PRESENT EXPERIENCE WITH AGGREGATE TESTING IN NORWAY

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ABSTRACT

In Norway concrete aggregates are tested for possible alkali reactivity by the use of two successive test methods, namely a petrographic analysis (Norwegian method) and the South African accelerated mortar bar test (NBRI). The Canadian concrete prism test (CSA CAN 3-A23.2-14A) was used as test method up to 1993 but is no longer recommended for testing of concrete aggregates.

The paper describes the Norwegian petrographic method which correlates with the NBRI mortar bar test. So far, testing of Norwegian aggregates shows poor correlation between the CAN 3 concrete prism test and the petrographic analysis, when aggregates are dominated by sedimentary rock types, and between the CAN 3 concrete prism test and the NBRI mortar bar test.

It can be concluded that the petrographic analysis followed by the NBRI method is presently the best "tool" to assess alkali reactive Norwegian slow/late expansive aggregates. So far results show acceptable correlation between the two methods. Test results suggest that the Norwegian limits of 20 volume% reactive aggregates and the NBRI 14 day expansion of 0.10% are probably not conservative for Norwegian natural aggregates.

Keywords: Aggregates, Alkali Aggregate Reaction, Petrographic analysis, expansion tests

INTRODUCTION

Since the late 1980s alkali-aggregate reaction (AAR) has been recognised as a concrete durability problem in Norway. AAR in Norwegian structures is caused by the coarse aggregates derived from slow/late-expansive rocks. Diagenetic to low grade metamorphosed rhyolite, sandstones, siltstone, argillite (some carbonaceous), greywacke, and phyllite have reacted. More questioned AAR has been caused by granite, gneiss and hornfels. Cataclastic rocks e.g. cataclasite and mylonite are the most widely distributed reactive aggregate type in Norway. Common for Norwegian reactive aggregates are microcrystalline grain sizes e.g. due to cataclasis, developments of sub grains and recrystallization of quartz. The minerals *quartz-feldspar-muscovite (sericite)* are most frequently found in reacted Norwegian aggregates (Jensen 1990), (Jensen & Danielsen 1992), (Jensen 1993)

During the period 1990-1993 several laboratory test methods were investigated by SINTEF to find suitable test methods for Norwegian aggregates. This were the ASTM C 227 mortar bar test, the Danish accelerated mortar bar test TI-B 51, the Danish chemical shrinkage TK 84 test and the Japanese Fresh Con CBRI rapid test. Several aggregates proven to be alkali reactive in field concretes as well as some innocuous aggregates were tested. The most promising test methods found for Norwegian aggregates were the South African accelerated mortar bar test (NBRI) and the Canadian CSA CAN3-A23.2-14A concrete prism test. However, results suggested that the Canadian concrete prism test was not suitable for Norwegian alkali reactive sandstones and phyllite (Dahl et al. 1992), (Meland et al.1993), (Jensen 1993).

SPECIFICATIONS TO CONTROL AAR

Preventive measures, advisory notes and codes of practice to minimize the risk for AAR in Norway are limited. The Norwegian Standard NS 3420, L5 from 1986, dealing with aggregates for concrete, specifies that reactive aggregates in harmful amounts are not to be used in concrete. However no methods or recommendations to minimize the risk for AAR are presented in this standard.

In 1991 the Norwegian Concrete Society - aggregate committee, proposed methods for control and acceptance of concrete aggregates. Testing of aggregates were to be carried out in 3 steps; 1) a petrographic analysis, 2) an accelerated mortar bar test (South African NBRI method) and finally 3) a concrete prism test (CAN3-A23.2-14A). In 1991 it was believed that the concrete prism test was the most reliable test method relative to the more accelerated NBRI method.

In 1992 an optional arrangement for acceptance and approval of aggregates for concrete were introduced in Norway named DGB (Deklarasjon- og Godkjenningsordning for betongtilslag). Aggregates were to be tested according to the procedures given by the Norwegian Concrete Society, publication NB 19.

