P. Pimienta, B. Albert, B. Huet, M. Dierkens, P. Francisco, P. Rougeau, Durability performance assessment of non-standard cementitious materials for buildings: a general method applied to the French context, RILEM Technical Letters (2016) 1: 102 – 108, DOI: http://dx.doi.org/10.21809/rilemtechlett.2016.17
Supplementary Materials..

Fact sheet 8
Risk of degradation by an Alkali-Silica Reaction (ASR)

1. Introduction

Alkali reactions are a range of reactions between certain soluble forms of silica or silicates and the alkali present in concrete in presence of water. This reaction creates an expansive gel that, in extreme cases, can destroy parts of the structures it affects. The general procedure for preventing this reaction is described in FD P 18464 [1].

2. Consequences

- Large and deep cracks in the affected concrete elements.
- Very significant loss of mechanical properties.
- Increased risk of steel corrosion due to concrete cracking and failure of reinforcement.

3. Physiochemical mechanisms

Current work highlights the importance of the mechanisms described below.

Solubility of certain unstable forms of silica or silicates in alkaline environment.
The FD P 18 542 [2] documentation booklet details how aggregate is classified into three categories: non-reactive (NR), potentially reactive (PR), and potentially reactive with pessimum effect (PRP). For this last category, the risk is only present when soluble silica content falls within certain "pessimal" critical value ranges.

This classification is done based on some or all of the following criteria:
- silica content
- petrographic analysis
- performance testing (screening test or long-term test).

Quantity of accessible alkalis.
Risk exists above ~3 kg of alkaline equivalents per cubic metre of concrete (taking K and Na into account). The alkalis that may contribute to these reactions are those present in the interstitial solution, which may come from any of the constituents (binder, mineral additive, admixture, aggregate, etc.).
Some environments, such as marine environments or those where de-icing salts are used are more aggressive because they enrich the concrete's interstitial solution with alkalis.

Presence of liquid water.
If, in the months and years after its placing, the material comes into frequent contact with free water (stagnant water, a immerged element, etc.), an expansive silico-calco-alkaline gel forms. In this instance, the cement paste is subject to generalised expansion that leads to cracking. This reaction is generally quite slow and the first signs of structural degradation often do not appear for at least 10 years.

4. Main models

The RGIB model [3], which is part of the César-LCPC calculation code [4] is an example of a model that describes the structural expansion associated with ASR.

5. Influential parameters

"Material" parameters:
- Quantity and stability of the aggregate silica in a basic medium: aggregate classification into NR, PR, or PRP.
- Total alkaline equivalents generated by all components that may be found in solution and may be available for reactions (total calculated using the instructions given in FD P 18 464 [1]).
- Amount of binder, which is generally the main source of alkalis.
- Mineral additives, depending on their nature and amount, which may reduce or even counteract this phenomenon. The most effective additives are low-calcium silico-aluminous fly ash, blast furnace slag, and metakaolin. s

"Environment" parameters:
- Wetting/drying frequent cycles or constant contact with free water.
- Ingress of alkalis from external sources (de-icing salts, marine environment).

P. Pimienta, B. Albert, B. Huet, M. Dierkens, P. Francisco, P. Rougeau, Durability performance assessment of non-standard cementitious materials for buildings: a general method applied to the French context, RILEM Technical Letters (2016) 1: 102 – 108, DOI: http://dx.doi.org/10.21809/rilemtechlett.2016.17
Supplementary Materials..

6. Testing method stages

There are two scenarios to distinguish: the measurement of an aggregate's reactivity (or that of any other type of component) in relation to the alkali reaction, or the measurement of the dimensional stability of cement based material, made with alkali-reactive aggregate. The quantity of interest is the dimensional variation of the test samples (swelling).

- Qualitative assessment of an aggregate:

The principles used to qualitatively assess aggregates are described in FD P 18 542 [2]. This booklet proposes two methodologies, one based on physio-chemical characterisation of the aggregate (petrographic methods along with chemical analyses), and the other based on dimensional stability tests. Dimensional stability tests involve a long-term test done on standard concrete (see Table 1), or two screening tests, which allow for faster results as long as the test results agree. In the case of standard materials, screening tests may be given preference. In the case of innovative materials, it is preferable to carry out a long-term concrete test.

- Qualitative assessment of a cement material:

Even if a material contains alkali-reactive aggregates, it can be formulated in order to reduce the alkali reaction process, eliminating harmful swelling. It is possible to approve a new product directly using a dimensional stability test (Table 2). These tests involve recording the dimensional variations in material samples over time. After they are withdrawn from the mould, samples are kept in a humid environment and at a temperature above 20°C to speed up the process, if it is to take place. The 38°C test (RILEM [6]) is used as a reference and should be used if there is any doubt about the mechanisms involved. When dealing with conventional mechanisms, it is possible to use the 60°C accelerated test (NF P 18 454 [7]).

