# INFLUENCE OF DIFFERENT PROCEDURES ON ACCELERATED MORTAR BAR AND CONCRETE PRISM TESTS: ASSESSMENT OF SEVEN NORWEGIAN ALKALI-REACTIVE AGGREGATES

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## ABSTRACT

The paper presents results from comparison testing of 7 Norwegian reactive aggregates by Accelerated Mortar Bar Test and Concrete Prism Test, tested at SINTEF, Norway and CANMET, Canada. The aggregates: black sandstone, red sandstone, rhyolite, quartzite, phyllite, mylonite and cataclasite are documented to have caused deleterious alkali reaction in several Norwegian structures. Petrographic descriptions and XRD analyses of the aggregates are given. The expansion results obtained by SINTEF gave significant lower results by the Accelerated Mortar Bar Test and Concrete Prism Test than at CANMET. It is concluded that for the Accelerated Mortar Bar Test the difference in bar size is the major reason on varying expansions. It is suggested that a factor on 0.6 should be used for transforming expansion results from ASTM bars (2.5cm x 2.5cm x 25cm) to RILEM bars (4cm x 4cm x16cm). For Concrete Prism Test, higher expansions obtained by CANMET could be explained by the storage conditions, which differ from SINTEF's. Reduced access of humidity and water for prisms in larger containers is most likely important for the lower expansion results obtained by SINTEF. However, reduced humidity in the larger containers has not been measured and documented to the authors' knowledge. The comparison testing clearly points out the importance using reference material before establishing commercial testing. The reference aggregate should be Spratt limestone as recommended by RILEM technical committee TC 106

Keywords: Concrete, reactive aggregate, alkali-aggregate reaction, laboratory test methods, accelerated mortar bar method, concrete prism method

## INTRODUCTION

In the early 1990's, no reliable test methods existed in Norway for evaluating the potential alkali-reactivity of concrete aggregates. As part of the first Norwegian research program “Alkalireaksjoner i betong”, 1990-1993, several international test methods were assessed using selected reactive and non-reactive aggregates from Norway. The most promising expansion test methods found were the NBRI Accelerated Mortar Bar Test (AMBT) and the Canadian CSA CAN3-A23.2-14A Concrete Prism Test (CPT). However, results suggested that the Canadian CPT was not suitable for Norwegian alkali reactive sandstones and phyllite (Dahl et al. 1992, Jensen 1993). Actually, several series of tests using this method for aggregates containing sedimentary rocks gave results that classified those aggregates as innocuous, even when field experience showed the opposite (Jensen 1996). Therefore, the CPT method was withdrawn from the Norwegian “Optional arrangement for declaration and approval of aggregates used for concrete purpose” (NB 19 1991) in 1993. No international reference aggregate has been tested in Norway for comparison of expansion results. Today the petrographic method and the AMBT method are the only methods used for aggregate testing in Norway (DGB 1994). The petrographic method, point counting in thin sections, is similar to the newly proposed “RILEM Petrographic Method” (Jensen & Lorenzi 1999).
With the aim of assessing and correlating expansion results obtained in Norway with those obtained in other countries, seven reactive Norwegian aggregate types were shipped to CANMET in Canada, for comparative testing. The paper presents the results from comparison testing of these aggregates by the AMBT and CPT methods between SINTEF and CANMET.

## MATERIALS

### Petrographic Analysis of Coarse Aggregates

Seven Norwegian aggregates with known deleterious field performance were selected for this study (Jensen 1993). The mylonite, cataclastite and quartzite come from commercial quarries, while blocks of the other rock types were collected and crushed in the laboratory. Fig. 1 show micrographs in thin sections and Table 1 give the major constituents of the aggregates.

Black Sandstone (Fig. 1-1) - Black grey, homogeneous occasionally slightly laminated and fine grained. Grains of feldspar, quartz and muscovite with grain size 0,2-0,8 mm are angular or elongated. Interstitial matrix is microcrystalline and contains quartz, feldspar, mica (illite), chlorite, carbonate minerals and thin “bands” of organic material.

