to be suitable for testing of Norwegian aggregates.

SOUTH AFRICAN NBRI MORTAR BAR METHOD

Eight mortar mixes with w/c-ratio 0.45 were made by the use of the eight aggregates mentioned under TEST MATERIALS.

For each mix three 40·40·160 mm prisms were cast. The prisms were stored in a moist cabinet at 23 ± 1.7°C for the first 48 hours. Thereafter they were put into water of 23°C and heated to 80°C

during a 24 hours period, before their reference length was measured. Further, they were stored in 1 N NaOH solution at 80°C for a period of 56 days during which their lengths were measured after 4, 7, 14, 28, 42 and 56 days, respectively. The development of expansion can be seen from Fig 1.

According to Davies & Oberholster (6), aggregates causing 12 days expansions:

≤ 0.10 % should be considered innocuous

> 0.10 % but < 0.25 % should be considered potentially deleteriously alkali reactive - slowly expansive

≥ 0.25 % should be considered potentially deleteriously alkali reactive-rapidly expansive

As can be seen from Fig 1, the greenstone- and granite mortars showed 12 days expansions of 0.01 % and 0.02 %, respectively. Consequently, they should clearly be classified as innocuous. Further, it can be seen from Fig 1 that five out of the six mortar mixes made with the aggregates that had caused AAR in field, gave expansions between 0.10 % and 0.20 % after 12 days in the NaOH-solution. According to the test results, these aggregates should all be considered potentially alkali reactive-slowly expanding, which corresponds well with their field performance. For the phyllite which also has shown AAR in field performance, the 0.10 % expansion limit was reached after 14 days.

Fig 2 shows 12 and 14 days expansion results obtained by Berg (7). The mortars were made with the non-reactive granite and the reactive rhyolite in different mix proportions. The purpose of these tests were to find the critical reactive aggregate content for alkali reactivity. As can be seen, 12 days expansions exceeding 0.10 % occurred when the rhyolite content exceeded 30 % by weight of total aggregate.

CANADIEN CAN3-A23.2-14A CONCRETE PRISM METHOD

Eight concrete mixes with non reactive granite as fine (< 5 mm)- and the eight aggregates used in the NBRI tests, as coarse aggregate (5 - 20 mm), were made. As recommended by Grattan-Bellew (8) the cement content was increased to approximately 400 kg per m^3 of concrete, and thereby the alkali content to 5 kg Na_2O eq per m^3.

Three 100•100•450 mm prisms were used as test specimens for each mix. The expansion development during the 12 months' test period is shown in Fig 3 and 4.

According to this method combinations that show expansions exceeding 0.040 % within one year, should be considered potentially deleteriously reactive.

As can be seen from Fig 3 and 4, the granite and the greenstone concretes showed 1 year expansions of 0.011 % and 0.009 %, respectively. Further, the rhyolite-, mylonite- and quartzite concretes showed expansions of 0.086 %, 0.069 % and 0.051 %, respectively. Consequently, the test results classified all these five aggregates in agreement with their field performance. However, the two sandstone concretes showed expansions between 0.024 % and 0.032 %, while the phyllite concrete hardly expanded at all during the one years test. For testing of Norwegian sedimentary rocks e.g. sandstones according to the Canadien concrete prism method, it cannot be excluded that other limit values than the recommended 0.040 % have to be used. However, further tests are necessary to establish such new limit values or to evaluate whether or not the method is usable for Norwegian phyllites.

RECOMMENDED TEST PROCEDURE FOR EVALUATION OF NORWEGIAN AGGREGATES FOR ALKALI REACTIVITY

The Norwegian Concrete Society's Publication, NB 19 (9) describes a test procedure for the alkali reactivity of Norwegian aggregates. The procedure is carried out in three steps as shown in Fig 5.

The firs step is a petrographic analysis including thin section microscopy of the aggregate. If the content of potentially alkali reactive aggregates is found to be less than 20 % (1), the aggregate is accepted as innocuous, and no further testing is recommended. Otherwise, the mortar bar - and/or the concrete prism test is recommended to be carried out.

The NBRI-mortar bar test is used also for the evaluation of the potential reactivity of blends of aggregates. Testing of blends is often actual in cases where utilization of maximum amounts of potential reactive aggregates is advantageous for economical or other reasons.