In both scenarios, dimensional variations in the samples are influenced by:

- the type of sample:
  - prism size, which should be adapted depending on the test,
  - composition (mortar or concrete),
- the testing conditions:
  - alkali content, with increasing or corrected content, depending on the test
  - temperature, humidity, pressure,

The quantity of interest is the dimensional variation of the test bodies over time. The duration of the test may be adapted depending on the composition of the material being tested.

7. Standard testing methods

Table 1: qualitative aggregate testing

Name	Initial treatment	Preservation	Test duration	Threshold	Comment
NF P18-594 [5] Accelerated test in an autoclave	24 hours, RH=90% 20°C + 48 hours submerged in water at 20°C	5 hours at 127°C, RH=100% P= 0.15 MPa	5 days	Average deformation value.	40x40x160 mm test on standard mortar control screen grid test
NF P18-594 [5] Microbar Test	steam cure: 4 hours in steam at 100°C	alkaline curing: 6 hours at 150 °C in 10% KOH	1 day	Average deformation value.	10x10x40 mm test on standard mortar screen grid test
NF P18-594 [5] Testing on concrete		38°C RH=100%	8 months	Average deformation value	70x70x280 mm long-term test on standard concrete. added alkalis (NaOH added to reach 1.25% Na_2O equivalent)

P. Pimienta, B. Albert, B. Huet, M. Dierkens, P. Francisco, P. Rougeau, Durability performance assessment of non-standard cementitious materials for buildings: a general method applied to the French context, RILEM Technical Letters (2016) 1: 102 – 108, DOI: http://dx.doi.org/10.21809/rilemtechlett.2016.17
Supplementary Materials..

Table 2: testing on concrete

Name	Initial treatment	Preservation	Test duration	Threshold	Comment
NF P 18 454 [7] FD P 18 456 [8]	In moulds at 20 ±2°C for 24 ±2 hours Immersion for 30 ±5 minutes in water at 20 ±2°C.	60 ±2 °C In reactors with an atmosphere of saturated humidity.	Between 3 and 12 months depending on the type of components and the intermediate testing results.	Changes in average values and individual deformation values depending on the type of components	70x70x280 mm Taking into account the components' alkali content variability.
AAR-3 RILEM Method [6, 9, 10]		38°C RH=100%	12 months	Measurement of expansion.	75x75x250 mm addition of alkalis (5.5 kg/m^3 of Na_2Oeq)

8. Performance assessment

Assessment method:

- "absolute" assessment: quantity of interest should conform to the thresholds from test NF P 18 454 [7] with interpretation according to FD P 18 456 [8].

9. References

[1] FD P18-464:2014. Béton - Dispositions pour prévenir les phénomènes d'alcali-réaction, 2014.
[2] FD P18-542:2015 Granulats - Critères de qualification des granulats naturels pour béton hydraulique vis-à-vis de l'alcali-réaction, 2004.
[3] N. Baghdadi, Modelisation du couplage chimico-mecanique d'un beton atteint d'une reaction sulfatique interne, ENPC, 2008, pp. 248.
[4] P. Humbert, A. Dubouchet, G. Fezans, D. Remaud, CESAR-LCPC, un progiciel de calcul dédié au génie civil, Bulletin des Laboratoires des Ponts et Chaussées, Bulletin des Laboratoires des Ponts et Chaussées, (2005) 7-37.
[5]NF P18-594:2015.Granulats - Méthodes d'essai de réactivité aux alcalis, 2013.
[6] B - TC 106-3 - Detection of potential alkali-reactivity of aggregates - Method for aggregate combinations using concrete prisms, Materials and Structures, 33 (2000) 290-293.
[7] NF P18-454:2004.Béton - Réactivité d'une formule de béton vis-à-vis de l'alcali-réaction - Essai de performance, 2004.
[8] FD P18-456:2004.Béton - Réactivité d'une formule de béton vis-à-vis de l'alcali-réaction - Critères d'interprétation des résultats de l'essai de performance, 2004.
[9] A - TC 106-2 - Detection of potential alkali-reactivity of aggregates - The ultra-accelerated mortar-bar test, Materials and Structures, 33 (2000) 283-289.
[10] Rilem TC 106-AAR: Alkali-aggregate reaction, Materials and Structures, 33 (2000) 283-283.