Red sandstone (Fig. 1-2) – Light grey-reddish homogeneous and fine grained. Grains of quartz and feldspar with grain size 0,2-0,5 mm are sub-rounded and often with concave-convex grain boundary. Iron hydroxide and sericite is found as coatings on grains (dustlines) and intergranular. Strained quartz, microstylolites and small areas with cataclase are observed, too.

Quartzite (sedimentary origin) (Fig. 1-3) – White grey, homogeneous with slightly red coloured bedding. Grains of quartz with grain size 0,2-0,5 mm are sub-rounded or with concave-convex grain boundaries and microstylolites. Iron hydroxide is found as coatings on grains in red coloured layers. Secondary epitaxic quartz fills up all the pore spaces and cements the rock together. Secondary quartz has been estimated to be 20%.

Rhyolite (Fig. 1-4) - Green/red/dark gray, homogeneous, occasionally porphyritic and laminated. Perlitic and spherolitic textures and large phenocrysts of feldspars and quartz (up to 4 mm) have been observed. The matrix has an average grain size of 0,01 - 0,02 mm, and mainly consists of inter-grown crypto-microcrystalline feldspar, quartz and sericite.

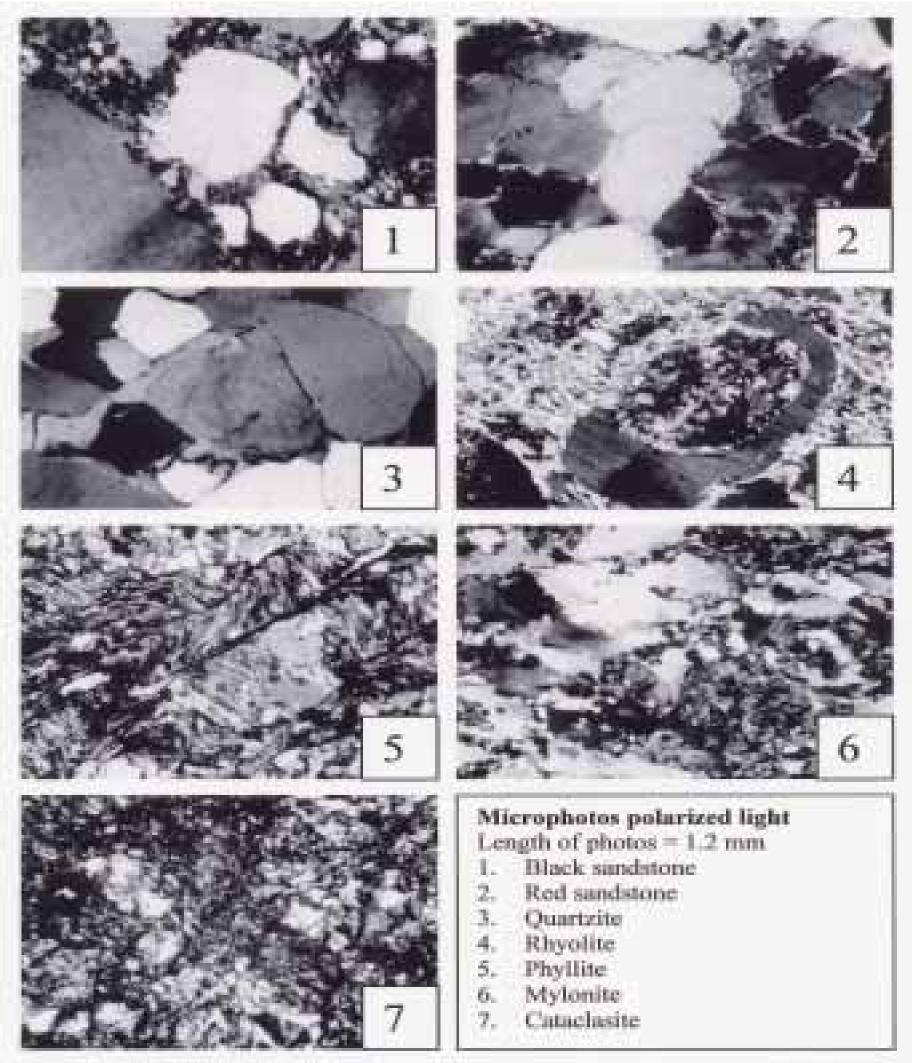


Fig. 1: Micrographs from thin sections of the Norwegian aggregates.

