

**M&S highlight**

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# M&S highlight: Provis (2014), geopolymers and other alkali activated materials—why, how, and what?

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## 1 Background

Global warming caused by CO<sub>2</sub> emission has been the center of major climate discussion and given big pressure to all nations. Buildings and construction industries generate nearly 40% of global CO<sub>2</sub> emissions, among them 5–8% of total global CO<sub>2</sub> emission are contributed by the cement industries [1]. In EU level, a 40% CO<sub>2</sub> reduction is aimed by year 2030, and CO<sub>2</sub> neutral target is set by year 2050 [2]. This means all sectors have to take this into consideration. The construction materials for future projects will be selected on the basis of the contribution they can make to reach requirements of CO<sub>2</sub> emission

reduction. Under this circumstance, the alkali-activated materials (AAMs), including the materials referred to as ‘geopolymers’, which are made from industrial by-products, or even wastes with the use of alkali-activators, are brought to evidence. In this regard, geopolymer are considered as eco-friendly alternatives to Ordinary Portland cement (OPC) and have attracted increasing attention in academic research and engineering practise in the past decades. Among all researchers, Prof. John L. Provis from Sheffield University, UK, is considered as an outstanding researcher who has contributed significantly to the research and development of geopolymers, and hence he was awarded the RILEM Robert L’Hermite Medal in 2013.

The paper ‘Geopolymers and other alkali activated materials: why, how, and what?’ [3], which corresponds to the Robert L’Hermite Medal lecture of Prof. Provis at the 2013 RILEM Annual Week, was considered as a milestone paper in the field of geopolymer sciences. In this paper, he summarized the most significant research works mainly carried out by himself and his co-workers in the field of geopolymers, focusing on alkali activation technology, from the atomic scale and chemical reaction path modelling, towards macroscopic observable characteristics such as strength and durability of alkali-activated concretes.

Alkali-activated materials and geopolymers are an extremely diverse grouping of materials, presenting a

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This commentary is part of our celebration of 75 years of RILEM, highlighting Materials and Structures most highly influential and cited publications.

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Highlighted paper: J.L. Provis, “Geopolymers and other alkali activated materials: why, how, and what?” Materials and Structures. 2014. 47(1–2), pp. 11–25.

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vast range of acceptable raw materials and thus additional mix-design related parameters when compared to conventional OPC mixes. For that reason, their properties can fall almost anywhere in the range from 'high' to 'low' according to different sets of criteria by which the performance of a material can be measured [3]. Such fact gives an answer to the puzzle why macroscopic properties or 'characteristic' of alkali-activated materials are diversity between labs.

This paper provided an overview on the fundamental mechanisms of alkali-activation reactions in different phases, ranging from characterization of raw materials and its influence on chemical reactions involved in early-stages, to the nucleation of reaction products and their evolution towards the formation of stable microstructures, through the implementation of advanced in-situ characterisation tools such as synchrotron radiation and attenuated total reflectance. These techniques have proven to be particularly valuable in understanding the details of chemical heterogeneity within geopolymer gels since the first moments of reaction. The author discusses the importance of a molecular-level understanding of the chemical and physical characteristics of the system taking place via particle-fluid interactions, as they are responsible for dictating kinetic and thermodynamic mechanisms for the development of mature systems. Such understanding can enable the engineered design of alkali-activated binders with more attractive performance in either fresh or hardened state, providing desirable properties in a predictable and reliable way. To finish, the paper summarizes the current knowledge on alkali-activated/geopolymer concrete during engineering practise applications and how it relates to standard durability aspects commonly used for conventional OPC concrete. The author provides an optimistic overview, as these alternative concrete mixes provide slow in-service carbonation evolution, hinder the formation of expansive gels via alkali-silica reactions due to the nature of its chemistry, and present resistance to chloride penetration in specific exposure environments. However, the conclusion is that durability performance must be carefully evaluated before strong conclusions are obtained, given the large number of variables in such mixes, and the uncertainty on the response of alkali-activated binders to traditional testing techniques.

## 2 Influence on RILEM works

Many research are being carried out world-wide on aspects like reaction and chemistry of alkali-acted materials, mechanical properties and durability. RILEM has been active within the field of alkali-activated materials, by the organisation of several RILEM Technical Committees, where Prof. Provis has led several committees in this field. The first RILEM Technical Committee on Alkali Activated Materials was RILEM TC-224 AAM in the period 2007–2013. The State-of-the-Art Report, edited by Prof. Provis, summarises research to date in the area of alkali-activated binders and concretes, with a particular focus on binder design and characterisation, durability testing, commercialisation, standardisation. In 2012–2019, the RILEM TC-247 DTA on durability testing of alkali-activated materials chaired by Prof. Provis was launched. The main task of this committee was to validate durability testing standards for alkali-activated materials, bringing scientific insight into the development of appropriate specifications for these materials. Follow up TC 247-DTA, in 2018, the RILEM TC-283 CAM on chloride transport in alkali-activated materials chaired by Prof. Arnaud Castel, and in 2019 the RILEM TC-294 MPA on mechanical properties of alkali-activated concrete chaired by Prof. Guang Ye were established.

## 3 Influence on research and practice

Since the publication of the review paper, more fundamental studies on alkali-activation reaction kinetics, binder gel formation, and computer modelling of the alkali-activate reaction and nano-scale/micro-scale structural development, haven been carried out. The pair distribution function (PDF) experimental technique [4] has been used worldwide in the research institutes. The performance based design methodologies of geopolymer concrete, proper curing methods, cautions have to be taken on reduction of degradation and the durability testing method summarized in the RILEM TC-DTA [5, 6], give excellent guidance to practitioner, and promote geopolymer concrete for wider uses in engineering practice.

#### 4 Current and future research on geopolymers

There are a few main research fields on geopolymers at the moment focused on:

- Search for alternative precursors, to be used as partial or full replacement of traditional reactive precursors, i.e., fly ash, blast furnace slag and metakaolin. These include less reactive mineral resources from industrial-by products or wastes, for example, municipal solid waste incineration ashes, biomass-fly ashes are investigated as precursors in alkali-activated materials.
- Besides low risk application, alkali-activated materials (geopolymers) concrete, as alternative to OPC concrete are used as structural element in infrastructural application. The short/long term mechanical properties, time depended properties, i.e. shrinkage and creep, bonding behaviour, durability and service life of geopolymer concrete structures, are significant.
- Standardization on geopolymer concrete production, mix design methodology and recommendations for structural design are absent, and they are becoming urgent in engineering practice. Fortunately more and more pilots or real projects made of geopolymer concrete are under construction or have been planning. These projects could provide validation to the standard and recommendations. Even though the progress has been slow, but the gap between academic research and engineering practise is becoming more narrow.

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