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REPORT

PARTNER

Report 3.1

Experience from using petrographic analysis according to the RILEM AAR-1 method to assess alkali reactions in European aggregates

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SINTEF Building and Infrastructure
Concrete

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TITLE

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Experience from using petrographic analysis according to the RILEM AAR-1 method to assess alkali reactions in European aggregates

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ABSTRACT

This report describes the results of an evaluation of the use of the petrographic method, developed by RILEM as AAR-1, to assess the alkali reactivity of European aggregates. It is one of a series of such evaluations, carried out under Work Package 3 in the PARTNER programme. The overall experience from the testing program is that the spread in results between the laboratories for about half of the aggregate types tested is very high, also between some of the six laboratories performing the test on a regular basis. However, for four of the most experienced laboratories the majority of the reported results seem to be more reliable.

With two exceptions the average results from the petrographic analyses of the 22 aggregate types correlate very well with the reported field performance.

Some recommendations to the RILEM AAR-1 method are given. In addition the results revealed the following main issues to be dealt with and solved if the AAR-1 method aims to be a widely used and reliable testing method to assess the alkali reactivity of aggregates both within Europe and world wide:

- The importance of education and round robin testing
- The importance of experience, both with the method and with the actual local aggregates
- The importance of calibrating the results with other RILEM methods and with field experience to be able to establish critical limits for acceptable content of suspicious rock types in different aggregate types
- The importance of accuracy, quality control and system for approval of laboratories and petrographers.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Materials technology	Materialteknologi
GROUP 2	Concrete	Betong
SELECTED BY AUTHOR	Alkali aggregate reactions	Alkalireaksjoner
	Aggregates	Tilslag
	Test methods	Prøvingsmetoder

PARTNER

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Report 3.1

Experience from using petrographic analysis according to the RILEM AAR-1 method to assess alkali reactions in European aggregates

Preface

This report is one of a series produced as output from PARTNER, a project funded by the European Community under the "Competitive and Sustainable Growth" programme.

The overall objective of this project is to provide the basis for a unified test procedure for evaluating the alkali reactivity of aggregates across the different European economic and geological regions. It will enable CEN TC-154, Aggregates, to fulfil the requirements of the Aggregates Mandate, M125, which identifies durability against alkalis as a necessary performance characteristic in the specification of aggregates for concrete (EN 12620) to meet the Essential Requirements of the CPD for Strength and Safety. The project will achieve this by:

- Evaluating the tests developed by RILEM, and some regional tests, for their suitability for use with the wide variety of aggregate and geological types found across Europe.
- Calibrating the results of these accelerated tests against behaviour in concrete in real structures and in field sites.
- Producing an "atlas" of the geology and petrography of European aggregates.
- Educating European petrographers and testing organisations in the effective use of these methods.
- Making recommendations, based on the above work, to CEN for suitable CEN methods of test and specifications to ensure durability against alkalis.

The project has 24 Partners from 14 countries, covering most of Europe, from Iceland to Greece.

Partners

BRE .... UK
PC Laboratoriet A/S .... DK
SINTEF .... NO
SP - Swedish National Testing and Research Institute .... SE
RAMBOLL .... DK
ISSeP – Institut Scientifique de Service Public .... B
LCPC Laboratory .... F
VDZ – German Cement Works Association .... D
TITAN Cement Company, S.A .... EL
LABEIN .... ES
CRIC – Centre National de Recherches Scientifiques et techniques pour
L'Industrie Cimentière .... B
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NORCEM A.S .... NO
CESI I
VOZ – Austrian Cement Association .... A
IBRI – Icelandic Building Research Institute
STATS .... UK
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DANISH TECHNOLOGICAL INSTITUTE .... DK
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ANEFA .... ES
Cemex .... ES
HOLCIM .... B
Hönnun .... IS

List of available reports in the PARTNER project

WP 2: Aggregates and structures (leader: RAMBÖLL)

Report no.	Report title	Author
2.1	State-of-the art report: Key parameters influencing the alkali aggregate reaction SBF52 A06018 / ISBN 82-14-04078-7 / 978-82-14-04078-7	Hönnun, RAMBÖLL, SINTEF

WP 3: Test methods (leader: SINTEF)

Report no.	Report title	Author
3.1	Experience from using petrographic analysis according to the RILEM AAR-1 method to assess alkali reactions in European aggregates SBF52 A06019 / ISBN 82-14-04079-5 / 978-82-14-04079-5	SINTEF
3.2	Experience from testing of the alkali reactivity of European aggregates according to the RILEM AAR-2 method SBF52 A06020 / ISBN 82-14-04080-9 / 978-82-14-04080-9	PC-lab
3.3	Experience from testing of the alkali reactivity of European aggregates according to several concrete prism test methods SBF52 A06021 / ISBN 82-14-04081-7 / 978- 82-14-04081-7	BRE
3.4	Experience from testing of the alkali reactivity of European aggregates according to two Danish laboratory test methods SBF52 A06022 / ISBN 82-14-04082-5 / 978- 82-14-04082-5	RAMBÖLL
3.5	Field site tests established in the PARTNER project for evaluating the correlation between laboratory tests and field performance SBF52 A06023 / ISBN 82-14-04083-3 / 978- 82-14-04083-3	VDZ

WP 4: Precision trials (leader: SP)

Report no.	Report title	Author
4.1	PRECISION TRIAL – Determination of repeatability and reproducibility of the amended RILEM methods SBF52 A06024 / ISBN 82-14-04084-1 / 978-82-14-04084-1	SP

WP 5: Dissemination (leader: PC-lab)

Report no.	Report title	Author
	Final results and recommendations of the PARTNER project. Paper to be published at ICAAR 2008, Trondheim, Norway	BRE + several co-authors
	Database / atlas of the alkali reactivity of European aggregates Published by Geological Survey of Belgium *see www.aarig.org/webatlas/atlas.htm*	PC-lab, ISSEP, Hönnun

Summary

This report describes the results of an evaluation of the use of the petrographic method, developed by RILEM as AAR-1, to assess the alkali reactivity of European aggregates. It is one of a series of such evaluations, carried out under Work Package 3 in the PARTNER programme.

In the work programme in task 3.1 22 selected aggregate types, both the fine and the coarse fraction, if available, were tested by petrographic examination. The prepared note gave instructions to each of the 13 participating laboratories which aggregate type to be tested at the specific laboratory and according to which of the three alternative procedures named “Whole rock petro”, “Particle separation” and “Point count analysis”, respectively. The note did not give any detailed instructions to the petrographers, but they could base their classification on the AAR-1 method, in addition to the national experience in the countries supplying the actual aggregate types. As a basis for calculating the total percentage of “reactive/possible reactive” rock types in an aggregate, each of the rock types detected should be placed in one of the three “reactivity classes”;

I. very unlikely to be alkali-reactive
II. alkali-reactive uncertain
III. very likely to be alkali-reactive.

SINTEF have collected the results from all the 123 single petrographic analyses, and put the data manually into an Excel worksheet. If some data were missing or seemed unreasonable, the actual laboratory was asked to look through the results once more and supply the requested information and/or revised results. This “second reporting round” improved the quality of the data supplied from many of the laboratories, but for some laboratories some information is still missing or is uncertain even after circulating a further request.

All the collected results are presented in detail in ANNEX 5. As an attempt to summarize all the results, SINTEF have also prepared two further sheets with the following content:

- Sum of rock types within the “reactivity classes” II and III, respectively
- Calculation of the *average, median, minimum* and *maximum* content of suspicious rock types with respect to ASR detected by the participating laboratories

The overall experience from the testing program is that the spread in results between the laboratories for about half of the aggregate types tested is very high, also between some of the six laboratories performing the test on a regular basis. However, for four of the most experienced laboratories the majority of the reported results seem to be more reliable.

With two exceptions the average results from the petrographic analyses of the 22 aggregate types correlate very well with the reported field performance.

The PARTNER project and the internal workshops in special have established a very good network of contacts between several experienced and inexperienced petrographers that may be helpful in the future to an informal education across the frontiers.

Some recommendations to the RILEM AAR-1 method are given. In addition the results revealed the following main issues to be dealt with and solved if the AAR-1 method aims to be a widely used and reliable testing method to assess the alkali reactivity of aggregates both within Europe and world wide:

- The importance of education and round robin testing
- The importance of experience, both with the method and with the actual local aggregates
- The importance of calibrating the results with other RILEM methods and with field experience to be able to establish critical limits for acceptable content of suspicious rock types in different aggregate types
- The importance of accuracy, quality control and system for approval of laboratories and petrographers.

Content

Annex

1. Introduction

This report describes the results of an evaluation of the use of the petrographic method, developed by RILEM as AAR-1, to assess the alkali reactivity of European aggregates. It is one of a series of such evaluations, carried out under Work Package 3 (task 3.1) in the PARTNER programme. The R&D programme has evaluated the tests developed by RILEM, and some regional tests, for their suitability for use with the wide variety of aggregate and geological types found across Europe and calibrated the results of these accelerated tests (9 in total) against behaviour in concrete in real structures and in field sites (cubes). The report is written by Jan Lindgård (jan.lindgard@sintef.no) and Marit Haugen (marit.haugen@sintef.no) from SINTEF in Trondheim, Norway.

2. Method

The petrographic method is a test method used as a "first step" to assess the reactivity of concrete aggregates. A detailed description of the RILEM petrographic method (AAR-1) was published in Materials and Structures in 2003 /1/.

The method is carried out by two mutually beneficial techniques; a standard petrographic examination of the aggregate particles and a detailed microscopical examination of thin-sections which may incorporate point-counting. An initial inspection of the aggregate material should be undertaken to assess which technique(s) should be employed.