Phyllite (Fig. 1-5) – Green–grey, shiny, laminated and foliated. Thin parallel bands/laminae or microfolds consist of mica, chlorite and opaque minerals. Matrix or segregated linsoides consist of microcrystalline quartz and dolomite crystals. Voids after sulphide minerals can be observed. The rock is more correctly classified as quartz phyllite.

Mylonite (Fig. 1-6) – Grey-greenish, foliated and fine-grained. Cataclasts or clusters with grain sizes ~0,4 mm dominate the rock and consist of altered feldspar, sericite, amphibole and carbonate minerals. Irregular bands and linsoides of elongated re-crystallised quartz, have individual crystals on 0.01-0.05mm. The rock was formerly classified as Quartz Diorite but is more correctly classified as blastomylonite.

Cataclasite (Fig. 1-7) - Greenish, homogenous and fine-grained. The major constituents are feldspar particles in a matrix of quartz, "crushed" feldspar, dark minerals and mica. Average grain size of the matrix is 0.01-0.03 mm. The feldspar crystals are max. 0.7 mm and the quartz crystals are mostly about 0.05 to 0.3 mm.

TABLE 1: Semiquantitative XRD Analysis of 6 Norwegian Aggregates (from Jensen 1993)

| **Semi-quantitative XRD-analysis (%)** | **Quartz** | **K-feldspar** | **Plagioclase** | **Mica** | **Chlorite** | **Calcite** | **Dolomite** | **Amphibole** | **Hematite** |
|---|---|---|---|---|---|---|---|---|---|
| **Black sandstone** | 50 | 6 | 28 | 5 | 2 | 3 | 8 | nd | nd |
| **Red sandstone** | 86 | 10 | nd | 1 | nd | nd | nd | nd | nd |
| **Quartzite** | 100 | nd | nd | nd | nd | nd | nd | nd | nd |
| **Rhyolite** | 31 | 42 | 20 | 4 | nd | nd | nd | nd | 3 |
| **Phyllite** | 56 | nd | 20 | 7 | 8 | nd | 9 | nd | nd |
| **Mylonite** | 24 | 21 | 51 | 2 | 1 | nd | 1 | 1 | nd |

nd = not detected

### Coarse and Fine Aggregates used in Concrete Prism Test

The seven coarse aggregates used at SINTEF and CANMET were crushed and fractionated as 1/3 part 0-5 mm, 1/3 part 5-14 mm and 1/3 part 14-20 mm. The fine aggregate used at SINTEF is a non reactive glacio-fluvial sand consisting of sub rounded gneiss and granite particles from Aardal, Norway. AMBT expansion after 14 days is 0.021%. The fine aggregate used at CANMET is non-reactive and derived from granite; it generated an AMBT expansion of 0.032% at 14 days.

### Cements

ASTM Type I cements were used both at SINTEF and CANMET. The SINTEF cement had a Blaine fineness of 310 $m^2$/kg and an alkali content of 1.07 % $Na_2O$eq (0.46% $Na_2O$, 0.92% $K_2O$). The cement used at CANMET had a Blaine fineness of 400 $m^2$/kg and an alkali content of 0.90% $Na_2O$eq (0.22% $Na_2O$, 1.03% $K_2O$).

