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Regionalne specifikacije in priporočila za preprečitev škodljivih alkalnosilikatnih reakcij v betonu

Regional Specifications and Recommendations for the avoidance of damaging alkali silica reactions in concrete

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Regional Specifications and Recommendations for the avoidance of damaging alkali silica reactions in concrete

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CEN

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Regional Specifications and Recommendations for the avoidance of damaging alkali silica reactions in concrete

Introduction

Several European countries have experienced damage to concrete as a result of alkali silica reaction and have developed specifications and test methods to avoid further problems. A few have developed such specifications in advance of identifying any damage. Others have identified damage only recently and have yet to develop solutions. Some have no identified problems and have felt no need for any specifications.

The situation in Europe is therefore complex and this reflects the major differences in geology and climate. In view of this it has been decided that at this stage it is not realistic to seek totally harmonised specifications and test methods to avoid damaging alkali silica reaction. Broad guidance on principles can be given and a more realistic longer term objective may be to develop harmonised solutions for specific aggregate types.

At this stage in the development of European standards it is felt that a guidance document summarising National Standards and Recommendations based on regional long term experience with local aggregates and materials is the most useful step that can be taken. This will be valuable to countries importing aggregates or buying aggregates from other regions and for contractors working in other parts of Europe.

Overall Principles

There is general agreement on the main mechanisms underlying alkali silica reaction problems and on the broad principles of preventing damaging reactions.

Alkali silica reaction (ASR) is the most common of a family of reactions which are generically termed alkali aggregate reactions. The other main type of reaction is alkali carbonate reaction which has been a major problem in, for example, Canada but has not been recognised as a significant problem in Europe.

Alkali silica reaction is a reaction between siliceous aggregates and the alkaline pore solution in mortar or concrete. The reaction produces an alkali silicate gel which absorbs water producing an expansive force which can crack the mortar or concrete.

The alkalinity of the pore solution is a normal result of the hydration of Portland cements. The alkali content of the cement and the cement content will primarily determine the level of alkalinity. Alkalis from other sources such as additions (flyash, slag etc) seawater, deicing salts or certain types of aggregate can also influence the pore solution alkalinity but there is no general agreement on how to take these into account.

Cement additions such as flyash, ground granulated slag, silica fume or natural pozzolanas are used quite widely to combat ASR damage. There is however no general agreement on how to include those in specifications or how to take into account their alkali content.

The reactivity of siliceous minerals in aggregates vary markedly. In general the finer and more disordered the silica crystal the greater its vulnerability to alkalis. Thus well crystallized quartz is very resistant whereas opaline silica is extremely reactive. Flints and cherts are common reactive rock types in Europe. In Denmark and Northern Germany there are opaline forms of silica. Other reactive rock types are acid volcanic rocks, siliceous limestones and greywackes.

An important factor determining the reactivity of some aggregates is the proportion of siliceous material. It is a characteristic of the reaction that the most damaging expansion is produced when a particular proportion of siliceous material is present. When the proportion of the siliceous material is lower or higher the expansion decreases and may be insignificant at high proportions. In some cases for very reactive forms of silica this critical proportion (sometimes called the 'pessimum') may be only a few percent of the aggregate whereas for less reactive forms of silica it may be when the siliceous material forms the entirety of the aggregate. Some countries exploit this to classify aggregates with high contents of eg flint as not needing further precautions against ASR damage.

Therefore for damage from ASR to occur the following must all be present:

- a high alkalinity in the concrete
- a sufficient amount of reactive silica
- availability of moisture.

In one way or another all the specifications designed to avoid ASR damage therefore seek to exclude one or more of these three factors.

Current experiences of ASR in Europe

We do not yet have information from every country but all the countries who have well developed specifications to avoid ASR damage have contributed summaries of their national experience and specifications. These follow below.

Of the countries about which we do have information neither Austria nor Finland have identified any damaging alkali silica reactions and neither have any specifications or recommendations. No cases have been identified in Ireland either but because of their consciousness of ASR problems in the UK recommendations have been developed by the Irish industry and they are detailed below.

In Portugal, Switzerland and Spain a very few cases of damage have been recorded. In Switzerland these were in old dams and became manifest between 30 and 60 years after the concrete was placed. In Portugal old dams have also been affected together with a concrete pavement and viaduct. In Spain road pavements, industrial pavements, tunnel linings and precast elements have been affected. In none of these countries are there any specifications specifically covering ASR.