This RILEM AAR-1 petrographic method allows for three different technique(s) / procedure(s) to determine the reactivity of a particular aggregate sample. These include:

1. The hand separation of aggregate particles by lithological characteristics prior to the production of any thin sections to determine that aggregates microscopical characteristics. This technique would be most appropriate with coarser gravel aggregates where the different constituent of an aggregate are easily separated by eye, colour, density, physical characteristics etc (i.e. porous flints, or light coloured limestones and dark coloured basalt in the same gravel). In such circumstances it may not be necessary to study thin-sections of selected aggregates to enable fuller identification of the material. After separation selected particles can if felt necessary then be thin sectioned to determine the microscopical reactivity related characteristics. This procedure is named "**Particle separation**" in this report.

2. Aggregates in which individual particle lithologies cannot be determined easily by either of the above or there is clear variability of reactivity between the different parts of the aggregate rock at a microscopical scale, then the pre-crushing (for coarse material) and point counting technique should be employed. The point counting method could be appropriate in determining the reactivity of a fine, varied aggregate sample too. This procedure is named "**Point count analysis**" in this report.

3. If a crushed rock aggregate has uniform characteristics for determination of its reactivity, for example a silicified limestone, greywacke, or a coarse holocrystalline granite, then a thin section of the total aggregate particles can be produced to determine lithological characteristics. This procedure is named "**Whole rock petro**" in this report.

All of these procedures are useful in establishing the reactivity of an aggregate, and none should be discounted as a technique of determining reactivity. The technique employed should be determined by an initial macro-examination of the aggregate sample received. In reference to the RILEM AAR-1 method it is not compulsory to have to use only one of these specified techniques.

Before the testing program started some of the experienced petrographers participating in the PARTNER programme produced a note describing how the tests should be performed in detail within task 3.1. The note is given in ANNEX 1. The note also included a test plan describing which procedure to be used in the examination of the different aggregate types at the different laboratories (see chapter 3), included which fractions to be examined.

For the **"Point count analysis"** technique the following procedure was described in the note (ANNEX 1): For the coarse fractions (> 4 mm) two thin sections of the fraction 2-4 mm (after crushing) should be prepared and analyzed. For the sand fractions (≤ 4 mm) two thin sections of the fraction 2-4 mm, one thin section of the 1-2 mm fraction and one thin section of the 0.063-1 mm fraction should be prepared and analyzed separately.

The point counting procedure is carried out by traverses in regular increments in two directions to form a virtual orthogonal grid. It is important that point-counting covers the whole thin-section. During the point-counting, the operator must identify and group all rocks and minerals located under the cross hairs at each point on the grid. Note that a minimum of 1000 points (excluding points falling on to resin) should be counted for all the counted fractions. Additionally the number of points may significantly exceed the number of particles, as several points may be counted across some larger particles.

Point-counting aims to identify and quantify both the reactive and the non-reactive rock and mineral particulate constituents present within an aggregate so that the content of reactive constituents can be determined. Suggestions for rock names are given in ANNEX 4 in the AAR-1 method /1/. During the point counting process there are two different "procedures" in use. In some countries it is common to determine the constituent and thus the reactivity assessment of the individual point which is directly under the crosshairs rather than a determination of the reactivity for that entire particular aggregate particle. An evaluation of the reactivity of the whole particle is, however, common to use in some countries (for instance in Norway). This method is also used by petrographers in some of the other countries for some rock types, for instance sandstone. All cross points placed within the sandstone particle is then recorded as sandstone. However, when particles consist of more than one type of rock e.g. sandstone with quartz vein, the cross point falling on to the sandstone should be recorded as sandstone, and cross points falling on to quartz vein should be recorded as quartz vein material. To determine which procedure to be used, the experience with the aggregates within each country should be taken into account.

When reporting the results in the PARTNER programme the operator should report which procedure that was used, i.e. "whole particle analysis on what is under the cross hairs" or "actual constituent under the cross hairs", named "WP" and "AC", respectively (see Table 1 in ANNEX 1). In any case all the points counted (at least 1000 for each thin section fraction examined) should be classified in one of the "reactivity classes" I, II or III, respectively.

Experience within some regions and with particular materials (i.e. highly metamorphic rocks) has shown that a determination of the quartz grain size within a particle is important in the assessment of the reactivity potential of that material. It such a rock (aggregate) the percentage of the material containing these varying sizes of quartz crystals are essential in the overall determination of the reactivity. However, at this stage the RILEM Petrographic method should primarily attempt to report the reactivity potential of such constituents based on the petrographer's own experience.

3. Work programme

The main goal of the testing programme in task 3.1 in PARTNER was to evaluate the suitability of the RILEM AAR-1 petrographic method to assess the alkali reactivity of the wide variety of aggregate and geological types found across Europe. As a basis for planning the testing programme for all the nine accelerated tests, included RILEM AAR-1, 22 different aggregate types from 10 different European countries were selected. For 14 of these both the fine (F ; ≤ 4 mm) and the coarse (C ; > 4 mm) fraction were selected – see the list in ANNEX 2.

Information about the field performance with the different aggregate types is given in ANNEX 3. The information is supplied by the participants from the different countries in the PARTNER project. For some of the aggregates there is a lack of information about the field performance, in particular with respect to which fractions that have proved to give problems in real concrete structures.

In the work programme in task 3.1 all the 22 selected aggregate types, both the fine and the coarse fraction if available, were tested by petrographic examination. The note gave instructions to each laboratory which aggregate type to be tested at the specific laboratory and according to which of the three alternative procedures (see ANNEX 1). Most of the laboratories followed the distributed testing plan, but for practical or other reasons some changes were made by some of the laboratories (i.e. more or fewer tests were performed or another technique were applied).

Most of the laboratories prepared their own thin section, if thin section techniques were applied.

Table 1 gives an overview of the number of tests performed at each of the different 13 participating laboratories in task 3.1. Details are given in ANNEX 4. Each laboratory is denoted with a number from 1-13, i.e. all the laboratories are made anonymous. These numbers are also applied in the tables presenting the results – see chapter 4. Based on a request to each of the laboratories, performed within WP4, the laboratories are divided into four groups (0, 1, 2 or 3, respectively) based on their experience with performing petrographic analyses.

In total 123 single petrographic analyses, either of a fine (F) or a coarse (C) aggregate type, were performed within the testing programme, i.e. most aggregates have been examined by more than one laboratory. For several of these analyses more than one fraction were examined (e.g. both the 5-15 mm and the 15-30 mm fraction of a given coarse aggregate type). Most of the aggregates were tested according to the point counting technique (80 single tests in total), but also the particle separation technique were widely used (39 single tests in total).

Table 1 Overview of the number of petrographic analyses performed in task 3.1

RILEM AAR-1 - NUMBER OF TESTS PERFORMED

"Name" of laboratory	Experience with AAR-1? [1)]	Whole rock petro	Particle separation	Point count analysis	Total number of analyses
1	2	1	3	5	9
2	3	0	0	11	11
3	3	1	2	11	14
4	3	0	6	9	15
5	1	0	1	5	6
6	3	0	10	11	21
7	3	0	4	12	16
8	1	0	1	2	3
9	2	0	3	3	6
10	3	0	5	5	10
11	1	0	1	4	5
12	2	1	1	2	4
13	0	1	2	0	3
	Sum	4	39	80	123

[1)] "Classified" according to a request performed in WP4:

3	= Performs the tests on a regular basis
2	= Has performed the test once or twice
1	= Equipement, but no experience
0	= No equipement, no experience
	= OK results (i.e. checked and found reasonable)
	= something is not clear or uncertain

4. Results

4.1 Reporting instructions

In the note (ANNEX 1) two tables are included for reporting the results, one for the “point count analysis” procedure (Table 1) and one for the two other procedures (Table 2). For all the three procedures the rock names should be stated according to suggested rock names given in the AAR-1 method /1/. For the “point count analysis” procedure also the thin section technique applied, i.e. either “whole particle analysis on what is under the cross hairs” or “actual constituent under the cross hairs” (named “WP” and “AC”, respectively), should be reported for all rock types detected.

As a basis for calculating the total percentage of “reactive/possible reactive” rock types in an aggregate, each of the rock types detected should be placed, based on the petrographers experience, in one of the three “reactivity classes”;

I. very unlikely to be alkali-reactive
II. alkali-reactive uncertain
III. very likely to be alkali-reactive.

The note (ANNEX 1) did not give any detailed instructions to the petrographers, but suggestions for rock names are given in ANNEX 4 in the AAR-1 method /1/. In addition the petrographers may base their classification on the national experience in the countries supplying the actual aggregate types.

Independent of procedure applied results for all the different fractions investigated (e.g. 5-15 mm and 15-30 mm for a given coarse aggregate type) should be reported separately. In particular when applying the “Point count analysis” technique on fine aggregates (< 4 mm), results from examination of the fractions 2-4 mm, 1-2 mm and 0.063-1 mm should be reported separately.

4.2 Collection and presentation of results

SINTEF have collected the results from all the 123 single petrographic analyses (see Table 1 in chapter 3). Unfortunately, several of the participating laboratories did not follow the distributed and agreed reporting instructions (see above); e.g. less than half of the laboratories reported all the requested detailed data when the results were supplied.

When receiving the results SINTEF performed a certain quality control of the data, i.e. evaluated if all the requested data were reported, in addition to make a preliminary evaluation whether the results seemed reasonable; e.g. did the different laboratories use the correct “reactivity class” (see above) for the different rock types; were the results in agreement with information collected for the different aggregate types (see ANNEX 3)?

To be able to handle all the results, SINTEF put all the data manually into an Excel worksheet. If some data were missing or seemed unreasonable, the actual laboratory was asked to look through the results once more and supply the requested information and/or revised results. This “second reporting round” improved the quality of the data supplied from many of the laboratories, but for some laboratories some information is still missing or is uncertain even after circulating a further request.

In Table 1-3 in this report and in ANNEX 4 and 5 the following “colour code system” is applied to divide between “approved data” and “uncertain data / data with some lack of information”:

	= OK results (i.e. checked and found reasonable)
	= something is not clear or uncertain

All the collected results are presented in detail in ANNEX 5 (enclosed worksheet). The same abbreviations as in Table 1 are used with respect to name of the laboratory and their experience with performing petrographic analyses.

