RILEM Technical Committee 258-AAA. Development of a performance-based testing concept

Børge Johannes Wigum (1), Jan Lindgård (2)

(1) HeidelbergCement NE, Reykjavik, Iceland, BorgeJohannes.Wigum@heidelbergcement.com

(2) SINTEF, Trondheim, Norway, Jan.Lindgard@sintef.no

Abstract

In the 6 years period from 2014 – 2020, the RILEM Technical Committee (TC) 258-AAA developed a performance-based testing concept for the prevention of deleterious Alkali-Silica Reactions (ASR) in concrete. A total of 5 new recommendations have been developed during this TC, summarized in an updated Outline Guide (RILEM AAR-0) which is an extended version of the previous edition (2016).

In the first Work Package (WP1), four different performance tests methods (RILEM AAR-10, -11, -12 & -13) were developed, based upon various national concrete prism tests and RILEM aggregate tests.

WP2 assessed results from accelerated performance-based test methods vs. results from field exposure sites at various climatic conditions around the world. Results will be published in various scientific papers, and in an overall State-of-the-art report (STAR) from this TC.

WP3 assessed the detailed alkali inventory in concrete and developed an accelerated test method (RILEM AAR-8) for measuring the potential alkali release from aggregates. However, within the TC is became clear that there is an urgent need to verify how much of the amount of releasable alkalis measured under accelerated conditions (AAR-8) is actually released in concrete in real structures. Hence, during the time of the work, WP4 was established in order to address this challenge. Results from WP3 will also be included in various scientific papers.

Strong emphasis was also put on the implementation of the RILEM methods and recommendations as national- and international standards.

Keywords: *AAR; Performance testing; RILEM*

1. INTRODUCTION AND BACKGROUND

The International Union of Laboratories and Experts in Construction Materials, Systems and Structures, i.e. RILEM, was founded in June 1947, with the aim to promote international scientific cooperation in the area of construction materials and structures. Today, the new meaning of the acronym RILEM (*Réunion Internationale des Laboratoires et Experts des Matériaux, systèmes de construction et ouvrages*) emphasises its dominant focus on people as well as its worldwide activities, covering 70 countries. Development and assessment of universal test methods for avoiding deleterious Alkali Aggregate Reaction (AAR) in concrete have been the focus of consecutive RILEM Technical Committees (TCs) for more than 3 decades. The first TC related to alkali aggregate reaction was established in 1988 as *TC 106*, with Dr Philip Nixon from the Building Research Establishment (BRE) in the UK as the Chairman and Dr Ian Sims from Sandberg, UK (now with RSK Environment Ltd) as the Secretary. The primary objective of the TC was to develop test methods for aggregate reactivity that could form the basis for internationally agreed test methods. The subsequent *TC 191-ARP*, formed in 2000, continued working on aggregate test methods. The 3rd RILEM TC on AAR, *TC 219-ACS* was established in 2007. Most of the issues included in the former TC proceeded, but a few new topics were added. One main new activity initialised in the TC 219-ACS was performance testing of concrete, i.e. how to safely use alkali-reactive aggregates. Early in 2014, the TC terminated its activities and concluded the work of the three TCs chaired by Dr Nixon with Dr Sims as the secretary for 25 years. A more detailed historical overview of the RILEM TCs is presented by Wigum et al. [1] in another paper at this ICAAR-conference.

2. ACTIVITIES IN RILEM TC 258-AAA

The 4th RILEM TC on ASR (*TC 258-AAA*) was established in October 2014, and was finalised during end of August 2020. It has been chaired by Professor Børge Johannes Wigum (*HeidelbergCement Northern Europe, Norway*), whereas the secretary has been Dr Jan Lindgård (*SINTEF, Norway*). The main purpose of this TC, comprising four Work Packages (WPs), was to develop and promote a performance-based testing concept for the prevention of deleterious ASR in concrete (the issue Alkali Carbonate Reaction (ACR) was not included). Emphasis was also put on implementing the RILEM methods and recommendations as national- and international standards.

RILEM TC 258-AAA has had a wide international membership, which helps to promote the eventual international use of RILEM methods and recommendations. Physical meetings were held twice a year. They have been the centre of the TC's activities. Table 2.1 presents an overview of the 12 meetings. Members from around the world that have not been able to travel to the meetings have been following the discussions through the extended minutes of the meetings. All relevant documents, including the minutes from the meetings, various presentations and working documents have been available for TC members on the RILEM internal website. The meetings were usually organised with pre-meetings in the various WPs during the first day, followed by a general TC meeting the second day. Often, the opportunity was used to have technical presentations by local participants, guest or PhD-students. During the course of the work, the TC's activities have been presented at several international conferences [2], [3] & [4].