In Belgium limited problems have been identified in recent years in bridges and road pavements. There is a national standard for low alkali cements and an adaptation of the guidance in ENV 206 in the concrete standard.

Experience of ASR in the Netherlands is both new and limited. They have identified about ten problems with an indigenous flint aggregate but their main concern is imported aggregate. Recommendations on avoiding damage have been published recently.

In Denmark where problems became apparent in the 1950's a high proportion of aggregates are potentially reactive with the main problems centring around flints and to a lesser extent opaline limestone. Aggregates are tested constantly and often stock-piled to overcome variability problems. A suite of tests for aggregate reactivity including petrography, mortars immersed in sodium chloride at 50° C, chemical shrinkage and measurements of density and water absorption has been evolved. Several of the tests are only used in Denmark. The allowable alkali in the concrete then depends on both the reactivity of the aggregate and the environment to which the concrete will be exposed. Consequently both materials suppliers and users have necessity to work within a fairly sophisticated system where information on aggregate reactivity and alkali levels in aggregates and cements are readily available and used in determining the appropriate concrete.

In contrast, in Germany, opaline sandstone has been the main reactive aggregate type and this is found in a fairly localised area of North Germany. Control centres around the identification of the suspect aggregate using a test regime evolved specifically for these aggregates. This regime includes both density measurements and solubility in alkaline solution. Early use of internationally acknowledged ASTM tests identified, as reactive, aggregates which use had shown to be satisfactory so it was necessary to evolve a specific test. Recently problems with greywacke aggregates have also been identified.

In France there have been problems in highway structures containing flints and also silicified limestones. These have been in the wetter north of the country and it is generally considered that concrete in the drier south is unlikely to have ASR problems. However, there have been problems with dams in the south and in these cases it is believed that the aggregates have contributed significant amounts of alkali to the concrete. Again a number of specific test methods have been evolved including a performance test for the concrete in which the concrete mix is stored at 60° C. It has been found necessary to modify existing tests so as to correlate them with French experience in the field.

The reactivity of young volcanic rocks together with severe driving rain has produced particular problems in Iceland but these have been largely overcome by the inclusion of silica fume in the Icelandic cement. Much attention has also been given to measures to reduce moisture ingress in order to minimise problems from pre-existing ASR.

Most of the ASR problems in Sweden relate to flints in the limestone bedrock in the south of the country and are akin to those in Denmark and northern Germany. There are no specifications in Swedish standards but guidance from the concrete industry focusses on the identification of potentially reactive aggregates.

Alkali silica reaction has only been identified as a problem in Norway fairly recently. The reaction is of the slow/late expanding type and damage has been observed in dams, hydroelectric plants and bridges. Guidance is given by the Norwegian Concrete Society and focusses on the classification of aggregates according to the environmental conditions and the end use of the concrete.

Alkali silica reaction has been identified as the cause of damage in a variety of structures and pavements in Italy. The cases are mainly localised on the Adriatic side of the country and are often in marine environments. Prevention focuses on identifying vulnerable aggregates. These have mainly been flints and opal in sands and gravels. Where these are present cement additions are extensively used to produce safe cement/aggregate combinations.

Problems in the UK centre around flints and cherts in sand and gravels, mainly in the south of the country. These are denser flints than those in Denmark and occur widely. Consequently specifications have evolved to enable the safe use of reactive aggregates rather than to exclude them and aggregate testing is mainly of the coarse and fine aggregate combination in concrete specimens in order to identify safe combinations. Because of the pessimum behaviour of these flints/charts a commonly used safe combination is when the sand and gravel containing flint are used together so that the total aggregate contains more than 60% flint or chart. In practice because of the lack of experience with tests for aggregate reactivity and the high proportion of aggregates which contain potentially reactive siliceous rocks, there is emphasis on limiting the alkali level in cements and concretes.

National Specifications and Recommendations

Summaries of the specifications and recommendations in the following countries are given:

Belgium

Denmark

France

Germany

Iceland

Ireland

Italy

Netherlands

Norway

Portugal

Sweden

United Kingdom

Where possible a flow chart which summaries the decision making process in that country is included.