For all the three petrographic procedures (see chapter 2) the following results are presented for each of the 36 aggregates included (i.e. aggregates from 22 quarries, whereas 14 of these aggregates were supplied in both a fine (F) and a coarse (C) fraction) - see the sheet named "*Results*" in ANNEX 5:

- Fraction size (e.g. 4-8 mm)
- Main rock types (volume percentage of the different rock types within the aggregate fraction)
- Main reactive rock types (volume percentage within the aggregate fraction)
- Sum of rock types within each of the three "reactivity classes" I, II and III, respectively (volume percentage of each of them within the aggregate fraction)
- Sum of rock types within the "reactivity classes" II+III (i.e. sum of rock types not likely to be non alkali reactive, i.e. these rock types are suspicious rock types with respect to ASR)
- Relevant comments and/or questions to the results reported
- Thin section analysis technique, if applied (i.e. "WP" or "AC" – see chapter 2)

For fine aggregates (< 4 mm) examined by use of the "Point count analysis" technique, results from point counting of each of the fractions 2-4 mm, 1-2 mm and 0.063-1 mm are (should be) reported separately. If other fractions are examined, results for these fractions are presented as well. A few laboratories have calculated the "mean content of reactive rock types" within an aggregate, based on results revealed in each of the fractions examined combined with the aggregate grading. These results are not checked or commented further in this report.

As can be seen in ANNEX 4 and 5 some aggregates have been examined by up to eight different laboratories according to the same petrographic procedure. As an attempt to summarize all the results, SINTEF have prepared two sheets with the following content (see ANNEX 5):

- "*Summary, II and III*":
  - Sum of rock types within each of the "reactivity classes" II and III, respectively
  - Sum of rock types within the "reactivity classes" II+III
  - Calculation of the *average, median, minimum* and *maximum* content of suspicious rock types with respect to ASR detected by the participating laboratories
  - Information about the number of results included in the presented statistical results

- "*Summary table*":
  - Summary of the results presented in the sheet named "*Summary, II and III*", but only summary results for the "reactivity classes" II+III. These results are also presented in Table 2 and 3 in this report.

The following abbreviations are used in the two tables:

[1] The fraction investigated in the petrographic analyses

[2] The **average** represents the mean results of all the investigated fractions at all laboratories

"Average" means that only one laboratory has performed the test (i.e. no statistical calculations are performed)

[3] The numbers represent the sum of the "reactivity classes" II and III, i.e. the sum of all the rock types not likely to be non alkali reactive

[4] lab. = laboratories ; frac. = fractions

[5] TS = thin sections

[6] R = proved to be alkali reactive based on field performance ; NR = not observed damage due to ASR in real structures (see ANNEX 3)

Table 2. Summary results from petrographic analyses performed on 18 aggregate types in task 3.1

= OK results (i.e. checked and found reasonable)

= something is not clear or uncertain

Aggregate	Fraction[1] (mm)	Statistics[2]	Whole rock petro (%) sum II+III[3]	Whole rock petro (%) Comments	Particle separation (%) sum II+III	Particle separation (%) Comments	Point counting (%) TS 2-4 mm[5] sum II+III	Point counting (%) TS 2-4 mm[5] Comments	Point counting (%) TS 1-2 mm[5] sum II+III	Point counting (%) TS 1-2 mm[5] Comments	Point counting (%) TS 0.063-1 mm[5] sum II+III	Point counting (%) TS 0.063-1 mm[5] Comments	Field performance[6]	Results in agreement with field performance ?
B1(F)	0-2	"average"									97	1 result (TS 0.125-2 mm)	R?	YES
B1(C)	4-20/"coarse"	"average"	16	1 result (1 lab., 1 frac.)			100	1 result (1 lab., 1 frac.)[4]			100	1 result (TS 0.063-2 mm)	R	YES
D1(F)	0-4	average median minimum maximum					36? 16? 6 85	7 results (7 lab., 1 frac.)	39 44 7 87	5 results (5 lab., 1 frac.)	48 35 28 81	3 results (3 lab., 1 frac.)	R (pessimum behavior)	YES
D1(C)	4-8 / 8-16	average median minimum maximum			<54 <49/71 13 96	8 results (6 lab., 2 frac.)							R (pessimum behavior)	YES
D2(F)	0-4	average median minimum maximum					38 28 2 100	5 results (5 lab., 1 frac.)	50 40 9 100	3 results (3 lab., 1 frac.)	53 -- 6 100	2 results (2 lab., 1 frac.)	R	YES
D2(C)	4-8 / 8-16	average median minimum maximum			56 65 4 100	3 results (3 lab., 2 frac.)							R	YES
D3(F)	0-2	average median minimum maximum							2 -- 0 3	2 results (2 lab., 1 frac.)			NR	YES
F1(C)	6-20	"average" median minimum maximum			95 97 90 98	3 results (3 lab., 1 frac.)	96 -- -- --	1 result (1 lab., 1 frac.)	96 -- -- --	1 result (1 lab., 1 frac.)	86 -- -- --	1 result (0-1 mm)	R (pessimum behavior)	YES
F2(F)	0-5	"average"					0	1 result (1 lab., 1 frac.)	0	1 result (1 lab., 1 frac.)	0	1 result (1 lab., 1 frac.)	NR	YES
F2(C)	5-20	"average"			0	1 result (1 lab., 1 frac.)							NR	YES
F3(F)	0-4	average median minimum maximum					53? 42 37 94	5 results (5 lab., 1 frac.)	54 35/70 30 82	4 results (4 lab., 1 frac.)	60 76 25 78	3 results (3 lab., 1 frac.)	NR?	NO
F3(C)	4-20	"average" median minimum maximum			63 -- 40 86	2 results (2 lab., 1 frac.)	26? -- -- --	1 result (1 lab., 1 frac.) (TS > 4 mm)					NR?	NO
G1(C)	"4-22"	"average" median minimum maximum			52 51/52 11 100	8 results (4 lab., 4 frac.)	46 -- -- --	1 result (1 lab., 1 frac.)	44 -- -- --	1 result (1 lab., 1 frac.)	33 -- -- --	1 result (1 lab., 1 frac.)	R	YES
G2(C)	"2-8"	average median minimum maximum			60 -- 30 89	2 results (2 lab., 2 frac.)	50? 43 14? 92	3 results (3 lab., 2 frac.)					R	YES
It1(F)	0-5	average median minimum maximum					32? 10 8 100	4 results (4 lab., 1 frac.)	61 -- 21 100	2 results (2 lab., 1 frac.)	55 -- 10 100	2 results (2 lab., 1 frac.)	R	YES
It1(C)	"5-30"	"average" median minimum maximum			40 17 4 100	3 results (3 lab., 2 frac.)	10? -- -- --	1 result (1 lab., 1 frac.?)					R	YES
It2(F)	0-5	average median minimum maximum					51? 24?/81 14 100	5 results (5 lab., 1 frac.)	82 86 60 100	3 results (3 lab., 1 frac.)			R?	YES
It2(C)	"5-30"	average median minimum maximum			84 100 36 100	4 results (4 lab., 2 frac.?)							R	YES

Table 3. Summary results from petrographic analyses performed on 18 aggregates in task 3.1

= OK results (i.e. checked and found reasonable)

= something is not clear or uncertain

Aggregate	Fraction[1] (mm)	Statistics[2]	Whole rock petro (%)		Particle separation (%)		Point counting (%)						Field perfor-mance[6]	Results in agree-ment with field performance ?
							TS 2-4 mm[5]		TS 1-2 mm[5]		TS 0.063-1 mm[5]			
			sum II+III[3]	Comments	sum II+III	Comments	sum II+III	Comments	sum II+III	Comments	sum II+III	Comments		
N1(C)	4-16	average					90?	3 results (3 lab., 1 frac.)					R	YES
		median					98							
		minimum					71?							
		maximum					100							
N2(C)	8-16	"average"					100	1 result (1 lab., 1 frac.)					R	YES
N3(F)	0-4	average					2	3 results (3 lab., 1 frac.)	2	3 results (3 lab., 1 frac.)	2	2 results (2 lab., 1 frac.)	NR	YES
		median					1		1		--			
		minimum					0		0		0			
		maximum					6		6		4			
N3(C)	2-8/8-16	"average"			5	2 results (1 lab., 2 frac.)							NR	YES
N4(F)	0-7	average					27	2 results (2 lab., 1 frac.)					R?	YES
		median					--							
		minimum					23							
		maximum					31							
N4(C)	7-16	average					25	2 results (2 lab., 1 frac.)					R	YES
		median					--							
		minimum					23							
		maximum					27							
N5(F)	0-8	"average"					22	1 result (1 lab., 1 frac.)	17	1 result (1 lab., 1 frac.)			R?	YES
N5(C)	8-16	"average"					22	1 result (1 lab., 1 frac.)					R	YES
N6(F)	0-8	"average"					37	1 result (1 lab., 1 frac.)	23	1 result (1 lab., 1 frac.)			R?	YES
N6(C)	8-16	"average"					33	1 result (1 lab., 1 frac.)					R	YES
S1(F)	0-8	average					52?	5 results (5 lab., 1 frac.)	61	3 results (3 lab., 1 frac.)			R?	YES
		median					44		45					
		minimum					35?		37					
		maximum					100		100					
S1(C)	4-16	average			59	3 results (3 lab., 1 frac.)	43?	1 result (1 lab., 1 frac.) (TS > 4 mm)					R?	YES?
		median			40		--							
		minimum			40		--							
		maximum			98		--							
UK1(F)	0-5	"average"					83	1 result (1 lab., 1 frac.)	66	1 result (1 lab., 1 frac.)	40	1 result (1 lab., 1 frac.)	R?	YES
UK1(C)	4-8	"average"	100	1 result (1 lab., 1 frac.)									R	YES
UK2(F)	0-5	average					52	5 results (5 lab., 1 frac.)	27	3 results (3 lab., 1 frac.)			R	YES
		median					54		9					
		minimum					15		7					
		maximum					89		66					
UK2(C)	5-20	average			59	4 results (3 lab., 1 frac.)	54	3 results (3 lab., 1 frac.)					R	YES
		median			73/75		48							
		minimum			10		15							
		maximum			79		98							
P1(C)	4-19	"average"			100	1 result (1 lab., 1 frac.)	100	1 result (1 lab., 1 frac.)					R	YES
P1(WR)	"Crushed 2-4"	average	53	2 results (2 lab., 1 frac.?)									R	YES
		median	--											
		minimum	6											
		maximum	100											
E1(F)	0-4	average					3?	3 results (3 lab., 1 frac.)	3?	2 results (2 lab., 1 frac.)			R?	NO
		median					--		--					
		minimum					0		0?					
		maximum					8		5					

5. Discussion / interpretation

Variation between laboratories with respect to evaluation of aggregate reactivity

Table 2 and 3 include results from 13 laboratories, both experienced and inexperienced with respect to performing petrographic analysis according to the AAR-1 method. Before the testing program started about one half of the petrographers had participated in one or two internal petrographic workshops in the PARTNER project, where selected European aggregate types were examined in microscope and "discussed". No other co-ordination was made between the laboratories.