We also use the Canadien concrete prism method in evaluation of the effect of other concrete constituents such as alkali content, pozzolanas etc. As a part of the research project, tests have recently been started to evaluate the effect of silica fume and pozzolanic cements. Less than twenty years ago pozzolanic materials were rarely used in Norway. Since deleteriously AAR has not been observed in less than twenty years old Norwegian concrete, we have no field experience with the effect of pozzolanic materials on AAR. When the test results are available by the end of this year, they will be met with great interest by the Norwegian concrete industry, which is a heavy user of pozzolanic cements and silica fume.

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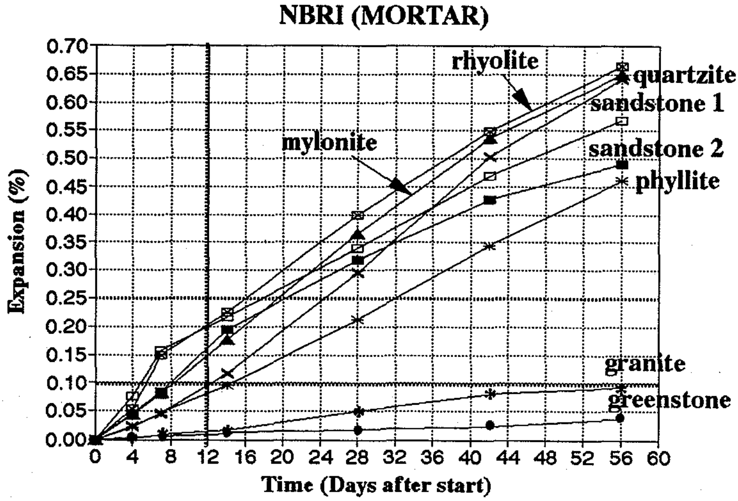


Fig 1. Developement of expansion of mortar bars produced with Norwegian aggregates. From Jensen (10)

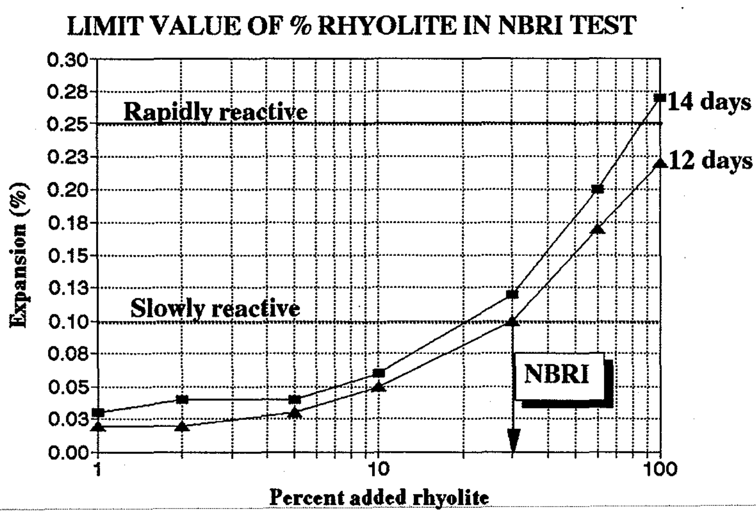


Fig 2. 12 and 14 days expansion of mortar bars as a function and rhyolite content. (10)

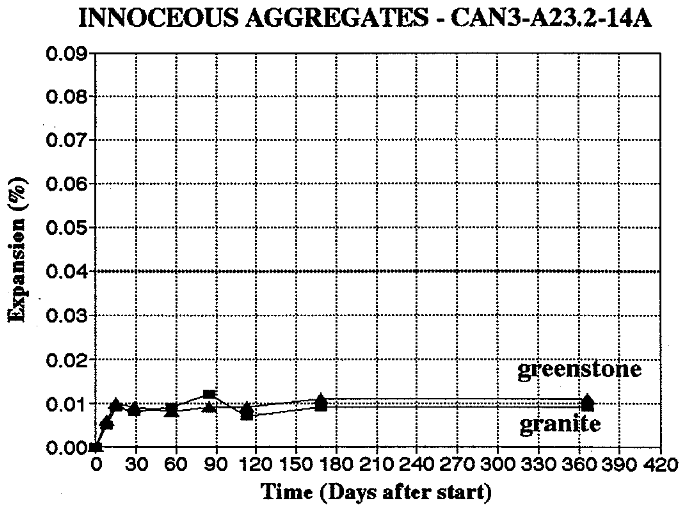


Fig 3. Developement of expansion of concrete prisms produced with innocuous Norwegian aggregates. (10)