The Norwegian R&D project ("KPN-ASR", partly funded by the Norwegian Research Council), dealing with the similar topics as TC 258-AAA, has provided valuable input to the TC work and partly funded some joint activities. Moreover, the R&D project has also enabled fruitful co-operation with leading researchers in Norway, Northern America and with LNEC in Portugal.

Table 2.1: Overview of all TC meetings

TC-meetings	Venue	Participants
1st meeting	Oslo, Norway, October 2014	27
2nd meeting	London, UK, April 2015	35
3rd meeting	Toronto, Canada, September 2015	23
4th meeting	Paris, France, March 2016	22
5th meeting	São Paulo, Brazil, July 2016	22
6th meeting	Copenhagen, Denmark, August 2016	28
7th meeting	Stockholm, Sweden, May 2017	32
8th meeting	Vienna, Austria, November 2017	25
9th meeting	Reykjavík, Iceland, June 2018	28
10th meeting	Dübendorf, Switzerland, November 2018	29
11th meeting	Rovinj, Croatia, March 2019	20
Working meeting	Lisbon, Portugal, September 2019	12
12th meeting	Delft, the Nederland's, December 2019	25

In total, 5 new recommendations have been developed during this TC, summarized in an updated Outline Guide (RILEM AAR-0) which is an extended version of the previous edition. The AAR-0 guide includes new recommendations; AAR-8 is an assessment procedure for aggregates, while AAR-10 to AAR-13 contain assessment procedures for combinations of aggregates and binders, i.e. performance testing that may be applied to assess mix design requirements when using reactive or potentially reactive aggregates.

Figure 2.1: Inaugural meeting, Oslo, Norway; October 2014 (Photo: *Patricija Kara De Maeijer*)

Figure 2.2: Final meeting, Delft, the Nederland's; December 2019 (Photo: *Patricija Kara De Maeijer*)

3. THE ACTIVITIES IN THE WORK PACKAGES

This TC has produced an updated version of the Outline Guide (RILEM AAR-0). The guide describes how to use the RILEM methods in the assessment of the alkali-reactivity of concrete. This new version is based on the version from 2016 [5]. In addition to the original content and description of the various test methods, the new version describes the new performance test methods (AAR-10, AAR-11, AAR-12 & AAR-13), along with the new test-method of measuring potential alkali release from aggregates (AAR-8).

The scope of the present AAR-0 is to explain how the above methods may be used as single tests or in combinations to assess properties of aggregates and concrete related to ASR. The guidance includes also preliminary advice on the interpretation of the results.

3.1 WP1 – Performance testing and accelerated testing in the laboratory

Dr Terje F. Rønning (*HeidelbergCement Northern Europe, Norway*) has been the leader of WP1, and Dr Jan Lindgård (*SINTEF, Norway*) has been the deputy.

By implementing performance test methods one can draw advantage from the mitigating effect of supplementary cementitious materials (SCMs) such as fly ash, silica fume, calcined clay, ground granulated blast-furnace slag (ggbfs) or other natural pozzolanic materials, or of low alkali cements. By using such mitigating measures, a much wider selection of aggregates can be safely used while increasing the sustainability of the concrete and aggregate industry. The performance testing concept includes performance assessment of combinations of aggregates and cement/binders at varying or fixed alkali contents. In some countries, for example Norway and Canada, concrete performance tests have been used for decades. By assessing existing methods and new findings in various national research projects, WP1 fulfilled the main aim developing one or more concrete performance test methods.

The new 38°C performance test method, RILEM AAR-10, and the new 60°C performance test methods, RILEM AAR-11 and RILEM AAR-12, have been developed for testing aggregate combinations together with various binder combinations (i.e. composite cements or pure Portland cements + supplementary cementitious materials; SCMs). The methods consist of measuring the expansion produced by AAR of concrete prisms stored in environments which accelerate the reaction. The new "performance test method", RILEM AAR-13, is a new procedure introducing wrapping of the prisms in fabric soaked in alkaline solution aiming to prevent loss of alkalis during testing.