In the further discussion focus is made on the variation between the laboratories with respect to the sum of rock types detected within the "reactivity classes" II+III, i.e. sum of rock types not likely to be non alkali reactive (i.e. suspicious rock types with respect to ASR).

The overall experience from the testing program is that the spread in results between the laboratories for about half of the aggregate types is very high, also between some of the six laboratories performing the test on a regular basis. For 8 of the 22 aggregates types (D1, D2, G1, G2, It1, It2, UK2 and P1) the number of rock types detected by the participating laboratories within the "reactivity classes" II+III varies from less than 15 % to more than 85 %, even when applying the "point counting procedure". The rock names used also vary a lot.

However, for four of the most experienced laboratories (no. 2, 3, 4, and 10) the majority of the reported results seem to be more reliable. The cases where also these laboratories from time to time deviate from the average/median results when applying the "point counting procedure", are mainly connected to the aggregate types D1, D2, It1 and UK2. These aggregate types are not familiar for most of these experienced petrographers, thus the importance of local knowledge about the reactivity of different alkali reactive aggregates is obvious.

The majority of the "point counting results" reported from the two remaining experienced petrographers (laboratory no. 6 and 7) deviates much from the average/median results. For laboratory no. 7 the sum of aggregate types classified in the "reactivity classes" II or III is in many cases some lower than reported from the other laboratories. This laboratory has also only reported the content of "suspicious rock types", and not the total rock composition for the examined aggregates. For laboratory no. 6 the percentage of aggregate types classified within the "reactivity classes" II or III is in most cases much higher than for all the other laboratories. The main reason for this is that this petrographer, in contrast to most of the other petrograpers, classifies the following aggregate types either in "reactivity class" II or III; limestone, gneiss, granite and granitoide.

Other rock types that are placed in different "reactivity class" by different laboratories are:

- Sandstone (e.g. in the aggregate types D2, F3, G1 and G2); class I by several laboratories (e.g. lab. no. 2, 8, 9 and 10), class II or III by other laboratories
- Siltstone (e.g. aggregate type UK1); class I by lab. no. 10, class II or III by other laboratories
- Flint (e.g. in the aggregate types D1, D2, F1, G2 and It1); different types of flint (often named chert by several laboratories) detected/named by different laboratories; the classification of reactivity also varies a lot (all three "reactivity classes" are used).

Link to field performance

In the last but one column in Table 2 and 3 information about the field performance of the 22 "PARTNER aggregates" are given (see also ANNEX 3 for further details). The abbreviation "R" means that the actual aggregate type is proved to be alkali reactive based on field performance. "NR" means that no damage due to ASR is observed in real structures. As mentioned in the past the information is supplied by the participants from the different countries in the PARTNER project.

The last column in Table 2 and 3 summarize the evaluation of whether the average detected contents of "suspicious aggregates" are in agreement with the reported field performance of the different aggregate types. The RILEM AAR-1 petrographic method does not give any critical limits for accepted and harmless content of such rock types, thus the evaluation is based on the Norwegian experiences with our Norwegian rock types. This experience does not cover the aggregates with known pessimum behaviour.

As can be seen, the results from the petrographic analyses of almost all the 22 aggregate types correlate very well with the reported field performance. Two exceptions are the French aggregate F3 and the Spanish aggregate E1. Both the performed petrographic analyses and the brief petrographic description given in ANNEX 3 states that the F3 aggregate contains many reactive rock types. Despite of this, no deterioration of real concrete structures containing this aggregates type has been reported.

The situation for the E1 aggregates is opposite. Only a small content of reactive constituents are detected in the petrographic analyses performed, but serious damage is reported on a 30 years old precast concrete element. This aggregate type has also been discussed as a special case on one of the internal petrographic workshops in PARTNER, and several of the participating petrographers questioned whether E1 could lead to ASR.

In almost all known cases of Norwegian ASR-damaged structures, the damages are mainly caused by the coarse aggregate fractions (> 8-10 mm). For several of the other European aggregate types included, there is a lack of information about which fractions that have proved to give ASR-problems in real concrete structures - thus the abbreviation "R?" is included in Table 2 and 3. This lack of information makes the evaluation of several of the fine aggregates uncertain.

Results from testing of the aggregates according to other "PARTNER laboratory methods" are given in several other PARTNER reports – see the report list on page 4 in this report.

Variation between aggregate fractions examined?

Overall the content of suspicious rock types ("reactivity class" II+III) detected within the different fractions examined (i.e. > 4 mm, 2-4 mm and 1-2 mm) for a given aggregate type does not vary much compared to the variations revealed between the different laboratories participating (see above). In particular, point counting of the smallest fraction from 0.063-1 mm did not give any complementary information about the reactivity of any of the aggregate types included in the test programme. For many of the aggregates types, e.g. N3 and N4, free minerals were also to a large extent detected within this fraction. Taking into account the time consuming examination of this small fraction, for most of (all?) the fine aggregate types one should consider to count the fractions 1-2 and 2-4 mm only, as has been done in Norway for the last 15 years /2, 3/.

Should one procedure be preferred?

Both the "particle separation procedure" and the "point counting procedure" have been applied on 14 coarse aggregate types (but not always on the same aggregate types). The overall experience is that the content of suspicious rock types detected is either a bit higher by use of the "particle separation procedure" (in about 55-65 % of the cases) or the two procedures detect a similar content of "reactive rock types" (in about 35-45 of the cases). However, several of the petrographers seem more uncertain in their classification of reactivity by use of the "particle separation procedure". This procedure was also applied in Norway about 15 years ago, but due to a too uncertain classification of the reactivity of many of our dense rock types, only the "point counting procedure" has been applied since 1993 /2/. In the case of other European aggregates types containing rock types that can be easier separated and classified, also the "particle separation procedure" may be a good tool in the petrographic examination.

Is the RILEM AAR-1 petrographic method a good tool to assess the alkali reactivity of aggregates?

The reported results from the testing programme within task 3.1 in PARTNER have detected large inter-laboratory variations between the participating laboratories, and revealed the following main issues to be dealt with and solved if the RILEM AAR-1 method aims to be a widely used and reliable testing method to assess the alkali reactivity of aggregates both within Europe and world wide:

- The importance of education and round robin testing
- The importance of experience, both with the method and with the actual local aggregates
- The importance of calibrating the results with other RILEM methods and with field experience to be able to establish critical limits for acceptable content of suspicious rock types in different aggregate types (e.g. as we successfully have been able to establish in Norway /4, 5/)
- The importance of accuracy, quality control and system for approval of laboratories and petrographers.

The situation in Norway after about 15 years of experience with use of the petrographic method, is that the method is regarded as a very reliable tool to assess the alkali reactivity of our Norwegian aggregates. Since the mid 90'ties the petrographic method has been the overall dominating method in use. The main reasons for this success is that we from the early 90'ties have focused on the above mentioned issues and implemented the results and experience into the "Norwegian approval system for handling the ASR problem" /6, 7/. Today, only three Norwegian laboratories are approved to perform petrographic analysis of concrete aggregates on a commercial basis.

Final remark

Both the internal workshops and the testing within task 3.1 in the PARTNER project have shown that geological evaluations across the frontiers are difficult. National petrographic atlases with pictures of all the known national alkali reactive rock types, as has been prepared and used in Norway for almost a decade /8/, may be a good tool to reduce these difficulties.

The PARTNER project and the internal workshops in special have established a very good network of contacts between several experienced and inexperienced petrographers that may be helpful in the future to an informal education across the frontiers.

6. Comments on the method

In addition to reporting the results from the petrographic analyses, all the participating laboratories were encouraged to make comments on the RILEM AAR-1 method and/or the prepared note (see ANNEX 1). Such comments are received from four laboratories; no. 4, 7, 8 and 10. Below some of these comments are presented.

Comments from lab. no. 4 (performs the test on a regular basis):

Point counting process

*It has to be decided which of the two different "procedures" (*i.e. "whole particle analysis on what is under the cross hairs" or "actual constituent under the cross hairs", named "WP" and "AC", respectively) *that shall be used . The procedure when the whole particle is examined, the result will be highly dependent of the experience and subjectivity of the geologist. For instance if a porous flint is counted, at what stage is it considered to be reactive? When 50 % is porous or 25 %? If the individual point is recorded this part of the subjectivity is reduced .Our proposal is to actually perform what is stated in the method, i.e. point counting and let the statistics take care of the rest. This means that if your hair cross is above a porous part of a flint particle you count it as reactive. If it is above a dense part in a 90 % porous flint particle you have to count it as non-reactive. By* *using dense enough grid and enough points one will achieve a representative value of the amount of reactive components in the sample anyway without a subjective assessment of each point.*

…. about the point counting process and its different "procedures", it's right to say that it is dependent on the experience of the geologist : sometimes you'll count the particle as a whole rock (e.g. sandstone, silicified limestone, rhyolite,…), another time you'll count only what you actually see under the cross hairs (e.g. porous or non porous flint, microquartz < 60 µm,…). It's the reason why, I think, we must now plan a new education program more detailed than the previous ones (carried out in Düsseldorf and Trondheim), where each geologist having a good experience in this field will show exactly how he practically applies this method with "his own rocks".