## TEST METHODS

### Accelerated Mortar Bar Test (AMBT)

In that test, mortar bars with specified mixture design are immersed in a 1N NaOH solution at 80°C. The length changes of the bars is monitored and the 14-day expansion value is used as the criteria of possible reactivity of the aggregate. The procedures in Norway and Canada are both based on the NBRI/CSIR method originally from South Africa (Davies & Oberholster 1987). They are generally similar according to sampling, preparation and grading requirements for the aggregate, conditioning of the bars and calculation of results; however, as indicated in Table 2, some differences exist between the test procedures used in the above laboratories which may affect the expansion results.

TABLE 2: Parameters used for the AMBT at SINTEF and CANMET

| Parameters | SINTEF * | CANMET |
|---|---|---|
| Reference | SINTEF report STF 70 A93030 1993 | CSA A23.2-25A (1994) |
| Water-to-cement ratio | 0.45 | 0.50 |
| Cement alkalies ($Na_2O$eq.) | 1.07 | 0.90 |
| Bar size | 4 x 4 x 16 cm | 2.5 x 2.5 x 25 cm |
| Storage container; bars | 40 x 50 x 20 cm; 18 bars (max) | 19 x 29 x 7.5 cm; 3 bars |
| Calculation of length | length of bars | length between studs |
| Limit value after 14 days | 0.10% | 0.15% |
| Use | final assessment | screening test |

* In Norway, the effective length between studs is now used for the calculation of length and 3 mortar bars are stored in the container (19 x 21 x 17cm) with fixed amount of NaOH solution.

**Concrete Prism Test (CPT)**

In that test, concrete prisms with specified mixture design are maintained at 38°C and 100% relative humidity. The length change of the test prisms is monitored and the one-year expansion result is used as criteria of possible reactivity of the aggregate. The procedures in Canada and Norway are both based on the CSA standard A23.2-14A (CSA A23.2-M94). In both laboratories, storage containers consist of plastic pails in which test prisms are stored vertically on a perforated rack, with water in the bottom of the container and a wick of absorbent material placed around the inner wall from top to bottom (in water). CANMET and SINTEF did not wrap the test prisms for this series of tests. Table 3 compares the characteristics of the test procedures used by SINTEF and CANMET.

TABLE 3: Parameters used for CPT test at SINTEF and CANMET

| Parameters | SINTEF | CANMET |
|---|---|---|
| Reference | SINTEF:STF 70 A93030 1993 | CSA A23.2-14A |
| Coarse : fine aggregate | 55 : 45 | 60 : 40 |
| Water-to-cement ratio | slump 8 +/-2cm (about 0.45) | 0.42 - 0.45 |
| Cement:kg/$m^3$;alkali content | 400 kg; 5.0 kg/$m^3$ $Na_2O$eq | 420 kg; 5.25 kg/$m^3$ $Na_2O$eq |
| Cement alkalis (eq.) | 1,07 (1.25% with NaOH) | 0.90 (1.25%, with NaOH) |
| Prism size | 10cm x 10cm x 45cm | 7.5cm x 7.5cm x 30cm |
| Storage container; prisms | 80cm x 100cm; max. 24 prisms | 30cm x 45 cm; 4 prisms |
| Calculation of length | length of prism | length between studs |
| Limit value after 1 year | 0.04% | 0.04% |
| Use | not used for aggregate | final assessment |

* In Norway, the effective length between studs is now used for the calculation of length and 3 test prisms are stored in the container (dia. 35cm x 55cm). The method is only used for assessment of mix design.

# TESTS RESULTS

Accelerated Mortar Bar and Concrete Prism expansion tests results obtained by SINTEF and at CANMET are given in Fig. 2, 3 and in Table 4.