It is planned to include summaries for further countries as information becomes available.

BELGIUM

Introduction

Limited problems of damage from ASR have been identified in recent years, mainly in bridges and road pavements.

Specifications against ASR

The primary precaution against ASR damage is the use of low alkali cements according to the new Belgian standard, NBN B 12-109 (1), which covers both Portland (CEM I) and slag (CEM III) cements and defines the following limits:

Category and class of the cement	Alkali limit in the cement (Na_2O equivalent % by mass)
CEM I	≤ 0.6
CEM III A	≤ 0.9 (slag < 50%) ≤ 1.1 (slag ≥ 50%)
CEM III B and C	≤ 2.0

The Belgian concrete standard (NBN B 15-001 (2)) which is the national adaptation of ENV 206 also gives the following guidance:

Some aggregates containing particular varieties of silica are susceptible to attack by alkalis originating in the cement or from other sources. In humid conditions this can produce an expansive reaction leading to cracking or movement of the concrete. In such conditions one or more of the following precautions should be taken;

- limit the total alkali content of the concrete mix, depending on the type of cement used,
- use a low alkali cement (according to NBN B 12-109),
- change the aggregates,
- limit the degree of saturation of the concrete, for example by using an impermeable membrane.

If the route of limiting the total alkali in the concrete is followed the following limits apply:

Category and class of the cement	Alkali limit in the concrete kg Na_2O eq/m^3
CEM I	≤ 3
CEM III A	≤ 4.5 (slag < 50%) ≤ 5.5 (slag > 50%)
CEM III B and C	≤ 10

References

1. NBN B 12-109 Cement - Low alkali limited cement.
IBN September 1993.

2. NBN B 15-001 Concrete - Performance, production placing and compliance criteria.
IBN March 1992.

DENMARK

Introduction

Denmark is in the most unfortunate situation that a large number of aggregate sources all over the country contain reactive components. The first description of the effects which could be attributed to ASR was reported in 1914. Systematic research on ASR was started in 1951. The research on ASR in Denmark can broadly be divided into two phases - those carried out before 1970 and those afterwards, with fairly clear difference in their research philosophies [1].

In the first phase flint and opaline limestone were identified as the most prevalent reactive aggregate types in Denmark. The reactive components were found in both sand and gravel fractions of many aggregate sources. Suggested preventive measures were the use of low-alkali cement and/or the use of aggregates containing less than 2% reactive component. At this stage the basic assumption was that the alkali content of concrete is determined by that of the cement and the alkalis are evenly distributed.

The second phase of alkali-silica research started with an investigation of concrete roads which had deteriorated within 4 years of their construction. This investigation showed that extensive ASR had taken place although the coarse aggregate was non-reactive granite and the cement contained about 0.6% eq. alkali. It was the result of an interaction between the deicing salt and reactive silica present in the sand. The explicit assumption of this phase of research was that the structures often receive alkalis from outside sources and that there is nearly always a concentration gradient of alkalis in any structure.

Specifications against ASR

The development of ASR and cracking of concrete depends primarily on the following parameters:

1. The environmental condition (temperature, humidity, salt).
2. The alkali content of the concrete.
3. The type and content of the reactive silica in the aggregate.
4. The quality of the concrete (strength, w/c, air content).

The Danish specifications against ASR are given in "Basisbeton-beskrivelsen" (BBB) [2] based upon the above-mentioned parameters in 1., 2. and 3.

Environment Classification : The requirement refers to three environmental classes, characterised by different degrees of aggressiveness commonly found in Denmark:

Passive environmental class. Comprises dry, unaggressive environment, i.e. particularly an indoor climate.

Moderate environmental class. Comprises moist, outdoor and indoor environment and flowing and standing fresh water.

Aggressive environmental class. Comprises environment containing salt or flue gases, seawater or brackish water and environments where deicing salt is being used.

In addition severely aggressive environments where special precautions have to be taken, for example swimming pools, are defined.

Aggregate classification The aggregates are classified in 3 groups:

Class P for use in passive environment
Class M for use in moderate environment
Class A for use in aggressive environment.