Comments to WP3.1 test procedure and results

The comment concerns the "particle separation" part. In the RILEM-method on page 14 it says that if the constituents of the material not are identified, point counting should be used. To do particle separation you need to have experience of the material. Many of the petrographers in PARTNER do not have experience of each material that they have analyzed. The description of each material presented in WP3.1 does not give enough information about the material. The result of the particle separation is probably therefore not reliable.

Comments from lab. no. 7 (performs the test on a regular basis – long experience):

Point counting method

Although I was involved in the technical committee working on this method, I think now, in retrospect, that some points, which were included in the original text of some previous drafts of the method, are now missing and consequently not clear at all : it concerns the "Technique for point-counting of thin-section samples", p.13.

1. *About the "procedure for determination, § 7.4.2": the fractions proposed for analysis are < 2, 1-2 and 2-4mm.*
   - *We must accept also thin sections in other fractions: for example 0.125-2 mm, 2-4 mm and > 4 mm : indeed, some labs in different countries have a long experience with these.*
   - *Each fraction, after sieving, must be separately weighed*

REM: in the method, the fraction > 4 mm is considered as coarse aggregate, but in practice, everybody knows that a "sand" can contain a certain amount, sometimes not negligible, of "coarse" fraction > 4mm. This leads to a confusion in the text. In the § 7.4.1 one talks about the "coarse aggregate", but farther on in the text, we don't clearly find a § with the second case "fine aggregate" or "sand". As the method must be practically used, I think that we must clearly make the distinction between the coarse aggregates and the sands, and describe the method for each case.

2. *About the "calculation of results, §7.4.4.":*

As a basis for the discussion, I give hereafter an actual example: an aggregates producer ask to assess the alkali-reactivity of a sand.After sieving, weighing and counting, the sand "composition" is:

- *Fraction "0-2" mm (mass proportion : 78 %): 2% of chert*
- *Fraction 2-4 mm (mass proportion: 12%): 8 % of chert*
- *Fraction >4 mm (mass proportion : 10 %): 32 % of chert*

The method doesn't explain how to calculate the global content of chert in the whole sand! The method such as can't be practically used !

Comments from lab. no. 8 (inexperienced with point counting):

> *"As mentioned already, due to the lack of a point counting system we are not able to analyze precisely the reactive minerals and to calculate their volume fractions in the whole aggregate under test. Therefore the only possibility we would have is to assign each particle to a definite rock type. But, this has not been carried out due to the following observations.In a certain cut out of the thin section visible through the ocular in many cases you can see for example a feldspar, which is of a size from 1 to 4 mm. Due to crushing the natural texture of the rock this definite feldspar originally belonged to has been destroyed. Thus, it can not be detected e.g. whether the original structure was layered or whether the feldspar was a crystal in a Granite. Consequently it is both impossible to assign this feldspar to the original rock type and to determine precisely the volume fractions of certain rock types during a whole particle analysis. This is especially valid for aggregate N5".*

Comments from lab. no. 10 (performs the test on a regular basis):

> *……All kinds of aggregates were tested: coarse aggregates- hand sorting method and fine aggregates-point count analysis/ on thins sections. Therefore G1 sample was tested only hand sorting methods. How can I do representative thin section sample with coarse aggregate?*

Comments from SINTEF (performs the test on a regular basis – long experience):

In addition to the comments presented in the past, SINTEF as an author of this report, have given some comments to the method in connection to the discussion of the results (see chapter 5).

7. Conclusions

This report describes the results of an evaluation performed within task 3.1 in the PARTNER programme of the use of the petrographic method, developed by RILEM as AAR-1, to assess the alkali reactivity of European aggregates.

In total 22 aggregate types across Europe, both the fine and the coarse fraction, if available, were selected for testing by petrographic examination according to one or more of the three alternative procedures named "Whole rock petro", "Particle separation" and "Point count analysis", respectively.

SINTEF have collected the results from all the 123 single petrographic analyses performed, and put the data manually into an Excel worksheet. All the collected results are presented in detail in ANNEX 5 (enclosed worksheet). The main results are presented in tables and discussed within this report.

The overall experience from the testing program is that the spread in results between the laboratories for about half of the aggregate types tested is very high, also between some of the six laboratories performing the test on a regular basis. However, for four of the most experienced laboratories the majority of the reported results seem to be more reliable.

With two exceptions the average results from the petrographic analyses of the 22 aggregate types correlate very well with the reported field performance.

The PARTNER project and the internal workshops in special have established a very good network of contacts between several experienced and inexperienced petrographers that may be helpful in the future to an informal education across the frontiers.

Some recommendations to the RILEM AAR-1 method are given. In addition the results revealed the following main issues to be dealt with and solved if the RILEM AAR-1 method aims to be a widely used and reliable testing method to assess the alkali reactivity of aggregates both within Europe and world wide:

- The importance of education and round robin testing
- The importance of experience, both with the method and with the actual local aggregates
- The importance of calibrating the results with other RILEM methods and with field experience to be able to establish critical limits for acceptable content of suspicious rock types in different aggregate types
- The importance of accuracy, quality control and system for approval of laboratories and petrographers.

8. References

1. RILEM TC 191-ARP: ”RILEM Recommended Test Method AAR-1: Detection of potential alkali-reactivity of aggregates – Petrographic method”, Materials and Structures, Vol. 36, August-September 2003, pp 480-496
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7. Dahl, P.A., Lindgård, J., Danielsen, S.W., Hagby, C., Kompen, R., Pedersen, B. and Rønning, T.F., ”Specifications and guidelines for production of AAR resistant concrete in Norway”, paper presented at the 12th ICAAR Conference, Beijing, October, 2004.

Test plan: RILEM Petrographic method

The RILEM test method shall be used. This note contains some clarifying key-elements, which have to be observed when performing this test.

Outline
The petrographic method is a test method used to assess the reactivity of concrete aggregates.

General
The RILEM petrographic method is carried out by two mutually beneficial techniques; a standard petrographic examination of the aggregate particles and a detailed microscopical examination of thin-sections which may incorporate point-counting. An initial inspection of the aggregate material should be undertaken to assess which method(s) should be employed.

This RILEM petrographic method allows for a number of different procedures to determine the reactivity of a particular aggregate sample. These include:

1. The **hand separation** of aggregate particles by lithological characteristics prior to the production of any thin sections to determine that aggregates microscopical characteristics. This technique would be most appropriate with coarser gravel aggregates where the different constituent of an aggregate are easily separated by eye, colour, density, physical characteristics etc (i.e. porous flints, or light coloured limestones and dark coloured basalt in the same gravel). In such circumstances it may not be necessary to study thin-sections of selected aggregates to enable fuller identification of the material. After separation selected particles can if felt necessary then be thin sectioned to determine the microscopical reactivity related characteristics (there is little point in undertaking the separate aggregate crushing technique set out below on a greywacke for example in which the material is 100% greywacke and observed to be 100% potentially reactive).

2. Aggregates in which individual particle lithologies cannot be determined easily by either of the above or there is clear variability of reactivity between the different parts of the aggregate rock at a microscopical scale then the pre-crushing (for coarse material) and **point counting technique** discussed below should be employed. (Experience from Norway: A few locations produce crushed aggregates consisting mainly of innocuous aggregates (e.g. gneiss/granite), but there are zones in the mines consisting of mylonite or fine grained gneiss. Visually, aggregate particles from these zones are similar to those produced from the innocuous parts of the mine, and therefore impossible to detect without thin sections. In such cases the point counting technique should be used). The point counting method could be appropriate in determining the reactivity of a fine, varied aggregate sample too.

3. If a crushed rock aggregate has uniform characteristics for determination of its reactivity for example a silicified limestone, greywacke, or a coarse holocrystalline granite, then a thin section of the total aggregate particles **("whole rock petro")** can be produced to determine lithological characteristics.

All of these techniques are useful in establishing the reactivity of an aggregate, and none should be discounted as a method of determining reactivity. The method employed should be determined by an initial macro-examination of the aggregate sample received. In reference to the RILEM method it is not compulsory to have to use only one of these specified techniques.

The different aggregates in the Partner project shall be tested according to the different methods (1-3). The test plan (see page 7) describes which method to be used for the different aggregate types at the different laboratories.

Aggregate particles hand sorting technique (1)

The hand sorting petrographic examination should be carried out on the dominant sized fraction of the fine aggregate and the coarse aggregate respectively. The minimum number of particles to be examined and counted depends on the percentage of rock/minerals of interest and the confidence limits required set down in the standard. This method can be best used for coarse gravel, all-in and crushed rock aggregates. Where there is doubt over the identification of a particular rock/mineral type in the hand sorting technique it is recommended that thin-sections of representative particles are to be prepared to assist in the identification (e.g. dense and fine grained rock types).

Aggregate particles from each examined size fraction are divided into individual rock/mineral groups by hand sorting. As a minimum requirement, this grouping must include one group designated as innocuous aggregates and one group designated as potentially reactive aggregates. Aggregate particles may be divided into more specified groups of constituents based on an assessment of grain form, colour, texture rock/mineral type, and/or classification of the aggregates. In samples where the reactivity of certain aggregates is difficult to assess, a group designated, as potentially reactive (uncertain) aggregates should be included. Reference to Class I, II and III in the method should be included for all the detected constituents.

Point counting technique (2)

As a basis for point count testing method the performing laboratory has to read carefully the description of the point counting technique in thin sections (note particularly paragraph 7.4.3. and 7.4.4 in the method description).