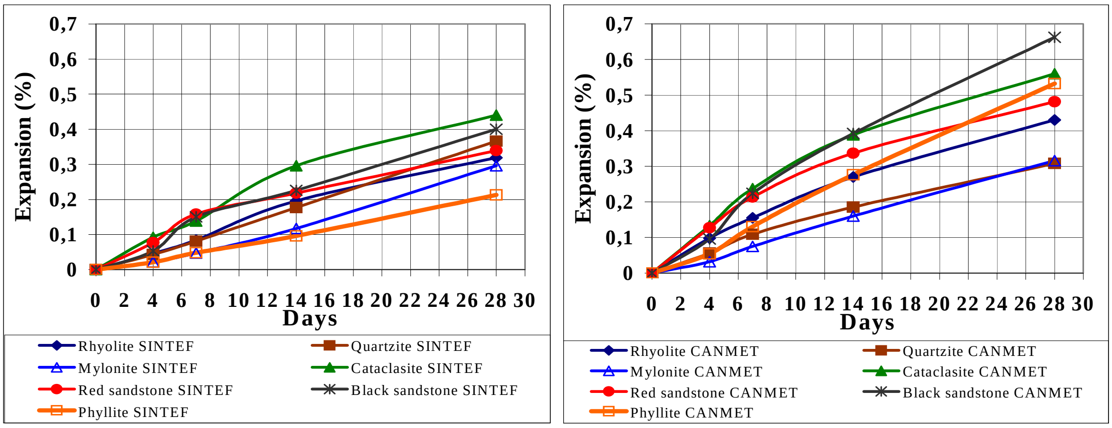


Fig. 2: Expansions of AMBT, SINTEF (left figure) and CANMET (right figure)

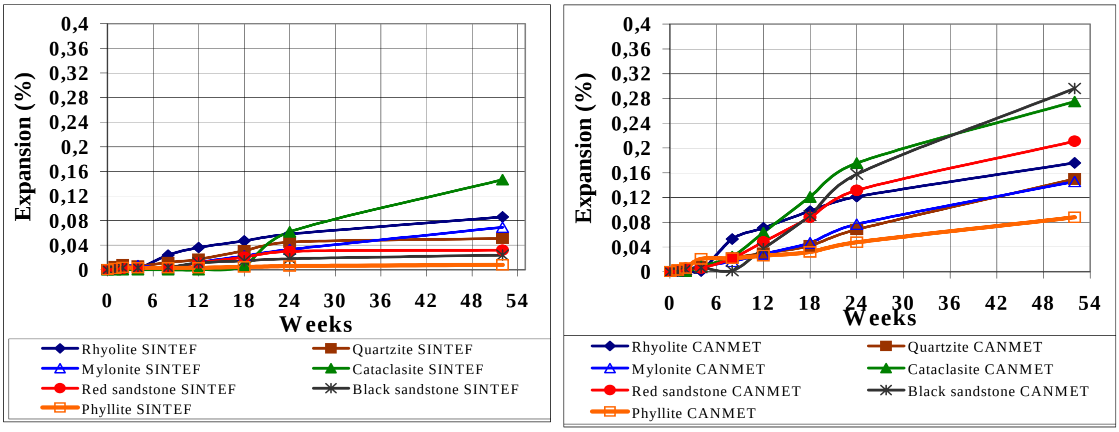


Fig. 3: Expansions of CPT tests, SINTEF (left figure) and CANMET (right figure)

TABLE 4: Expansion results in percent obtained by SINTEF and CANMET

| Aggregate types | AMBT, 14-day expansions | | CPT, One-year expansions | |
|---|---|---|---|---|
| | SINTEF | CANMET | SINTEF | CANMET |
| **Black sandstone** | 0,226 | 0,392 | 0,024 | 0,296 |
| **Mylonite** | 0,117 | 0,160 | 0,069 | 0,141 |
| **Phyllite** | 0,096 | 0,276 | 0,008 | 0,086 |
| **Quartzite** | 0,177 | 0,185 | 0,051 | 0,150 |
| **Rhyolite** | 0,196 | 0,271 | 0,086 | 0,176 |
| **Cataclasite** | 0,296 | 0,388 | 0,146 | 0,276 |
| **Red sandstone** | 0,218 | 0,337 | 0,032 | 0,210 |