In 1993 the concrete prism test was withdrawn from the DGB recommendation because of discrepancies between field experience and test results.

TEST METHODS

Two test methods are now used for assessment of alkali reactivity of Norwegian concrete aggregates, namely a petrographic analysis and the South African accelerated mortar bar test (NBRI). As mentioned earlier the Canadian Concrete Prism test CSA CAN3 A23.2-14A is no longer recommended for testing of concrete aggregates. However, this method is still recommended for assessment on cement type, admixture and concrete mix design.

Petrographic analysis

Before 1992 petrographic analysis followed the principles given in ASTM C 295, "Standard Practice for Petrographic Examination of Aggregates for Concrete". However, only 1 size fraction was counted from the sand and the coarse fraction respectively and results were given as the average grain% of the counted fractions and not as a weighted composition. Since most Norwegian alkali reactive aggregates are microcrystalline, identification and classification of aggregate grains is difficult without the use of thin section microscopy.

An improved petrographic analysis by use of point counting of thin sections has been developed to classify concrete aggregate samples (Jensen et al 1993). This method is now required by DGB for petrographic analysis of concrete aggregates. The petrographic analysis is used to classify both natural sand, coarse gravel and crushed rocks. Before point counting examination of the thin sections is carried out. Rock types are then classified according to geological nomenclature, microstructure of the rock, degree of deformation and alteration.

Results are reported as volume percentage of major rock/minerals in addition to alkali reactivity based on field experience. Based on this evaluation rocks have been divided into three main groups (Jensen et al. 1993), (Haugen & Jensen 1994), (Wigum & Lindgaard 1994):

- Reactive aggregates: Sandstone, siltstone, cataclastic rocks, acid volcanic rocks, argillaceous rocks, greywacke, marl and rock types with microcrystalline quartz (grain size less than 0.06 mm).

- Potentially reactive aggregates: Fine grained quartzite or rock types containing micro-very fine grained quartz (crystal size 0.06 - 0.13 mm).

- Innocuous aggregates: Gneiss, granite, coarse grained quartzite, crystalline limestone, gabbro and rock types with coarse grains and/or minor amounts of quartz.

Where more than 20 volume% reactive + potentially reactive rocks are found the material is classified as alkali reactive. If less than 20 volume% is found the material is classified as innocuous. The petrographic analysis is to be performed by an experienced geologist with knowledge of AAR. This is important because Norwegian rocks are varied and difficult to identify.

South African accelerated mortar bar test (NBRI)

The method follows the test procedures given by NBRI/CSIR (Davies & Oberholster 1987) but the size of mortar bars used are 4 x 4 x 16 cm.

Aggregates are assessed as potentially reactive when the 14 day expansion are higher than 0.10%, innocuous when less than 0.10%. Both sand, gravel, crushed rock and blends of natural and crushed aggregates are tested by the NBRI method.

Canadian concrete prism test CSA CAN3-A23.2-14A

The method follows the test procedures given by the Canadian standard CAN/CSA-A23.2-M90 but with increased cement content of 410 kg/m^3 concrete and prism dimensions of 100x100x400mm. After demoulding the prisms are stored in 100% humidity at 38°C with measurements up to one year.

If the expansion within one year exceeds more than 0.040% the aggregate is classified as deleterious.

ASSESSMENT OF AGGREGATE REACTIVITY

According to the DGB procedures aggregates are tested in two steps. The first step is the petrographic analysis. If less than 20 % of reactive + potentially reactive rock types is found, the aggregate is classified as innocuous and no further testing is necessary. If 20 % or more of reactive + potentially reactive rock types are found, a second step is recommended but not mandatory namely the South African accelerated mortar-bar test (NBRI). If the mortar bars expand more than 0.10% the aggregate is classified as reactive. According to the DGB recommendation the NBRI test overrule the result from the petrographic analysis.