In the Partner project the aggregates used shall consist of one of the following:

- The fine aggregate (F)
- The coarse aggregate (C)
- Coarse and fine aggregate (C+F)

In the point counting testing method according to RILEM AAR-1 the following fractions should be counted: **Sand**: 2 thin sections of the fraction 2-4 mm, 1 thin section of the fraction 1-2 mm and 1 thin section of the fraction 0.063-1 mm. Each laboratory can choose if they alternatively want to prepare 1 thin section of the fraction 0.063-2 mm. However, both fractions should be counted separately (see the result sheet on page 5). For a **coarse aggregate**: 2 thin sections of the fraction 2-4 mm. If the aggregate is crushed (i.e. from a rock quarry), the thin sections may either be produced from the fine or the coarse fraction. For natural aggregates the fine and the coarse fraction have to be examined separately (see the test plan).

Point-counting aims to identify and quantify both the reactive and the non-reactive rock and mineral particulate constituents present within an aggregate so that the content of reactive constituents can be determined.

The point counting method is carried out by traverses in regular increments in two directions to form a virtual orthogonal grid. It is important that point-counting covers the whole thin-section. During the point-counting, the operator must identify and group all rocks and minerals located under the cross hairs at each point on the grid. Note that a minimum of 1000 points (excluding points falling on to resin) should be counted for the <2 mm, 1-2 mm, or 2-4 mm fractions respectively. Additionally the number of points may significantly exceed the number of particles, as several points may be counted across some larger particles. Where the point counting method is employed, the whole thin section must be traversed. To be able to do this, the thin section must be turned in the holder during the testing.

During the point counting process there are two different “procedures” in use. In several countries (for instance Belgium and United Kingdom) it is common to determine the constituent and thus the reactivity assessment of the individual point which is directly under the crosshairs rather than a determination of the reactivity for that entire particular aggregate particle. An evaluation of the reactivity of the whole particle is, however, common to use in some countries (for instance in Norway). This method is also used by petrographers in some of the other countries for some rock types, for instance sandstone. All cross points placed within the sandstone particle is then recorded as sandstone. However, when particles consist of more than one type of rock e.g. sandstone with quartz vein, the cross point falling on to the sandstone should be recorded as sandstone, and cross points falling on to quartz vein should be recorded as quartz vein material. To determine which procedure to be used, the experience with the aggregates within each country should be taken into account. In the result sheet the operator shall report which procedure that is used, i.e. “whole particle analyses on what is under the cross hairs” or “actual constituent under the cross hairs”.

Experience within some regions and with particular materials (i.e. highly metamorphic rocks) has shown that a determination of the quartz grain size within a particle is important in the assessment of the reactivity potential of that material. It such a rock (aggregate) the percentage of the material containing these varying sizes of quartz crystals are essential in the overall determination of the reactivity. However, at this stage the RILEM Petrographic method should primarily attempt to report the reactivity potential of such constituents based on the petrographer’s own experience.

The results of the point count method shall be reported in the enclosed result sheet (Table 1). However, in the case of aggregates in which method 1 (i.e. particle hand sorting technique) has been employed, an overall assessment of reactivity of the various detected hand selected or whole rock determinations / components shall be reported as suggested below in Table 2 (i.e. main point count results). In the RILEM petrographic method description (ANNEX 4) there are suggestions for rock names which can be used.

Thin section preparation: Each laboratory is encouraged to prepare their own thin sections (alternatively ask another laboratory for assistance). If a laboratory can produce larger standard thin sections, 75 x 50mm for example, it will not always be necessary to produce the pairs of thin sections in the 2-4 mm fraction as described above. The whole being undertaken on one thin section. However, if BRE may produce them, the samples have to be pre-crushed, sieved to the correct fractions, labelled and bagged. (If BRE are going to produce thin sections for a lot of laboratories, it will take much time).

Table 1. Results from method no. 2: point count analysis (the MS Excel result sheet shall be used to report the results to SINTEF)

RILEM Petrographic method AAR-1 - Results

Rock name	2-4 mm		1-2 mm		0.063-1 mm		Method used [2]	Alkali-reactivity class [1]
	Number	%	Number	%	Number	%		

[1] Class I - very unlikely to be alkali-reactive
Class II - alkali-reactivity uncertain
Class III - very likely to be alkali-reactive

[2] WP = "Whole Particle"
AC = "Actual Constituent"

Laboratory: ____________________

Operator: ______________

Date: ________

Table 2. Results from method no. 1 and 3: hand sorting technique/particle separation and uniform rock type/whole rock petro (the MS Excel result sheet shall be used to report the results to SINTEF)

Rock - / constituent name	Percentage detected	Comments on lithological characteristics and ASR reactivity source	Alkali reactivity class [1]
Example:			
Mega-grungite	*100%*	*Highly reactive bobbles of micro-quartz making up 20% of the total rock are found evenly distributed in a microcrystalline grungite matrix.*	*Class III*

[1] Class I – very unlikely to be alkali-reactive
Class II – alkali-reactivity uncertain
Class III – very likely to be alkali-reactive

Laboratory: ---

Operator: --

Date: ------------------------------

Test plan:

See the Excel worksheet "WP3.1-SINTEF-031024-PLAN FOR RILEM AAR-1 – final version"

AGGREGATES FRACTIONS

Country	Sample no.	Short name	C/F	Sand	Coarse 1	Coarse 2	Coarse 3 / 4	Comment
Belgium	**B1**	*Cr.* Silicified limestone	C+F	0-2, 2-4	4-7	7-14	14-20	
Denmark	**D1**	Gravel with opaline flint	C+F	0-4	4-8	8-16	---	
	D2	Sea gravel semi-dense flint	C+F	0-4	4-8	8-16	---	
	D3	**Non reactive** siliceous sand	F	0-2	---	---	---	
France	**F1**	Gravel with flint	C	---	6-20	---	---	
	F2	*Cr.* **Non reactive** limestone	C+F	0-5	6-20	---	---	
	F3	*Part. Cr.* Siliceous gravel	C+F	0-4	4-20	---	---	
Germany	**G1**	*Part. Cr.* Gravel with silicified limestone and chert	C	---	6-8	8-11	11-16 16-22	
	G2	Gravel with opaline sandstone and flint	C	---	2-8	---	---	
Italy	**I1**	*Part. Cr.* Gravel with limestone, chert and flint	C+F	0-5	5-15	15-30	---	
	I2	*Part. Cr.* Gravel with quartzite and gneiss	C+F	0-5	5-15	15-30	---	
Norway	**N1**	*Cr.* Cataclasite	C	---	4-8	8-11	11-16	
	N2	*Cr.* Sandstone	C	---	8-12	12-16	---	
	N3	**Non reactive** granitic sand	C+F	0-4	2-8	8-16	---	
	N4	Gravel with sandstone and cataclastic rocks	C+F	0-7	7-16	---	---	
	N5	Gravel with rhyolite and quartzite	C+F	0-8	8-16	---	---	
	N6	Gravel/sand with argillaceous rocks and sandstone	C+F	0-8	8-16	---	---	
Portugal	**P1**	*Cr.* Silicified Limestone	C	---	4-8	8-16	---	
Sweden	**S1**	Gravel with porphyritic rhyolite	C+F	0-8	8-16	---	---	
Spain	**E1**	Silicified and clayed dolostone	F	0-4	---	---	---	
UK	**UK1**	*Cr.* Greywacke	C+F	0-5	10	14	20	”Single sized” coarse fractions
	UK2	Gravel with quartzite and chert	C+F	0-5	5-20	---	---	

Total number of aggregates : 22

Cr : crushed; Part. Cr. : partly crushed.
C/F : the aggregate is used as coarse (C) or fine (F) aggregate in the concretes (the grain size usually used is sometimes indicated within the following descriptions).

Petrographic composition and field performance of the aggregates tested

Aggregate combination	Origin	Brief petrographic description	Reported alkali reactivity
B1 (C+F)	Western Belgium	Crushed silicified, dark-grey argillaceous limestone with fossil debris; reactive mineral is crypto-microcrystalline quartz with sometimes fibrous habit.	Aggregate has caused damage in several concrete structures such as bridges and water structures.
D1 (C+F)	Denmark	Glaciofluvial gravel containing white to creamy white opaline flint; reactive mineral is opal.	Aggregate has produced severe deterioration in all types of concrete structures (can be very quick under severe conditions, clear pessimum effect).
D2 (C+F)	Denmark	Sea dredged, polymictic gravel originally derived from glaciofluvial sediments, main component of interest is partly porous dense chalcedonic flint, in smaller amounts pure porous chalcedonic flint is included; reactive mineral is chalcedony.	Dense porous flint is considered to be non reactive, porous flint to be reactive. Aggregate has produced severe deterioration in all types of concrete structures (normally after 10-15 years). Not as severe as D1.
D3 (F)	Denmark	No description available yet.	No deterioration reported.
F1 (C)	France (Seine Valley)	Polymictic river gravel, mainly composed of flint/cherts; reactive mineral is micro-cryptocrystalline quartz.	Is in France considered to be potentially reactive but with clear pessimum effect. No evidence of damage in structures.
F2 (C+F)	France	Fine grained limestone with some fossils; no reactive minerals.	Non-reactive.
F3 (C+F)	France (Rhine Valley)	Polymictic river gravel (partly crushed), mainly composed of quartzite, alkali reactive constituents are flint, greywacke and granitoids; reactive minerals are micro-cryptocrystalline quartz and strained, highly metamorphically sutured quartz.	No deterioration reported.
G1 (C)	Germany (Upper Rhine Valley)	Partly crushed polymictic river gravel, considerable variation in constituent lithologies, aggregates of interest are silicified limestone and chert; reactive minerals are micro- to cryptocrystalline quartz and chalcedony.	Considered to be reactive, concrete pavements with this aggregate have been deteriorated due to ASR. (Damage observed after 10 years under very severe conditions).
G2 (C)	Northern Germany	Polymictic gravel from glaciofluvial deposit, alkali reactive due to opaline sandstone (with tridymite/christobalite) and flint (with crypto-crystalline quartz and chalcedony).	Has produced severe deterioration, very quickly, in concrete structures. No damage observed after introduction of national regulations.
It 1 (C+F)	Italy (Marche region in central Italy)	Polymictic river gravel, containing mainly micritic limestone, but also silicified limestone, flint, chert and strained quartz; reactive minerals are micro- to cryptocrystalline quartz and strained, high metamorphically sutured quartz).	Quick reaction (5-10 years) observed in all types of concrete structures.

