



RELEVANCE of STAR 224-AAM

TC 224-AAM was the first RILEM Technical Committee to address the topic of alkali-activation as a method of producing construction materials. The objectives of Technical Committee 224-AAM was primarily to analyse the state of the art in alkali activation technology. With this as main objective in mind, the Committee was formed in 2007 and STAR 224-AAM was published in 2014. Further work toward the identification of appropriate testing methods has been further developed through the work of successor committees including TCs 247-DTA, 283-CAM, and 294-MPA.

STAR in a nutshell 224-AAM **"Alkali-Activated Materials"**

Alkali activated materials (AAMs) are generated by the reaction of alkaline activators with aluminosilicate-containing solid precursors. The alkali sources used as activators can include alkali hydroxides, silicates, carbonates, sulfates, aluminates or oxides – essentially any soluble substance which can supply alkali metal cations, raise the pH of the reaction mixture and accelerate the dissolution of the solid precursor. The solid aluminosilicate-rich precursors are generally those which are familiar in use as supplementary cementitious materials, such as metallurgical slags, calcined clays, natural pozzolans, and combustion ashes.

There have been **different factors motivating the scientific developments in AAM** depending on economic, regulatory and climatic factors in different parts of the world, and this is reflected to some extent in the ways in which the technology has evolved.

AAM technology has been developed and implemented in a number of countries for differing reasons over the past century, most prominently since the mid 1950s in the former Soviet Union, in the context of a demand for Portland cement (PC) alternatives. In China, the key driver in the initial stages of the development of this technology was the demand for high-strength concretes with low energy requirements during production. In Europe, the motivation behind the AAM research was essentially the pursuit of new construction materials able to compete in performance with PC, but with a much lower environmental impact. In Australia, research activity in AAMs was initiated in the mid-1990s, with the primary initial aim of developing methods of treating and immobilising mining wastes containing elevated levels of heavy metal contaminants.

The recent **focus on global warming**, public and consumer preference for "green" products, and the associated market in carbon credits, have all now combined to make AAMs for the first time a viable large-scale proposition in the (conservative) cement and concrete industry. One of the often-claimed advantages of alkali activated materials over traditional Portland cements is the **much lower CO₂ emission** associated with AAM production, due to the avoidance of a high-temperature calcination step in AAM synthesis from ashes and/or slags. While further work is clearly needed in generating and validating life-cycle assessments of AAM products in specific applications, and particularly in understanding the emissions footprint of the activator components, this does appear to be a primary pathway for the wider use of AAMs in a carbon-constrained world.

Alkali activation technology also provides the opportunity for the **utilisation of waste streams** that may not be of significant benefit in PC-blending applications. For example, work on magnesia-iron

slags, ferronickel slags, and tungsten mine waste, which would otherwise have little commercial value, has shown that these materials can be effectively converted to valuable materials by alkali activation, while they are of little or no benefit as mineral additions to PC.

The **mechanical properties** of AAM elements can definitively be competitive (if not better) when compared to those of PC concretes. Although no single formulation will achieve all of these characteristics simultaneously, AAMs can be designed to show, amongst other properties: abrasion resistance, resistance to high temperature and fire, resistance to acid and chemical attack, low susceptibility to degradation by alkali-silica reaction, excellent compressive and flexural strength, low permeability and low cost.

Two of **the major barriers** to the introduction of a new material into the construction industry are: (1) the need for standards in each governmental jurisdiction and (2) the open questions relating to durability of concrete. These are each being addressed through ongoing work in the RILEM community and other organisations.

The most critical role of the alkaline activator in an AAM is to accelerate the activator-precursor reaction to take place within a reasonable timeframe for the production of an engineering material, and this is most readily achieved by the generation of an elevated pH. Alkali-activated binders require the identification and optimisation of the most desirable activator chemistry for each precursor. The **main precursors** of interest can usefully be classified according to their calcium content:

Calcium-rich precursors: these are blast furnace slag (BFS) and other Ca-rich industrial by products. The effect of variability in BFS chemistry between sources is important in defining AAM behaviour, and requires further investigation to enable more accurate predictions of material performance.

Low-calcium precursors: these are low-calcium or calcium-free systems, often derived from fly ashes or clays. Low-calcium AAM binders are often referred to as “geopolymer”. The use of alkali metal hydroxide or silicate solutions with these precursors has in general provided the products with the highest mechanical performance, while carbonate or sulfate activating solutions are in general less effective in the absence of high levels of calcium.