The classification of the sand with regard to alkali silica reactive components is shown in the table below. The methods used are the petrographic thin-section point count method TI-B52 and the mortar bar expansion test TI-B51. These 2 methods are described below. For the coarse aggregate the amount of reactive aggregate is limited by the allowable amount of particles with a density below 2400 kg/m^3. Furthermore, there is a limit on the water absorption of the flint with density larger than 2400 kg/m^3. This value is determined on those 10% of the flint with highest amount of porous crust.

Classification Sand			
	Class P	Class M	C Class A
Volume reactive flint - % TI - B52	No requirement	Max. 2%	Max 2%
Mortar bar expansion at 8 weeks % TI - B51	No requirement	Max. 0.1%	Max. 0.1%

Classification Coarse Aggregate			
	Class P	Class M	Class A
Particle density below 2400 kg/m³ %	No requirement	Max. 5.0%	Max 1.0%
Absorption %	No requirement	Max. 2.5%	Max. 1.1%

Alkali Content in Concrete The alkali content in the concrete should be calculated as the sum of the acid soluble equivalent Na_20 content in the cement (obtained from cement supplier), the water soluble eqivalent Na_20 content in the sand and coarse aggregate (obtained from the aggregate supplier) and the equivalent Na_20 content in the admixtures (obtained from the admixture supplier). The alkali content from fly ash (PFA) and microsilica are not included.

Requirements

The requirements depend on the environmental class and are given in the table below. For severely aggressive environment no requirements are given in the Danish regulations. For example a proposal for requirements for swimming pools are given in [5].

Requirements			
Property	Passive Environment	Moderate Environment	Aggressive Environment
Alkali content in cement - %	No	≤ 0.8[1)]	≤ 0.8[1)]
Alkali content in concrete - kg/m³	No	≤ 3.0[1)]	≤ 3.0[1)]
Sand class	No	M[2)]	A
Coarse aggregate class	No	M	A

Notes to Table:

1) Alkali content in the cement may be higher than 0.8% and the alkali content in the concrete may be higher than 3.0 kg/m^3 if the following conditions are fulfilled:
Sand: Class A + expansion max. 0.1% after 20 weeks (or max. 1.0% reactive aggregates).

   Coarse aggregate: Max. 1.0% with density below 2500 kg/m^3.

2) Class P sand is allowed if the alkali content in the cement is max. 0.6% and the alkali content in the concrete is below 1.8 kg/m^3.

Assessment of Aggregate Reactivity

The following test methods are used:

1. The alkali-silica reactivity of sand.
   TI-B 51.

   Principle : Prisms (40 x 40 x 160 mm) made from mortar, consisting of one portion by weight of cement and three portions by weight of the sand to be tested. The w/c ratio is 0.50. The prisms are water cured for 28 days and then put into a saturated sodium chloride solution at a temperature of 50°C.

   The linear expansion of the prisms is measured for 8 weeks, or alternatively for 20 weeks, after they have been put into the saturated sodium chloride solution.

   Use : The method should be used for the relative comparison of the alkali-silica reaction of different sands tested, making it possible to choose the sand that will result in the smallest expansion.

   Test result : Mortar prism expansion.

2. Petrographic investigation of sand.
   TI-B 52.

   Principle : Fluorescent impregnated thin sections made from epoxy encased sand, which is to be tested, are analysed using a polarizing microscope to determine the mineralogy of the individual grains of sand.

   Use : The method is used to determine the mineralogical composition of sand for the specific purpose of determining the quantity of alkali reactive material, i.e. porous flint and opal lime.

   Test Result : Distribution of rock minerals and content of reactive materials.

In addition the reactivity may be determined by the socalled "chemical shrinkage" method when the relations to one or both of the two above-mentioned methods have been documented.

References

[1] "The Alkali-Silica Reaction in Concrete",
Edited by R.N. Swamy 1991, chapter 6 Alkali-silica reaction - Danish experience.

[2] "Basis Concrete Specifications for Building Structures", National Building Agency 1988.

[3] Test Method TI-B51 "Alkali Silica Reactivity of Sand" (in Danish), Technological Institute, Copenhagen.

[4] Test Method TI-B52 "Petrographical Investigation of Sand" (in Danish), Technological Institute, Copenhagen.

[5] Beton-Teknik "Sv¢mmebassiner", Aalborg Portland/CtO, 1992.