The Canadian concrete prism test CAN3-23.2A-14A (step 3 in the NB 19 publication) is no longer recommended for testing of concrete aggregates. Several tests using this method on aggregates containing sedimentary rocks (e.g.sandstones) gave results which classified the aggregates as innocuous even when field experience showed the opposite. Therefore, the concrete prism method is no longer recommended for testing aggregates and was withdrawn from the DGB recommendations in 1993.

CORRELATION BETWEEN TEST METHODS

Where more than one test method is required to be used, as suggested by DGB, it is required that both methods classify aggregates in the same way and correlation occur between the methods. However, for geological materials which often are inhomogeneous and tested by different methods the correlation should not be expected to be high. For test methods where limits are specified results can be given by one of two statements, namely, - *yes* - the aggregate is reactive or - *no* - the aggregate is innocuous. In graphical plot lines of the limit values will depict four quadrants and four types of results or statements will be possible. In figs 1-4 it can be seen that analyze results which plots into the quadrants 1 and 3 gives the same answer by both methods. In quadrant 1 both methods classify the material as reactive and in quadrant 3 as innocuous. On the other hand in the quadrants 2 and 4 the methods gives opposite answers.

Results from the petrographic analyses, NBRI mortar bar tests and CAN 3 concrete prism tests on Norwegian concrete aggregates are shown in Figs 1-4. The figures are in many ways self-explaining.

Petrographic analysis versus CAN 3-A23.2-14A

Figure 1 shows the relationship between the petrographic analysis and the concrete prism test CAN 3-A23.2-14A. The four quadrants are defined by the value 20% reactive aggregate and 0.040% expansion of one year.

In Figure 1 the scatter of results and lack of correlation between the two methods are apparent. The majority of samples fall into the quadrant 4. Only a few samples correlate by falling into the quadrants 1 and 3. The majority of sedimentary rocks (filled triangles) give low expansions even when large amounts of reactive aggregates occur in the samples. Several of the sedimentary aggregates depicted in fig 1 come from deposits which have caused AAR in structures. Only one sample, a sedimentary rock composed of impure carbonaceous rock (metamarl) was classified reactive as known from field experience. It can be concluded the results show poor correlation between the petrographic analysis and the CAN 3-A23.2-14A concrete prism test and the CAN 3-A23.2-14A method.

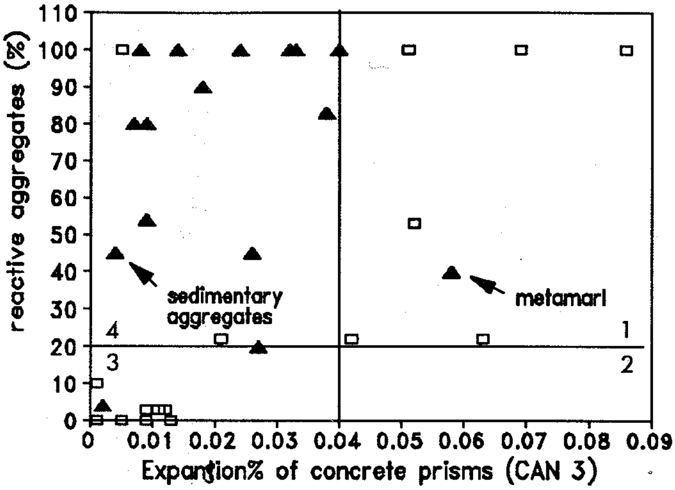

Fig. 1 Petrographic analysis versus CAN 3-A23.2-14A (34 samples)

NBRI versus CAN 3-A23.2-14A

Figure 2 shows the relationship between the South African accelerated mortar bar test NBRI and the CAN 3-A23.2-14A concrete prism test. The four quadrants are defined by the values 0.10% NBRI (14 days) and 0.040% CAN 3 (one year).