Blended systems: a combination of a calcium-rich precursor with a predominantly aluminosilicate precursor can be used to form a hybrid alkali-activated binder system. This is an area in which there is a wealth of empirical information available, but only a much smaller number of detailed scientific studies, and certainly provides a good deal of scope for future scientific and technical developments.

Alkali activated materials (AAMs) do not conform to most **national and international cement standards**, which are inherently based on the composition, chemistry and hydration products of Portland cement and its blends. The large variety of approaches to formulation and production of AAMs makes it seem almost impossible to prescribe this class of new materials in the same narrow compositional and procedural way that has been adopted by the PC market over the last 150 years. So, TC 224-AAM reached the conclusion that standards development for AAMs should adopt a predominantly performance-based approach. An exhaustive survey of the existing cement and concrete standards available at the time of publication and relevant to Alkali Activated Materials (AAM) is available in the STAR.

An overview of the available test methods for **assessment of the performance** of construction materials under a wide variety of modes of attack is provided in the report in terms of ‘chemical’, ‘transport’ and ‘physical’ degradation.

Chemical: The most important chemically-induced binder degradations are probably those related to attack by sulfates, alkali-aggregate reaction processes, and leaching of matrix components or immobilised species into neutral or acidic conditions. It has not been possible in any of these scenarios to recommend a single particular test as being the most preferred option for analysis of AAMs, because there are a range of service conditions which must be simulated in the laboratory, and so different tests are required to simulate different service conditions and the corresponding degradation processes.

Transport: The transport-related durability properties of alkali-activated binders depend very strongly on pore structure, which is determined both by binder chemistry and maturity, as well as differences in interfacial transition zone behaviour. The issues of steel corrosion and carbonation in

AAM concretes are both critical in determining in-service performance and durability. It appears necessary to validate accelerated testing methods in detail for AAMs by comparison with in-service performance. The details of the chemistry (particularly pore solution chemistry) and microstructure of alkali-activated binders from PC lead to significant differences in the mechanisms which control transport-related durability of these materials, and it is likely that several of the widely-used and standardised testing protocols provide results for these materials which are not fully reliable in predicting long-term performance.

Physical: The use of correlations based on concretes derived from Portland cement and its blends in predicting the performance of alkali-activated concretes is prone to error, as the physicochemical properties of the alkali-activated binder and its interactions with aggregate particles are notably different from those of Portland cement. Important differences are identified as being related to the curing and sample conditioning regimes which are applied prior to testing. More research is needed to fully characterise the mechanical properties of AAM concretes and to more effectively correlate these to each other for use in codes and structural design standards.

There are numerous tangible examples of structures and applications in which alkali-activated concretes have been utilised throughout the past decades. However, there have not yet been a large number of studies of a sufficiently wide range of AAMs exposed under different environmental conditions for decades or more to provide definitive proof of durability performance in service.

The case studies presented in the report display that, in general, the alkali-activated concretes which have been placed into service have been able to serve the purposes for which they were designed, without evident problems related to carbonation, freeze-thaw resistance, mechanical or chemical stability, acid resistance, protection of reinforcing steel, alkali-silica reaction, or any other forms of degradation.

RELATED DOCUMENTS:

1. Provis, J.L. Geopolymers and other alkali activated materials: why, how, and what?. [Mater Struct 47, 11-25 \(2014\)](#).
2. Bernal, S. A. Advances in Near-Neutral Salts Activation of Blast Furnace Slags. [RILEM Tech Lett 2016, 1, 39-44](#).
3. Provis, J.L., Arbi, K., Bernal, S.A. *et al.* RILEM TC 247-DTA round robin test: mix design and reproducibility of compressive strength of alkali-activated concretes. [Mater Struct 52, 99 \(2019\)](#).
4. Winnefeld, F., Gluth, G.J.G., Bernal, S.A. *et al.* RILEM TC 247-DTA round robin test: sulfate resistance, alkali-silica reaction and freeze-thaw resistance of alkali-activated concretes. [Mater Struct 53, 140 \(2020\)](#).
5. Gluth, G.J.G., Arbi, K., Bernal, S.A. *et al.* RILEM TC 247-DTA round robin test: carbonation and chloride penetration testing of alkali-activated concretes. [Mater Struct 53, 21 \(2020\)](#).