3.1.1 RILEM Recommended Test Method: AAR-10. Determination of binder combinations for non-reactive mix design using concrete prisms – 38°C test method

The principle of the AAR-10 is founded upon AAR-3 [5], but based on experiences from the Norwegian concrete prism test [6] an increased prism dimension is applied to reduce the alkali leaching during the exposure of the prisms [7]. The procedures of AAR-10 include the following applications for performance assessment of combinations of aggregates and cement/binders (incl. maximum CEM I (EN 197-1) content) at various or specific alkali content(s):

- Application 1: AAR-10.1: Assessment of how the SCM content may reduce ASR susceptibility of an aggregate combination: Enabling the use of a specific reactive aggregate product together with critical binder combination(s) (minimum binder requirements) for producing non-reactive concrete. AAR-10.1 includes assessment of alkali threshold with CEM I for a specific aggregate combination
- Application 2: AAR-10.2: Assessment of how available binder alkali content can be reduced by SCMs: Enabling the determination of the required general binder composition together with a regional worst-case aggregate combination for producing non-reactive concrete (within that region)

3.1.2 RILEM Recommended Test Method: AAR-11. Determination of binder combinations for non-reactive mix design or the resistance to alkali-silica reaction of concrete mixes using concrete prisms – 60°C test method

The principle of AAR-11 is based upon AAR-4 [5]. The procedures of AAR-11 include the following applications for the performance assessment of combinations of aggregates and cement/binders (incl. maximum CEM I (EN 197-1) content) at various or specific alkali content(s) and for the assessment of the ASR-resistance of concrete mixes:

- Application 1: AAR-11.1: Assessment of how the SCM content may reduce AAR susceptibility of an aggregate combination: Enabling the use of a specific reactive aggregate product together with critical binder combination(s) (minimum binder requirements) for producing non-reactive concrete

- Application 2: AAR-11.2: Assessment of how available binder alkali content can be reduced by SCMs: Enabling the determination of the required general binder composition together with a regional worst-case aggregate combination for producing non-reactive concrete (within that region)
- Application 3: AAR-11.3: Assessment of the ASR-resistance of specific concrete compositions to verify its suitability in a performance test

3.1.3 RILEM Recommended Test Method: AAR-12. Determination of binder combinations for non-reactive mix design or the resistance to alkali-silica reaction of concrete mixes using concrete prisms – 60ºC test method with alkali supply

The new 60°C performance test method RILEM AAR-12 covers environmental conditions with the impact of de-icing salts and agents, i.e. it covers concrete that is exposed to moisture and de-icing salts, seawater or salt spray. It is essentially the same as RILEM method AAR-11 (concrete prism test at 60 °C), but the storage conditions have been modified to evaluate the impact of de-icing salts and agents. It is based on a method issued by the German Road and Transportation Research Association (FGSV) for evaluating the potential for deleterious ASR in concrete proposed for use in pavements and road structures [8]. The procedures include the following applications for the performance assessment of combinations of aggregates and cement/binders (incl. maximum CEM I (EN 197-1) content) at various or specific alkali content(s) and for the assessment of the ASR-resistance of concrete mixes:

- Application 1: AAR-12.1: Assessment of how SCM content may reduce ASR susceptibility of an aggregate combination: Enabling the use of a specific reactive aggregate product together with critical binder combination(s) (minimum binder requirements) for producing non-reactive concrete
- Application 2: AAR-12.2: Assessment of how available binder alkali content can be reduced by SCMs: Enabling the determination of the required general binder composition together with a regional worst-case aggregate combination for producing non-reactive concrete (within that region)
- Application 3: AAR-12.3: Assessment of the ASR-resistance of specific concrete compositions to verify its suitability in a performance test

