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Rilem activities on alkali–silica reactions: from 1988–2019

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Since 1988, the International Union of Laboratories and Experts in Construction Materials, Systems and Structures (Rilem) technical committees (TCs) have been seeking to establish universally applicable test methods for assessing the alkali-reactivity potential of aggregates, and from later on, for concrete mixes. TC 106, in the years 1988 to 2001 focused on accelerated aggregate tests, and presented the findings at the International Conferences on Alkali Aggregate Reactions (ICAAR) in Kyoto in 1989, London in 1992, Melbourne in 1996 and Quebec in 2000. The successor committee TC 191-ARP in the years 2001 to 2006 also included work on diagnosis/appraisal and specification, and presented the findings at the ICAAR in Beijing in 2004. TC 219-ACS in the years 2006 to 2014 introduced work on performance testing and modelling, and presented its findings at the ICAARs in Trondheim in 2008 and in Austin in 2012. The major recommendations were published as a Rilem state-of-the-art report in 2015. In 2014, the TC 258-AAA was established, and it scheduled the completion of work on performance-based assessment for 2019. The preliminary findings will be published at the ICAAR in São Paolo in 2016.

Alkali–aggregate reactions (AAR) can be defined as chemical reactions between the alkali hydroxides (sodium and potassium) in the pore solution of concrete and certain minerals in the aggregate. The product of the AAR is typically a hygroscopic gel that expands on hydration and may introduce cracking in the surrounding hardened concrete, thereby debilitating the mechanical properties of the concrete, reducing the structure's service life and increasing the cost to society. The incubation time needed before AAR damage starts ranges from a few months to several decades, with much depending on the aggregate type, binder type and exposure climate.

The development and assessment of universal test methods to avoid deleterious AAR in concrete have been the focus of the International Union of Laboratories and Experts in Construction Materials, Systems and Structures (Rilem) technical committees (TCs) for more than two decades. The first TC regarding AAR was established in 1988 as TC-106, with Dr Philip Nixon from the Building Research Establishment in the UK as the chairman, and Dr Ian Sims from Sandberg, UK (now with RSK Environment Ltd) as the secretary. The TC was proposed by Micheline Regourd-Moranville. The formation of this TC was reported at the Eighth International Conference on Alkali Aggregate Reaction (ICAAR) in Kyoto, where the second and third meetings of the TC were held immediately before and during the conference. The primary objective of the TC was to develop tests for aggregate reactivity that could form the basis for internationally agreed methods and monitoring of progress, as presented by Nixon and Sims (1992).

In addition, some extra tasks were undertaken, in particular, a survey of national specifications for avoidance of AAR damage, and conducting an assessment of reports of damage to structures made with low-alkali cement or that contain fly ash or ground granulated blast-furnace slag. In 1993, an interim report was presented on the progress of the TC-106 in developing tests for aggregate reactivity that could form the basis for internationally agreed methods (Nixon and Sims, 1993). In 1996, TC-106 had members from 21 countries, including virtually all those, who at that time, were regarded as having significant AAR problems. The TC conducted a survey of test methods in use in the participating countries, presented by Nixon and Sims (1996). Following trials to demonstrate effectiveness in differentiating reactive and non-reactive aggregate combinations worldwide, TC-106 finalised two expansion tests in 2000 presented by Nixon and Sims (2000) at the 11th ICAAR in Québec. The concrete prism test (CPT) (Figure 1) was considered to be reliable for

most aggregate combinations, and an accelerated mortar-bar test (Figure 2) was usually found to be suitable for predicting behaviour in the concrete test.

The work of TC-106 culminated in 2000 in an integrated assessment scheme, presented by Sims and Nixon in (2001). After considering a wide range of methods for assessing