Aggregate combination	Origin	Brief petrographic description	Reported alkali reactivity
It2 (C+F)	Italy (Piemont region)	Polymictic river gravel, aggregate of interest is fine grained quartzite with strained quartz; reactive mineral is strained highly metamorphically sutured quartz.	Considered to be reactive, slowly (one example is 50 years old water constructions).
N1 (C)	Norway (middle)	Crushed cataclasite, homogeneous and fine-grained, feldspar particles lie scattered within a matrix of about 0.02 mm grain size; reactive mineral is crypto- to microcrystalline quartz.	Used as concrete material. Has caused severe damage in local areas (e.g. 11 years old airport pavement).
N2 (C)	Norway (south east)	Crushed sandstone, homogeneous and fine grained, with a sediment grain size ranging between 0.05 and 0.5 mm. These variously sized particles are embedded in a fine grained matrix; reactive mineral is crypto- to microcrystalline quartz.	Used as concrete material. Has caused severe damage in local areas (damage observed in bridges and dams after 15 to 20 years).
N3 (C+F)	Norway (south western)	Natural gravel/sand from a glaciofluvial deposit, originally composed of Precambrian crystalline rocks, consists of granites and gneisses; no reactive constituents.	No damage reported.
N4 (C+F)	Norway (south east)	Natural gravel/sand from a moraine deposit.; Sandstones, siltstones and cataclastic rocks are reactive rocks; reactive mineral is crypto- to microcrystalline quartz.	Used as concrete material. The coarse fraction has caused moderate damage, if the humidity and the alkali content are high (e.g. 20-25 years old constructions, mainly bridges).
N5 (C+F)	Norway (south)	Sand and coarse gravel from a glaciofluvial deposit. Rhyolite and fine grained quartzite are reactive rocks; reactive mineral is microcrystalline-fine grained quartz.	Used as concrete material. The coarse fraction has caused moderate damage, if the humidity and the alkali content is high (e.g. 20-25 years old constructions, mainly bridges).
N6 (C+F)	Norway (south)	Sand and coarse gravel from a glaciofluvial deposit. The reactive rocks are mainly argillaceous rocks and sandstones in addition to small amounts of hornfels, rhyolite and mylonite. Reactive mineral is crypto- to microcrystalline quartz.	Used as concrete material. The coarse fraction has caused moderate damage, if the humidity and the alkali content are high (e.g. 20-25 years old constructions, mainly bridges).
P1 (C)	Portugal	Crushed, poorly silicified limestone; reactive minerals could be micro- or cryptocrystalline quartz.	Similar limestone, probably with higher content of silica, has caused damage in several concrete structures like bridges and dams.
S1 (C+F)	Sweden	Polymictic glaciofluvial gravel and sand, primarily composed of meta-rhyolite and granite, aggregates of interest are meta-rhyolite and greywacke; reactive minerals are micro- or cryptocrystalline quartz or chalcedonic quartz.	Similar aggregate used as concrete material has caused moderate damage. The source is variable in composition.
UK1 (C+F)	United Kingdom	Crushed greywacke, poorly sorted; reactive minerals are micro- or cryptocrystalline quartz, possibly volcanic glass.	Concrete with this aggregate has demonstrated high damage at moderate to high alkali levels in many real structures (more than 20 years until observed damage).

Aggregate combination	**Origin**	**Brief petrographic description**	**Reported alkali reactivity**
UK2 (C+F)	United Kingdom	Polymictic mature river gravel and sand, composed primarily of metaquartzite, ortho-quartzite, quartz (vein) and chert, which is the reactive portion in the aggregate; reactive minerals are micro- or cryptocrystalline or chalcedonic quartz.	Both, fine and coarse constituents have demonstrated high reactivity at moderately high alkali levels in many real structures, mainly bridges (damage after 10 to 15 years).
E1 (F)	Spain	Dolostone with prismatic dolomite chrystals cemented with calcite, also opal and clay are apparent in considerable amounts, reactive mineral is opal.	Serious damage (due to ASR?) reported in 30 years old precast element (big water pipe).

C = coarse aggregate (> 4 mm); F = fine aggregate (≤ 4 mm)

RILEM AAR-1 - NUMBER OF TESTS PERFORMED

"Name" of laboratory	Experience with AAR-1? [1)]	Number reported [2)]	Comments
1	2	9	Some questions should be answered by the laboratory
2	3	11	Several questions should be answered by the laboratory
3	3	14	
4	3	15	
5	1	6	Calculation of percentages?
6	3	21	Some questions should be answered by the laboratory
7	3	16	Several questions should be answered by the laboratory
8	1	3	
9	2	6	Some questions should be answered by the laboratory
10	3	10	Some questions should be answered by the laboratory
11	1	5	Some questions should be answered by the laboratory
12	2	4	
13	0	3	Have performed all the tests they are able to do (no point counting)
	Sum	123	

[1)] "Classified" according to a request performed in WP4:

3	= Performs the tests on a regular basis
2	= Has performed the test once or twice
1	= Equipement, but no experience
0	= No equipement, no experience
	= OK results (i.e. checked and found reasonable)
	= something is not clear

[2)] Total number of analyses performed (three procedures - see page 2-4). In most of the analyses several fractions were investigated

RILEM AAR-1

WHOLE ROCK PETRO

"Name" of laboratory	Experience with AAR-1? [1]	B1 WR (Silicified limestone (C+F, HR) [1])	UK1 WR (Greywacke (C+F, R))	P1 WR (Silicified Limestone (C, ?))	Number reported [3]	Comments
1	2			1	1	
2	3				0	
3	3		1		1	
4	3				0	
5	1				0	
6	3				0	
7	3				0	
8	1				0	
9	2				0	
10	3				0	
11	1				0	
12	2			1	1	Fraction investigated?
13	0	1			1	Fraction investigated?
	Sum	1	1	2	4	

[1] The type of aggregate, the fractions available and the supposed reactivity (NR=non reactive; R=reactive; HR=highly reactive) is based on a request (see Annex 3)

[2] "Classified" according to a request performed in WP4:

3	= Performs the tests on a regular basis
2	= Has performed the test once or twice
1	= Equipement, but no experience
0	= No equipement, no experience
	= OK results (i.e. checked and found reasonable)
	= something is not clear

[3] Total number of analyses performed according to the whole rock petro procedure

RILEM AAR-1

PARTICLE SEPARATION

"Name" of laboratory	Experience with AAR-1? 1)	Gravel with opaline flint (C+F, HR) 1) D1 C	Sea gravel semi-dense flint (C+F, SR) D2 C	Gravel with flint (C, HR) F1 C	Non reactive limestone (C+F, NR) F2 C	Siliceous gravel (C+F, PR/NR) F3 C	Gravel w/sil. limestone and chert (C, R) G1 C	Gravel w/opaline sandstone and flint (C, HR) G2 C	Gravel w/limestone, chert and flint (C+F, HR) It1 F	Gravel w/limestone, chert and flint (C+F, HR) It1 C	Gravel w/quartzite and gneiss (C+F, R) It2 C	Non reactive granitic sand (F, NR) N3 C	Silicified Limestone (C, ?) P1 C	Gravel w/porphyritic rhyolite (C+F, SR) S1 C	Gravel w/quartzite and chert (C+F, R) UK2 C	Number reported 3)	Comments
1	2	1	1												1	3	"AR-classes" not given for D1C
2	3															0	
3	3	1													1	2	
4	3	1					1	1		1	1			1		6	
5	1		1													1	
6	3	1	1	1	1	1	1	1		1	1			1		10	
7	3			1		1			1	1						4	Not able to give rock names or classify the reactivity
8	1						1									1	
9	2			1						1			1			3	
10	3	1					1					1		1	1	5	"AR-class" for sandstone?
11	1										1					1	
12	2	1														1	
13	0					1					1					2	
	Sum	6	3	3	1	3	4	2	1	4	4	1	1	3	3	39	

1) The type of aggregate, the fractions available and the supposed reactivity (NR=non reactive; R=reactive; HR=highly reactive) is based on a request (see Annex 3)

2) "Classified" according to a request performed in WP4:

3 = Performs the tests on a regular basis
2 = Has performed the test once or twice
1 = Equipement, but no experience
0 = No equipement, no experience
(orange) = OK results (i.e. checked and found reasonable)
(pink) = something is not clear

3) Total number of analyses performed according to the particle separation procedure. In most of the analyses several fractions were investigated

RILEM AAR-1

POINT COUNT ANALYSIS

"Name" of laboratory	Experience with AAR-1? [2]	B1 F Silicified limestone (C+F, HR) [1]	B1 C Silicified limestone (C+F, HR)	D1 F Gravel with opaline flint (C+F, HR)	D2 F Sea gravel semi-dense flint (C+F, SR)	D3 F Non reactive siliceous sand (F, NR)	F1 C Gravel with flint (C, HR)	F2 F Non reactive limestone (C+F, NR)	F3 F Siliceous gravel (C+F, PR/NR)	F3 C Siliceous gravel (C+F, PR/NR)	G1 F Gravel w/sil. limestone and chert(C, R)	G1 C Gravel w/sil. limestone and chert(C, R)	G2 C Gravel w/opaline sandstone and flint (C, HR)	It1 F Gravel w/limestone, chert and flint (C+F, HR)	It1 C Gravel w/limestone, chert and flint (C+F, HR)	It2 F Gravel w/quartzite and gneiss (C+F, R)	N1 C Cataclasite (C, R)	N2 C Sandstone (C, SR)	N3 F Non reactive granitic sand (F, NR)	N4 C+F Gravel w/sandstone and catacl. rocks (C+F, PR/NR)	N5 C+F Gravel w/rhyolite and quartzite (C+F, PR/NR)	N6 C+F Gravel w/rhyolite and quartzite (C+F, SR)	S1 C Gravel w/porphyritic rhyolite (C+F, SR)	S1 F Gravel w/porphyritic rhyolite (C+F, SR)	UK1 F Greywacke (C+F, R)	UK2 C Gravel w/quartzite and chert (C+F, R)	UK2 F Gravel w/quartzite and chert (C+F, R)	P1 C Silicified Limestone (C, ?)	E1 F Dolostone (F,?)	Number reported [3]	Comments
1	2			1	1	1																				1	1			5	"AR-classes" not given for D1F. Will more tests be performed?
2	3			1	1	1	1		1							1			1					1		1	1		1	11	Is D1 marked wrong? C or F tested? AC/WP? AR-classes?
3	3			1													1	1	1	2	2	2					1			11	
4	3			1										1		1				2				1		1	1		1	9	
5	1	1			1	1														2										5	Calcultation of percentages?
6	3		1	1	1			1	1		1		1	1		1								1				1		11	
7	3			1	1				1	1		1	1	1	1	1	1						1	1						12	Only the reactive material is reported. What about the rest?
8	1												1				1				X									2	Only comments are given to the rock/mineral composition of N5(C+F)
9	2								1			1		1																3	
10	3			1															1					1	1		1			5	
11	1								1					1		1													1	4	Assume that IT1(F) is investigated, not IT1(C)
12	2			1	1																									2	
13	0																													0	
	Sum	1	1	8	6	3	1	1	5	1	1	2	3	5	1	5	3	1	3	6	2	2	1	5	1	3	5	1	3	80	