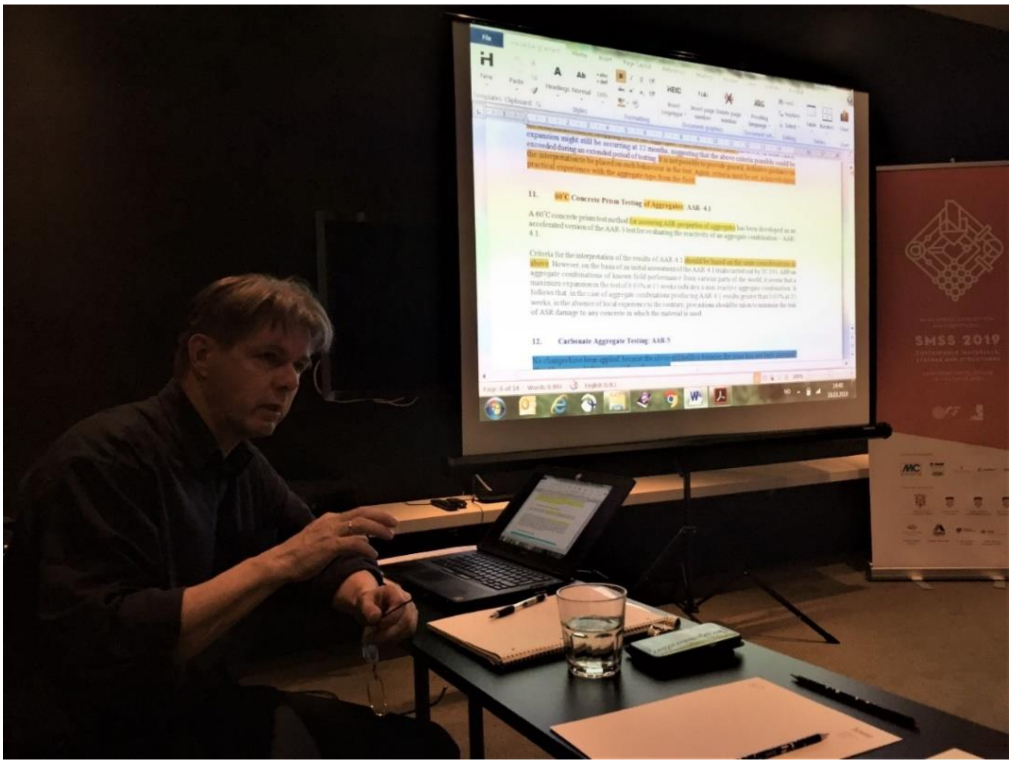

Figure 3.1: Terje F. Rønning, WP1-leader at Rovinj-meeting (2019) (Photo: *Børge J Wigum*)

3.1.4 RILEM Recommended Test Method: AAR-13. Application of alkali-wrapping for concrete prism testing to assess the expansion potential of alkali-silica reaction

The new "performance test method" RILEM AAR-13 provides a wrapping procedure aiming to prevent loss of alkalis by providing an equilibrium of alkali concentration at the specimen surface while also supplying additional moisture for concrete prisms during expansion tests for ASR. A technical committee of the Japan Concrete Institute [9] originally proposed the wrapping procedure.

This may be of particular relevance if the internal alkali content risks being reduced to a level below the alkali threshold level of the aggregate, or if the internal moisture level may drop, preventing further reaction. This procedure is intended being used in combination with various concrete prism tests such as RILEM AAR-3 & AAR-4.1 and CSA-A23.2-14A-14 for aggregate testing, RILEM AAR-10 & AAR-11 for performance testing, and JASS5N T603 for the actual concrete mixture with combinations of aggregate and binders considering various pessimum effects.

3.2 WP2 – Performance testing and laboratory vs. field; Exposure sites

Professor Benoît Fournier (*Université Laval, Québec, Canada*) has been the leader of WP2, and Dr Renaud-Pierre Martin (*Université Gustave Eiffel (prev. IFSTTAR), France*) has been the deputy.

An important tool for validating the performance testing concept is to assess the link between accelerated results from laboratory testing and behaviour of these concrete mixtures in field, either on field exposed blocks or on real structures. One key objective of WP2 was to establish a link between outdoor exposure sites dedicated to ASR investigations located in different parts of the world, and thereby generating an international database on the effect of environmental conditions on the kinetics of ASR. A paper [10] giving an overview of field exposure sites world-wide has also been presented.

3.2.1 The LNEC-cube study

The initial work of WP2 included preparation of about 80 monitored concrete cubes (300x300x300 mm^3) for outdoor storage at 10 different exposure sites in Europe and North America (Portugal, France, Germany, Norway, Iceland, Canada & USA). The concrete mixing and casting of the cubes were carried out at LNEC in Portugal. The concrete mixtures included ordinary Portland cement and addition of fly ash (20 & 30 wt.%), along with control mixtures (highly reactive and non-reactive). The expansion of the cubes is measured once or twice a year for at least ten years, preferably longer.

Figure 3.2: Exposure site cubes ready for shipment from LNEC in Lisbon (2015). João Custódio (left) and WP2 leader: Benoit Fournier (Photo: *Jan Lindgård*)

Custódio et al. [11] will present an overall summary of the LNEC-cube study in a paper at this ICAAR-conference. In addition, it is the intension, to publish a scientific paper regarding the; "*Correlating field and laboratory investigations for preventing ASR in concrete – the LNEC cube study*", by Custódio et al., and a second scientific paper regarding; "*Focus on the field data; exposure conditions, five years expansion and cracking*", by Lindgård et al.. An electronic database will also be developed.