# CORRELATION

## Accelerated Mortar Bar Test

Figure 4 shows the correlation between SINTEF using 4 x 4 x 16cm prisms (RILEM size) and CANMET using 2.5 x 2.5 x 25cm prisms (ASTM size). These figures also include results from a recently completed European research project (STAR 1998). Table 5 gives some statistical results on the correlation between prism sizes. After 14 days of testing, expansion values obtained at CANMET using ASTM-type mortar bars were about twice as high as those obtained by SINTEF using RILEM-type bars; however, the test results show that RILEM bars gave somewhat similar expansions after 28 days exposure. Although Wigum et. al (1995) did not measure any significant difference between RILEM and ASTM mortar bar expansions, a similar difference to that reported between SINTEF and CANMET data was also obtained in the STAR European research project (STAR 1998). Indeed, laboratories using ASTM bars obtained about twice as much expansion compared to those using RILEM bars, the most commonly used bar size in Continental Europe. All the laboratories used the same procedure (RILEM Ultra Accelerated Mortar Bar Test), same European aggregates and RILEM standard cement; the only difference was the bar size. The data obtained in our research, together with those of the STAR project suggest that a linear correlation factor converting expansion results from RILEM bars to ASTM bars varies from 0.54 to 0.65. Calculation of all the expansion results from the STAR project together with our results gave an average factor of 0.59. However the correlation factor $R^2$ is only 0.70. Taken into account the variation of expansions, we recommend that a factor of 0.60 be used.

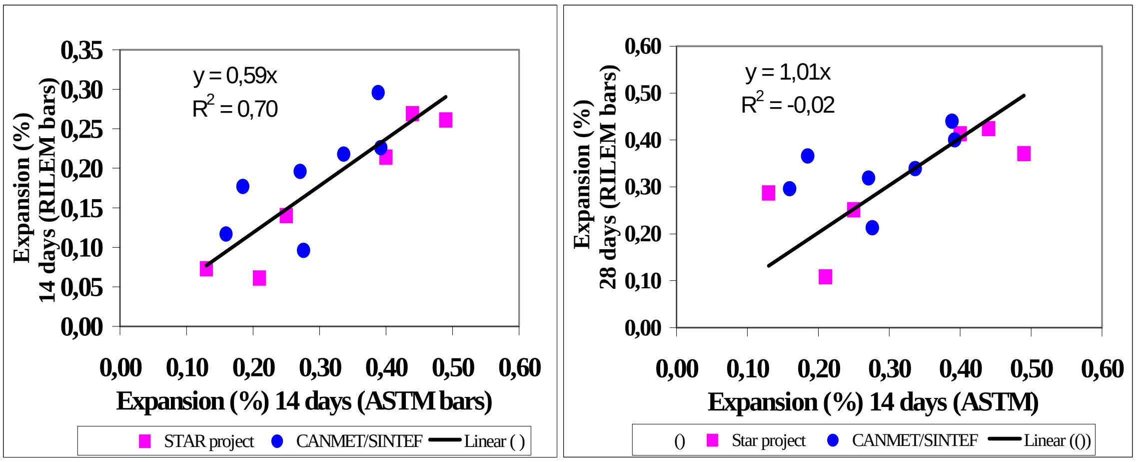


Fig. 4: Correlation of RILEM vs. ASTM bars between SINTEF and CANMET, inclusive results from the STAR project. Left is 14 days results RILEM-ASTM and right is 28 days results RILEM prisms and 14 days results ASTM prisms.

TABLE 5: Some statistical results on the correlation between mortar bar sizes.

| **Correlation Data** | **Y=** | **$R^2$** |
|---|---|---|
| STAR project | 0.54x | 0.91 |
| CANMET/SINTEF | 0,65x | 0,51 |
| All 14-day expansions | 0.59x | 0.70 |
| All 14-day (ASTM) / 28-day (RILEM) | 1.01x | -0,02 |

## Concrete Prism Test

Figure 5 compares the concrete prism expansions obtained at SINTEF and CANMET. Significantly higher concrete prism expansions were obtained at CANMET than by SINTEF for all seven aggregates tested. With the exception of the two reactive sandstones for which the potential alkali-reactive was not recognized at SINTEF, a somewhat linear correlation can be established between the expansions obtained by SINTEF and at CANMET.