[1] The type of aggregate, the fractions available and the supposed reactivity (NR=non reactive; R=reactive; HR=highly reactive) is based on a request (see Annex 3)

[2] "Classified" according to a request performed in WP4:

3 = Performs the tests on a regular basis
2 = Has performed the test once or twice
1 = Equipement, but no experience
0 = No equipement, no experience
= OK results (i.e. checked and found reasonable)
= something is not clear

[3] Total number of analyses performed according to the point counting procedure. In most of the analyses several fractions were investigated

WP3.1 - Summary results of petrographic analyses

Annex 5

= OK results (i.e. checked and found reasonable

= something is not clear or uncertain

Aggregate	Fraction[1] (mm)	Statistics[2]	Whole rock petro (%) sum II+III[3]	Whole rock petro (%) Comments	Particle separation (%) sum II+III	Particle separation (%) Comments	Point counting (%) TS 2-4 mm[5] sum II+III	TS 2-4 mm[5] Comments	TS 1-2 mm[5] sum II+III	TS 1-2 mm[5] Comments	TS 0.063-1 mm[5] sum II+III	TS 0.063-1 mm[5] Comments	Field perfor-mance[6]	Results in agree-ment with field performance ?
B1(F)	0-2	"average"									97	1 result (TS 0.125-2 mm)	R?	YES
B1(C)	4-20/"coarse"	"average"	16	1 result (1 lab., 1 frac.)			100	1 result (1 lab., 1 frac.)[4]			100	1 result (TS 0.063-2 mm)	R	YES
D1(F)	0-4	average					36?	7 results (7 lab., 1 frac.)	39	5 results (5 lab., 1 frac.)	48	3 results (3 lab., 1 frac.)	R (pessimum behavior)	YES
		median					16?		44		35			
		minimum					6		7		28			
		maximum					85		87		81			
D1(C)	4-8 / 8-16	average			<54	8 results (6 lab., 2 frac.)							R (pessimum behavior)	YES
		median			<49/71									
		minimum			13									
		maximum			96									
D2(F)	0-4	average					38	5 results (5 lab., 1 frac.)	50	3 results (3 lab., 1 frac.)	53	2 results (2 lab., 1 frac.)	R	YES
		median					28		40		--			
		minimum					2		9		6			
		maximum					100		100		100			
D2(C)	4-8 / 8-16	average			56	3 results (3 lab., 2 frac.)							R	YES
		median			65									
		minimum			4									
		maximum			100									
D3(F)	0-2	average							2	2 results (2 lab., 1 frac.)			NR	YES
		median							--					
		minimum							0					
		maximum							3					
F1(C)	6-20	"average"			95	3 results (3 lab., 1 frac.)	96	1 result (1 lab., 1 frac.)	96	1 result (1 lab., 1 frac.)	86	1 result (0-1 mm)	R (pessimum behavior)	YES
		median			97		--		--		--			
		minimum			90		--		--		--			
		maximum			98		--		--		--			
F2(F)	0-5	"average"					0	1 result (1 lab., 1 frac.)	0	1 result (1 lab., 1 frac.)	0	1 result (1 lab., 1 frac.)	NR	YES
F2(C)	5-20	"average"			0	1 result (1 lab., 1 frac.)							NR	YES
F3(F)	0-4	average					53?	5 results (5 lab., 1 frac.)	54	4 results (4 lab., 1 frac.)	60	3 results (3 lab., 1 frac.)	NR?	NO
		median					42		35/70		76			
		minimum					37		30		25			
		maximum					94		82		78			
F3(C)	4-20	"average"			63	2 results (2 lab., 1 frac.)	26?	1 result (1 lab., 1 frac.) (TS > 4 mm)					NR?	NO
		median			--		--							
		minimum			40		--							
		maximum			86		--							
G1(C)	"4-22"	"average"			52	8 results (4 lab., 4 frac.)	46	1 result (1 lab., 1 frac.)	44	1 result (1 lab., 1 frac.)	33	1 result (1 lab., 1 frac.)	R	YES
		median			51/52		--		--		--			
		minimum			11		--		--		--			
		maximum			100		--		--		--			
G2(C)	"2-8"	average			60	2 results (2 lab., 2 frac.)	50?	3 results (3 lab., 2 frac.)					R	YES
		median			--		43							
		minimum			30		14?							
		maximum			89		92							
It1(F)	0-5	average					32?	4 results (4 lab., 1 frac.)	61	2 results (2 lab., 1 frac.)	55	2 results (2 lab., 1 frac.)	R	YES
		median					10		--		--			
		minimum					8		21		10			
		maximum					100		100		100			
It1(C)	"5-30"	"average"			40	3 results (3 lab., 2 frac.)	10?	1 result (1 lab., 1 frac.?)					R	YES
		median			17		--							
		minimum			4		--							
		maximum			100		--							
It2(F)	0-5	average					51?	5 results (5 lab., 1 frac.)	82	3 results (3 lab., 1 frac.)			R?	YES
		median					24?/81		86					
		minimum					14		60					
		maximum					100		100					
It2(C)	"5-30"	average			84	4 results (4 lab., 2 frac.?)							R	YES
		median			100									
		minimum			36									
		maximum			100									
N1(C)	4-16	average					90?	3 results (3 lab., 1 frac.)					R	YES
		median					98							
		minimum					71?							
		maximum					100							
N2(C)	8-16	"average"					100	1 result (1 lab., 1 frac.)					R	YES
N3(F)	0-4	average					2	3 results (3 lab., 1 frac.)	2	3 results (3 lab., 1 frac.)	2	2 results (2 lab., 1 frac.)	NR	YES
		median					1		1		--			
		minimum					0		0		0			
		maximum					6		6		4			
N3(C)	2-8/8-16	"average"			5	2 results (1 lab., 2 frac.)							NR	YES
N4(F)	0-7	average					27	2 results (2 lab., 1 frac.)					R?	YES
		median					--							
		minimum					23							
		maximum					31							
N4(C)	7-16	average					25	2 results (2 lab., 1 frac.)					R	YES
		median					--							
		minimum					23							
		maximum					27							
N5(F)	0-8	"average"					22	1 result (1 lab., 1 frac.)	17	1 result (1 lab., 1 frac.)			R?	YES
N5(C)	8-16	"average"					22	1 result (1 lab., 1 frac.)					R	YES
N6(F)	0-8	"average"					37	1 result (1 lab., 1 frac.)	23	1 result (1 lab., 1 frac.)			R?	YES
N6(C)	8-16	"average"					33	1 result (1 lab., 1 frac.)					R	YES
S1(F)	0-8	average					52?	5 results (5 lab., 1 frac.)	61	3 results (3 lab., 1 frac.)			R?	YES
		median					44		45					
		minimum					35?		37					
		maximum					100		100					
S1(C)	4-16	average			59	3 results (3 lab., 1 frac.)	43?	1 result (1 lab., 1 frac.) (TS > 4 mm)					R?	YES?
		median			40		--							
		minimum			40		--							
		maximum			98		--							
UK1(F)	0-5	"average"					83	1 result (1 lab., 1 frac.)	66	1 result (1 lab., 1 frac.)	40	1 result (1 lab., 1 frac.)	R?	YES
UK1(C)	4-8	"average"	100	1 result (1 lab., 1 frac.)									R	YES
UK2(F)	0-5	average					52	5 results (5 lab., 1 frac.)	27	3 results (3 lab., 1 frac.)			R	YES
		median					54		9					
		minimum					15		7					
		maximum					89		66					
UK2(C)	5-20	average			59	4 results (3 lab., 1 frac.)	54	3 results (3 lab., 1 frac.)					R	YES
		median			73/75		48							
		minimum			10		15							
		maximum			79		98							
P1(C)	4-19	"average"			100	1 result (1 lab., 1 frac.)	100	1 result (1 lab., 1 frac.)					R	YES
P1(WR)	"Crushed 2-4"	average	53	2 results (2 lab., 1 frac.?									R	YES
		median	--											
		minimum	6											
		maximum	100											
E1(F)	0-4	average					3?	3 results (3 lab., 1 frac.)	3?	2 results (2 lab., 1 frac.)			R?	NO
		median					--		--					
		minimum					0		0?					
		maximum					8		5					

[1] The fraction investigated in the petrographic analyses

[2] The **average** represents the mean results of all the investigated fractions at all laboratories. **"Average"** means less than three results available, and thus no statistical calculation performed

[3] The numbers represent the sum of the "reactivity classes" II and III, i.e. the sum of all the rock types not likely to be non alkali reactive

[4] lab. = laboratories ; frac. = fractions

[5] TS = thin sections

[6] R = proved to alkali reactive based on field performance ; NR = not observed damage due to ASR in real structures (see ANNEX 3)