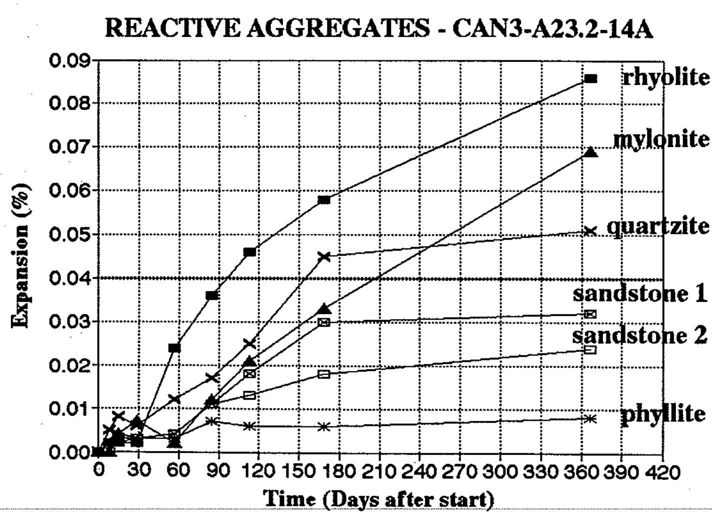
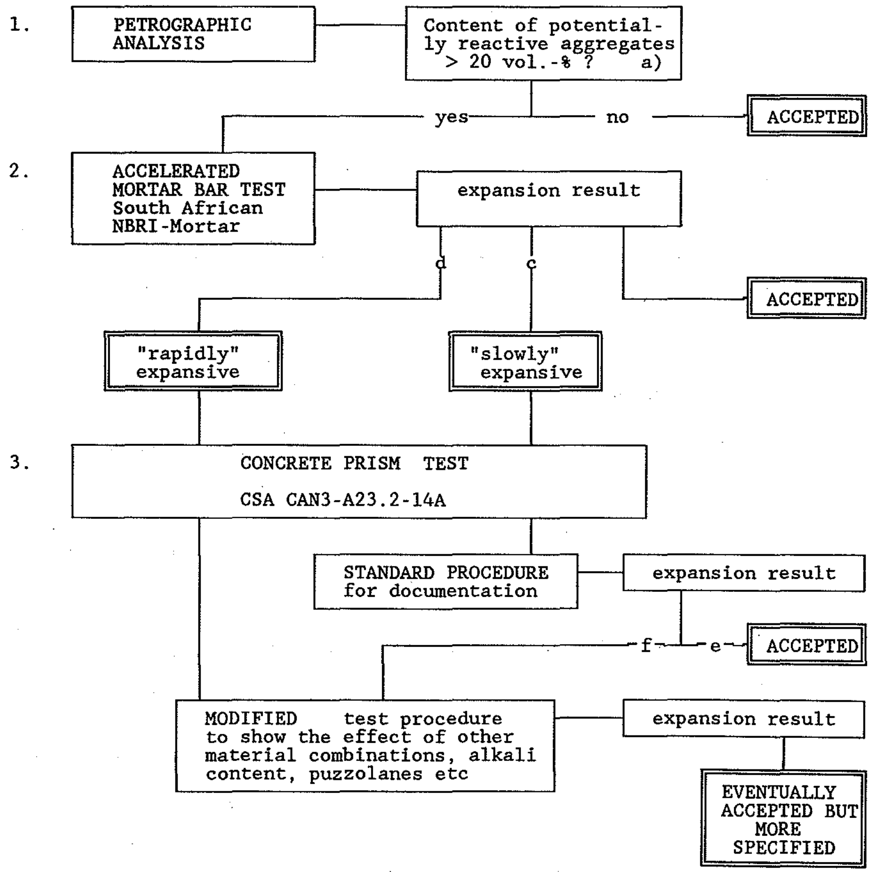


Fig 4. Developement of expansion of concrete prisms produced with potentially reactive Norwegian aggregates. (10)



a)	Applies for substantiated potentially reactive rocks in Norway			
b)	Mortar expansion	< 0,10 %	after	14 days
c)	----""----	0,10-0,25 %	""	""
d)	----""----	> 0,25 %	""	""
e)	Concrete expansion	< 0,04 %	""	1 year
f)	----""----	> 0,04 %	""	""

Fig 5. Flow chart showing the test procedures for the alkali reactivity of Norwegian aggregates. (9)