3.2.2 The PARTNER-cube post-documentation

The EU PARTNER project (2003-2006) produced 100 identical monitored concrete cubes (300x300x300 mm^3) from 13 aggregate combinations (all with a high alkali Portland cement) that were distributed to eight field exposure sites across Europe. In 2017, the laboratory of LNEC in Portugal shipped about 80 cores drilled from 21 selected PARTNER cubes after 13 years of field exposure to laboratories taking part in the post-documentation program being part of WP2. The coring was performed at LNEC, except the cubes stored in Valencia that were cored at IETcc-CSIC in Spain.

Results from the PARTNER study are presented at this ICAAR-conference in three papers; one paper by Borchers et al. [12] (updated field expansions compared with the previous accelerated laboratory expansions) and two papers from the post-documentation, one by Lindgård et al. [13] and one by Fernandes et al. [14]. In addition, it is the intension, to publish three corresponding journal papers. A summary report collecting all results, and all contributions, will also be produced.

3.2.3 State-of-the-art report – Part II regarding laboratory/field correlation

As part of an extensive State-of-the-art report (STAR) of this entire TC, a comprehensive part covers the laboratory/field correlation. The part covers:

- Introduction
- Exposure sites
    - Tools for assessing performance
    - Studies in progress
    - Studies in development
    - Older sites
    - Correlation field – lab (modelling)
    - How to develop an exposure site
- Field performance of concrete structure
- Solutions for improving performance testing
- Conclusions and recommendations

3.3 WP3 – Performance testing; Assessment of detailed alkali inventory in concrete, including internal alkali release from aggregates, recycling of alkali and external alkali supply

Dr Esperanza Menéndez Méndez (*Institute of Construction Science, "Eduardo Torroja" (CSIC), Spain*) has been the leader of WP3, and Dr António Santos Silva (*Laboratório Nacional de Engenharia Civil – LNEC, Portugal*) has been the deputy.

One important "missing link" with respect to testing methods for ASR is how to reliable measure the potential (maximum) amount of alkalis that might be released from various types of aggregates in the laboratory, under accelerated conditions, and in the field. The main aim of WP3 was to prepare a test method for measuring this potential alkali contribution from aggregates. In addition, as part of the TC's STAR, an assessment of detailed alkali inventory in concrete was carried out, including internal alkali release from aggregates, recycling of alkali and external alkali supply.

Figure 3.3: WP-3 leader: Esperanza Menéndez Méndez and WP-3 deputy: António Santos Silva, at the Reykjavik-meeting (2018) (Photo: *Børge J. Wigum*)

3.3.1 RILEM Recommended Test Method: AAR-8. Determination of Potential Releasable Alkalis by Aggregates in Concrete

The test method AAR-8 is intended to be used to assess the potential amount of alkalis released by aggregates in field concrete in the long-term. This is done through determination of the amounts of sodium and potassium ions released by aggregates immersed in (0.7 M) KOH and NaOH solutions, respectively, when in contact with excess calcium hydroxide. This accelerated method must be considered as a mere indication of potential alkali release by the aggregates rather than a quantification used for the alkali inventory calculations.

A “Round-Robin Test” (RRT1) of the draft "RILEM AAR-8" methods was completed, revealing some important issues to be reviewed in the testing procedure [15]. Hence, a second RRT2 was carried out, showing significantly less variations between the laboratories taking part.

3.3.2 State-of-the-art report – Part I regarding alkali inventory in concrete

A comprehensive part of the extensive State-of-the-art (STAR) report from the entire TC, covers the overview of the alkali-inventory in concrete. The part will cover:

- Introduction
- Sources of alkalis
  - Internal sources
  - External sources
  - Electrochemical treatments

- Analytical methods to determine the alkalis
    - Sample size and representativeness
    - Preparation of sample materials and specimen for analysis
    - Analytical methods to determine alkali content and constituents
    - In-situ determination of alkali content SEM-EDS and others
    - Reporting of analytical results, analytical error
- International standards and recommendations
    - Standardized method to quantify the total amount of alkalis
    - Standardized methods to determine the releasable alkalis
    - Standardized methods to quantify the total alkalis in the concrete
- Field concrete
    - Pavements
    - Dams

3.4 WP4 – Verification of alkalis released from aggregates

Professor Klaartje De Weerdt (*Norwegian University of Science and Technology, Norway*) has been the leader of WP4.