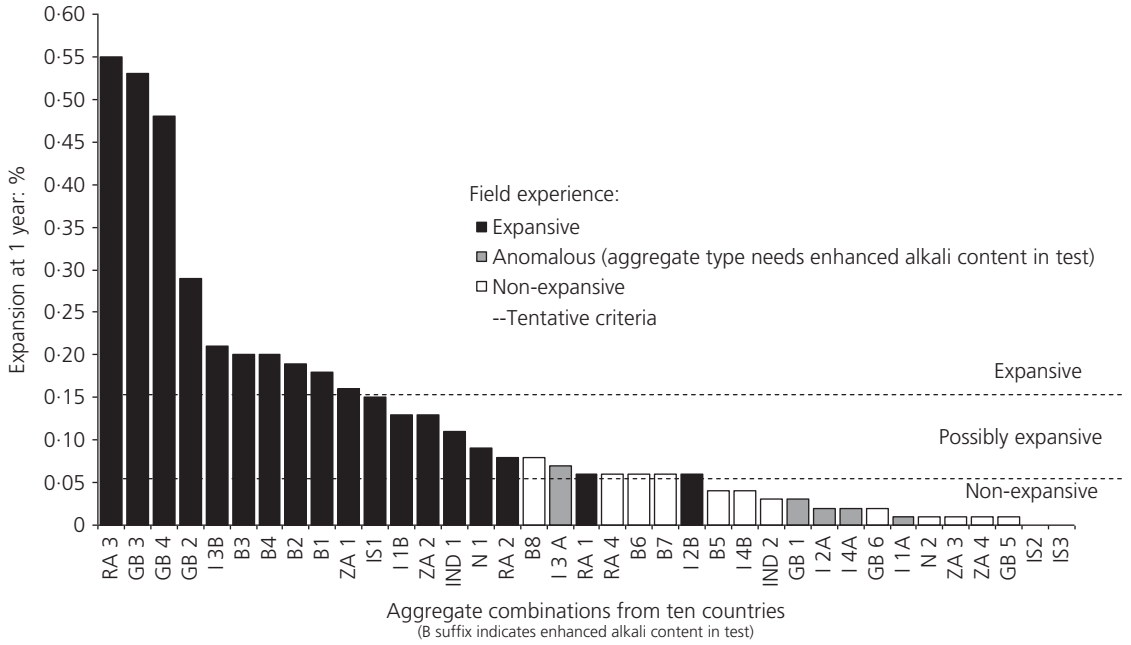

Figure 1. CPT trials (Nixon and Sims, 2000)

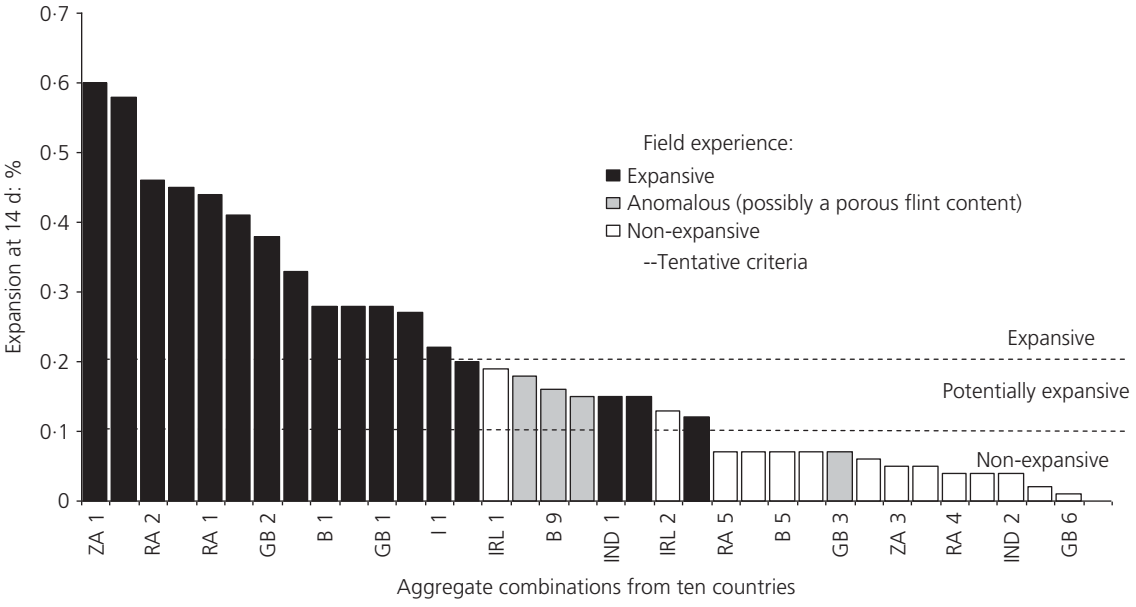

Figure 2. Accelerated mortar-bar test trials (Nixon and Sims, 2000)

aggregates for AAR, TC-106 initially concentrated on a three-stage procedure

- petrographical examination (AAR-1) (Rilem, 2003)
- an accelerated mortar-bar expansion test (AAR-2) (Rilem, 2000a)
- an accelerated concrete prism expansion test (AAR-3) (Rilem, 2000b).