## Accelerated Mortar Bar versus Concrete Prism Expansions

Figure 6 show accelerated mortar bar expansions versus concrete prism expansions obtained by SINTEF and CANMET. As indicated before, accelerated mortar bar and concrete prism expansions obtained by SINTEF are generally lower than those obtained at CANMET.

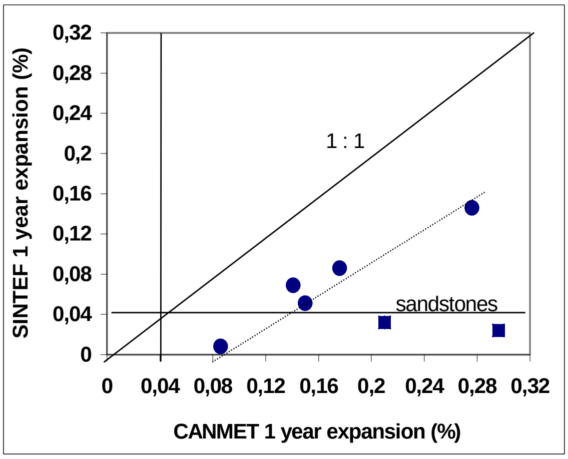


Fig. 5: Correlation of concrete prism expansions between SINTEF and CANMET

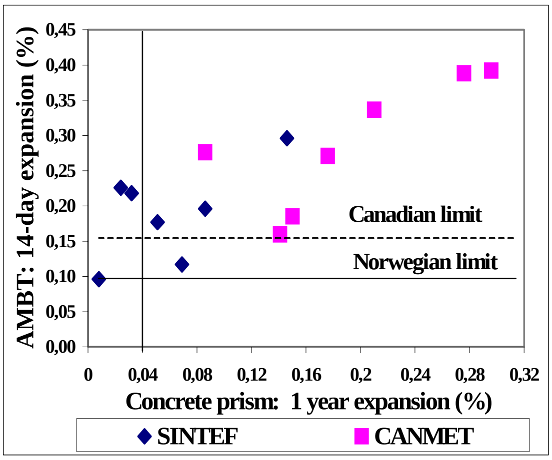


Fig. 6: Accelerated mortar bar expansions versus concrete prism expansions

## DISCUSSION

## Accelerated Mortar Bar Test

The results presented in this paper confirmed the finding of the STAR project that accelerated mortar bar expansions obtained using ASTM bars are about twice as high as those obtained using RILEM bars. What are the main factors that can explain that difference ? Based on past experience with this test, the use of ASTM Type I cements of different composition by the two partners in this investigation is not expected to have had any significant impact on the test results (Fournier and Bérubé 1991, Rogers 1996). In fact, in this test, alkali-silica reaction rates are greatly accelerated by the use of high temperature and immersion of test specimens in a very strong base, i.e. the 1N NaOH solution. Therefore, the expansion rates are likely to be influenced by the size of the test specimen and the speed at which the NaOH solution will be able to diffuse within that specimen. Even if the total surface area exposed to the NaOH solution is slightly greater in the case of the RILEM bars, i.e. 288 $cm^2$ vs. 263 $cm^2$ (including end sections of the bars), Jensen

(1996) wrote, that a small cross-section will favor rapid diffusion of NaOH compare to a larger cross-section. The relationship between the ASTM cross-section and the RILEM cross-section is 2.5/4 or 0.625. This value is very close to the correlation factor of 0.60 obtained from the comparative expansion values in this investigation. The use of a 0.45 water-to-cement ratio by SINTEF (compared to 0.50 at CANMET) is also probably contributing in reducing diffusion and expansion rates (Fournier and Bérubé 1991). Prolonging the expansion period to 28 days for the RILEM bars seems to help compensating for the slower expansion rate and/or diffusion process, and 28-day expansions of RILEM bars then become somewhat similar the 14-day expansions for the ASTM bars. In terms of expansion limits, RILEM and CSA recommends using 14-day expansions of a 0.10 and 0.15%, respectively. Using those limits, the potential alkali-silica reactivity of all seven aggregates was properly recognized by SINTEF and CANMET. The expansion value of 0.096% obtained by SINTEF for the phyllite falls very close to the 0.10% limit recommended, which is acceptable considering the inherent variability of the test. However, the phyllite would have failed the test if a 0.09% expansion limit had been used. Such a limit could be suggested from the correlation factor of 0.60 between RILEM and ASTM bars obtained in our study, i.e. 0.60 x the 0.15% CSA limit = 0.090% limit for RILEM bars.