Results from measured potential (maximum) alkali release from aggregates in accelerated laboratory tests (RILEM AAR-8) need to be verified and potentially calibrated to what actually will be released to the concrete pore water in real concrete structures. At the 4th TC meeting in Paris (2016) it became clear that there was a need for a new WP, which would deal with the verification issue. The main aim of WP4 was to assess results from WP-3 versus results from exposure sites and concrete structures worldwide to assess the "true" level of alkali released from various aggregates.

The Post-doc study of Gilles Plusquellec which was part of the Norwegian "KPN-ASR" project focused on this. He developed a test method to determine the alkali level in the pore water of field concrete [16]. He applied this method on an existing structure, the Votna Dam in Norway, in order to verify the level of potential alkali release from aggregates [17]. He discovered that depending on the assumption of how much of the alkali originating from the cement would be free in the pore solution (50-70%), the alkali contribution of the aggregates would range between 0.2 and 1.1 Na_2O_{eq} kg/m^3 (common limit for alkali content in concrete is 2.5 Na_2O_{eq} kg/m^3). Where 0.2 Na_2O_{eq} kg/m^3 would be almost negligible, whereas 1.1 could be a decisive contribution to ASR. Hence, this is a large variation in alkali contribution and does not allow us to conclude on the alkali contribution from the aggregates. It was concluded that for the verification of the alkali contribution of aggregates, one would need reference concrete with the same cement but with non-releasing aggregates (e.g. pure limestone). Based on this field study, De Weerdt et al. developed a concept for a verification strategy, which was presented at the Conference: SMSS 2019 in Rovinj [18].

The key message is that for future research projects on AAR a reference concrete containing the same binder but non-releasing aggregates (e.g. pure limestone) should be included. This would enable the determination of share of the total alkali from the cement is available in the concrete pore solution, which is cement and concrete specific. With this into place one would be able to determine the alkali release of time.

Research projects on the verification of alkali release from aggregates needs to have a long-term perspective (5-20 years) as the release in real concrete is slow process. One should also focus on the finer fractions of the aggregates e.g. sand as they present a larger surface and thereby a larger potential for release.

Finally, there is also room for improvement when it comes to the methods to determine free alkali content. Improvement in the accuracy of these methods would improve the accuracy of the alkali inventory calculations and would bring us closer to verifying the alkali release from aggregates.

Figure 3.4: WP-4 leader: Klaartje De Weerdt at the Rovinj meeting (2019). (Photo: *Børge J. Wigum*)

4. FUTURE FOLLOW-UPS

Through more than three decades, and four RILEM TCs, we have now thorough test-methods and procedures for testing the reactivity of various aggregates. We have also developed performance-based test procedures enabling assessment of concrete mixes. Expansion measurements from accelerated conditions in laboratories have been compared with results from various outdoor exposure sites, with various climatic conditions. The RILEM recommendations do not include specific critical expansion limits, and it is now a challenge for various countries or regions to establish their own critical limits correlated to local materials and local climatic conditions. A lot has been invested in the various outdoor exposure sites, and it is of paramount importance that those sites are followed up, with regularly measurements, in the years and decades to come.

A method to measure the potential alkali release from aggregates has finally been developed. However, it is very important to realise that this accelerated laboratory method must be considered as a mere indication of potential alkali release by the aggregates, rather than a quantification that can be used directly in the alkali inventory calculations. In order to apply the values obtained by the RILEM AAR-8 method, it is crucial to verify these numbers by comparing them to what is occurring in real concrete structures or concrete cubes stored at outdoor exposure sites. It is also important to consider if the potential alkali release from aggregates already are to some extent accounted for in the new presented performance testing concepts. This future comprehensive work of verification is of particular importance, as the European Committee for Standardization recently has had long discussions if to implement a method measuring potential alkali release from aggregates as a European Standard. However, at the moment it seems that such a method will not be implemented.

All these new challenges will be dealt with by a subsequent new RILEM TC, which was approved during the autumn of 2020. The chairman of this new TC is Professor Jason H. Ideker, from Oregon State

University, US, and deputy-chair is professor Klaartje De Weerdt, from Norwegian University of Science and Technology.

Figure 4.1: TC-Secretary: Jan Lindgård (left) and TC-Chairman: Børge Johannes Wigum at the Dübendorf/EMPA meeting in 2018.

5. ACKNOWLEDGEMENTS

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