The successor committee TC 191-ARP (*alkali-reactivity & prevention – assessment, specification and diagnosis*), formed in 2000, continued work on an accelerated test for concrete (AAR-4) and on specialised procedures for carbonate aggregates. This TC also had wider scope to seek international consistency in approaches to diagnosis (AAR-6) and specifications (AAR-7) and in the assessment of alkali release from aggregates (AAR-8). The overall progress of TC 191-ARP was presented by Nixon *et al*. (2004) and Sims *et al*. (2004) at the 12th ICAAR in Beijing in 2004. Following discussions at the 11th and the 12th ICAAR conferences, the TC 191-ARP developed the basis of specifications to avoid AAR damage to concrete worldwide (Nixon and Sims, 2006; Sims and Nixon, 2006).

The third TC 219-ACS was established in 2007, presenting findings at the ICAARs in Trondheim (2008) and in Austin (2012). The committee terminated its activities in early 2014, and concluded the work of the three TCs chaired by Dr Nixon with Dr Sims as the secretary for 25 years. In recognition of the fact that damaging expansion involves interaction between all the main components of a concrete mix, TC 219-ACS also focused on the assessment of the effect of the cement/binder on AAR – that is, performance testing. Several documents/recommendations were prepared by the TC, of which two were published during the course of the work: Godart *et al*. (2013) and Lindgård *et al*. (2010, 2011). The full set of Rilem recommendations has now finally been published (Nixon and Sims, 2016). This comprehensive and up-to-date-report contains five recommended test methods for aggregates (designated as AAR-1 to AAR-5) and an overall recommendation that describes how these should be used to enable a comprehensive aggregate assessment (AAR-0). Additionally, in this report, there are two recommended international specifications for concrete (AAR-7·1 and −7·2) and a preliminary international specification for dams and other hydro structures (AAR-7·3), which describe how the aggregate assessment can be combined with other measures in the design of the concrete to produce a concrete with a minimised risk of developing damage from AAR. There has also been considerable effort made towards publishing a petrographic atlas by Fernandes *et al*. (2016). This Rilem AAR-1·2 Atlas is complementary to the petrographic method described in Rilem AAR-1·1. It is designed and intended to assist in the identification of alkali-reactive rock types in concrete aggregates by thin-section petrography.

The current, fourth Rilem TC 258-AAA (*avoiding alkali aggregate reactions in concrete – performance based concept*) was established in 2014, chaired by Professor Børge Johannes Wigum from Norcem/HeidelbergCement Group, in Norway, and with Jan Lindgård from Sintef Building and Infrastructure, in Norway, as the secretary. The main purpose of this new TC is to develop and promote a performance-based testing concept for the prevention of deleterious AAR. Strong emphasis will be put on the implementation of the Rilem methods and recommendations as national and international standards.

The scheduled work, which will last until 2019, is organised in the following three work packages (WPs)

- WP1 – performance testing and accelerated testing in the laboratory. Headed by Dr Terje F. Rønning (HeidelbergCement Group Northern Europe, Norway)
- WP2 – performance testing and laboratory against field; exposure site. Headed by Professor Benoît Fournier (Université Laval, Québec, Canada)
- WP3 – performance testing; assessment of detailed alkali inventory in concrete, including internal alkali release from aggregates, recycling of alkali and external alkali supply. Headed by Dr Esperanza Menéndez Méndez (Institute of Construction Science, 'Eduardo Torroja', Spain).

The work in the three WPs has now started. In WP1, the main work concentrates on the performance test concept using a 38°C CPT. Previous CPT procedures (e.g. Rilem AAR-3 (Rilem, 2000b)) included the testing of the alkali reactivity of aggregates (AAR-3·1) and the determination of the alkali threshold of aggregate combinations (AAR-3·2). The performance test concept includes applications for the performance assessment of combinations of aggregates and cement/binders at various or specific alkali contents. The initial work in WP2 included the casting of about 80 concrete cubes ($30 \times 30 \times 30$ cm^3) for outdoor storage and monitoring at nine different exposure sites in Europe and North America (Portugal, France, Norway, Iceland, Germany, Canada and USA). The concrete mixtures included ordinary Portland cement and the addition of fly ash (20 and 30%), along with control mixtures. A round-robin test has been initiated in WP3 to evaluate the test procedure for measuring the potential amount of releasable alkalis from aggregates. In the test, the aggregates are submerged in two solutions for 52 weeks while being exposed to two temperatures (38 and 60°C). In addition, the initial work in WP3 includes the preparation of an outline of the literature review regarding the alkali inventory in concrete. Preliminary findings of TC 258-AAA will be presented to the ICAAR in São Paolo in July 2016.

The authors have struggled to understand, control and prevent damage from AAR in the 75 years since it was first reported

in concrete. In addition to the ICAARs, which started in 1974, this continuing series of Rilem TCs has helped to harness international co-operation to this struggle for nearly the past 30 years and will continue its work.

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