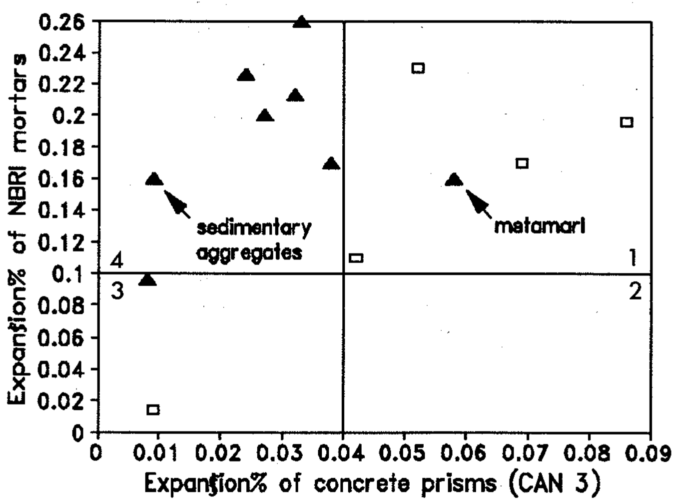

Fig. 2 NBRI mortar bar test versus CAN 3-A23.2-14A concrete prism test (13 samples)

In Figure 2 the scatter of results and lack of correlation between the two methods is apparent. Based on the 13 samples it can be concluded that there are poor correlation between the NBRI method and the CAN 3-A23.2-14A method.

Petrographic analysis versus NBRI mortar bar test of natural aggregates

Figure 3 shows the relationship between petrographic analysis and the NBRI mortar bar test of natural sand and gravel (crushed to give the NBRI grading). The four quadrants are defined by the values 0.10% NBRI (14 days) and 20% reactive aggregates.

In Figure 3 all 47 samples fall into the quadrant 1 and 3 and there is good correlation between the two methods. The correlation coefficient R^2 is only 0.46 which is rather low but not unexpected when the variability of natural aggregates is taken in account (note that the regression line goes through the intersection of limits).

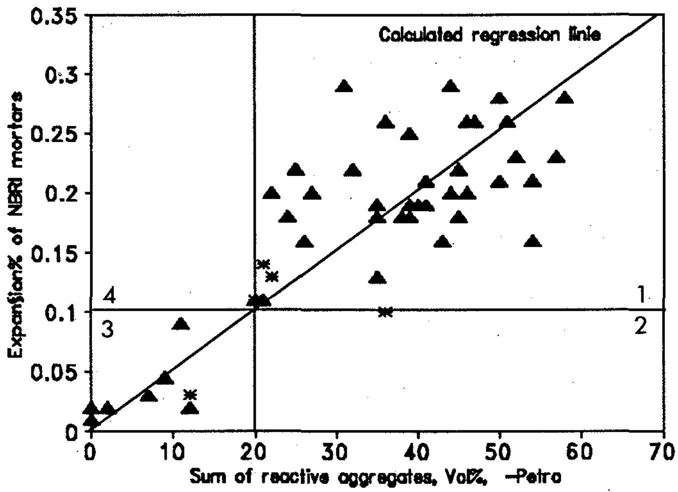

Fig. 3 Petrographic analysis versus NBRI mortar bar test of 47 natural sand and gravel.

Petrographic analysis versus NBRI test with crushed aggregates

Crushed aggregates are normally tested by petrographic analysis to identify if the aggregates are reactive. In some cases crushed aggregates are tested by the NBRI mortar bar method, too. So far there is good correlation between the two methods. This applies to for both innocuous and reactive aggregates. Testing of hornfels by the NBRI method has revealed both innocuous and reactive hornfelses. Reactive hornfels contain cryptocrystalline-microcrystalline quartz which is often difficult to identify by the petrographic analysis but is detected by the NBRI method.

Petrographic analysis versus NBRI test with blended natural/crushed aggregates

Figure 4 shows the relationship between petrographic analysis and the NBRI mortar bar test on blends of two natural sands, natural sand with crushed gravel and natural sand with crushed rock.