**Concrete Prism Test**

As indicated before, significantly higher concrete prism expansions were obtained at CANMET compared to SINTEF using the same seven Norwegian aggregates. Also, the potential alkali-reactivity of the two reactive sandstones and the phyllite, as determined from field performance survey, was correctly confirmed by CANMET, but failed to be as such by SINTEF. Since 1993, the CPT method has not been used for aggregate testing in Norway because of failure to detect reactive sedimentary aggregates, e.g. sandstone. As discussed below, the most likely reasons for the differences in expansions, in addition to the inherent multilaboratory variability of the test (Fournier and Malhotra 1996), are differences in the mixture design characteristics, storage conditions and concrete prism size. The use of a larger proportion of reactive coarse aggregates (coarse-to-fine aggregate ratio of 60:40 at CANMET vs 55:45 at SINTEF) and the relatively higher total alkali content in concrete (5.25 vs 5.0 kg/m$^3$) at CANMET may have contributed to increasing expansions. Research has shown that the cross-section of test specimens has great influence on the expansion result. Bakker (1983) observed that significantly higher expansions are obtained for mortar or concrete specimens of larger cross-sections when tested at 40$^o$ C and 100% RH. Bérubé and Fournier (2000) observed for three different aggregate types susceptible to alkali-silica reaction that concrete test specimens of smaller cross-sections showed a more rapid onset of expansion but lower long-term expansions than specimens of larger cross sections. Even if performed in two different laboratories, the results of our comparative test program suggest that lower concrete prism expansions could be obtained by the use of prisms of larger cross-section (like those used at SINTEF). Therefore, on the basis on available information from the literature, the effect of the test prism size is not clear and it is likely that the difference in expansions between CANMET and SINTEF can or should be explained by other technical reasons. Differences in storage conditions might be a possible explanation of the phenomena. During that series of test, SINTEF was using a larger storage container that can accept up to 24 prisms. It is possible that the relative humidity or access of water to the prisms is less in the larger containers used at SINTEF compared to the smaller containers used at CANMET. However, this has not been documented or reported in the literature to the authors knowledge. Release of alkalies from the test prisms can not explain the differences observed since the larger specimens used at SINTEF should be less sensible to alkali leaching than the smaller prisms used at CANMET.

## CONCLUSION

Significant differences in AMBT and CPT expansions were obtained as part of a comparative testing program between SINTEF and CANMET for seven Norwegian reactive aggregates. It is concluded that for the AMBT, the difference in specimen size is the major factor influencing expansion values. A factor of 0.6 can be used to transpose expansion results from ASTM bars to RILEM bars. However, the use of 0.10 and 0.15% expansion limits by RILEM and CSA, respectively, is likely to account for the above difference in expansion for evaluating the potential alkali-reactivity of aggregates. For the CPT method, a possible explanation for higher expansions obtained at CANMET could be slight differences in the mixture designs and by differences in the storage conditions. Reduced access of humidity and water for prisms in larger containers is most likely important for the lower expansion results obtained by SINTEF. However, reduced humidity in the larger containers has not been measured and documented, to the authors' knowledge. The CPT method appears to be sensitive to small variances in storage conditions. Other researchers have also observed this tendency. The comparison testing clearly points out the importance using international reference material before establishing commercial testing, e.g. Spratt limestone as recommended by RILEM technical committee TC 106.

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