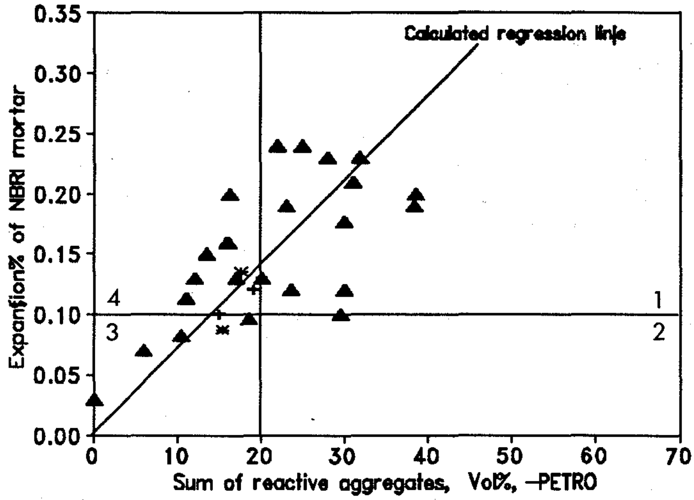

Fig. 4 Petrographic analysis versus NBRI test with 27 blends of natural/crushed aggregates.

In Figure 4 the results indicate only moderate correlation between the two methods as a number of points fall into quadrant 4. A regression analysis on 27 samples gives a regression coefficient R^2 of 0.49. Note that the regression line of the blended materials has a steeper inclination compared to natural aggregates shown in Figure 3. The reason why blends of natural aggregates and crushed rocks show poorer correlation between the petrographic method and the NBRI mortar bar test are unknown.

DISCUSSION

The research project carried out by SINTEF in 1990-1993 showed that the NBRI method was in good agreement with field experience and the CAN 3 concrete prism test was only in agreement with some types of aggregates and failed to detect reactive sandstone and phyllite. The results presented in this paper clearly suggest that the CAN 3-A23.2-14A concrete prism method does not correlate with the Norwegian petrographic analysis and the NBRI mortar bar test and more important does not agree with field experience of sedimentary aggregates. It has to be mentioned that sedimentary aggregates, sandstones, siltstone, greywacke and argillite are very common in glacio-fluvial aggregate deposits and located over large areas of Norway.

The petrographic analysis determines rock aggregates which by field experience have caused AAR in concrete structures and correlates with the NBRI test. The validity of the limit on 20 volume% reactive + potentially reactive aggregates recommended by the Norwegian Concrete Society (NB 19) and DGB can be discussed. However, for natural aggregates and crushed unmixed aggregate we have at present time not any disagreement between laboratory testing with the petrographic analysis and the NBRI method as well as field experience.

For blends of natural aggregates or natural aggregates with crushed aggregates where the amount of reactive particles have been diluted the NBRI method may give higher expansion than the 0.10% limit. This can occur even where there is less than 20 volume% reactive aggregates in the material as shown in Figure 4. The possible reason for this phenomena could be caused by pessimum relations as suggested by Shayan (1992) but could also be a testing problem caused by the NBRI method of blending materials.

It is important to note that all testing as well as the establishment of limit value in Norway with the NBRI method are based on the RILEM prism size of 4cm x 4cm x 16cm which differs from the ASTM C 490 prism size 2,5cm x 2,5cm x 28,5cm. Because the reaction in the NBRI test is influenced by diffusion of NaOH into the mortar bar the reaction will depend on the cross section of bars and the expansion time. This suggests that RILEM prisms will give lower expansion values relative to ASTM prisms at 14 days.

CONCLUSION

A combination of the Norwegian petrographic method of analysis and the South African accelerated test NBRI are presently the best tools to assess alkali reactive Norwegian slow/late expansive aggregates.

ACKNOWLEDGEMENTS

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