

Introduction to *Handbook of Alkali-activated Cements, Mortars and Concretes*

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1.1 Brief overview on alkali-activated cement-based binders (AACB)

According to Provis and van Deventer (2009) Purdon was the first to demonstrate in 1940 the synthesis of construction materials by alkaline activation of high-calcium blast furnace slags. Shi *et al.* (2011) gives credit for this achievement to the work of German cement chemist and engineer Kuhl in 1930. More recently a 1908 patent of Kuhl was recognized as the first use of the alkali activation of aluminosilicate precursors in order to obtain an ordinary Portland cement (OPC) alternative material (Provis and van Deventer, 2013; Provis, 2014).

In the next decades the field of alkali activation was almost non-existent, the only exception being the work of Glukhovsky (Table 1.1).

Relevant changes took place in the 1970s with the findings of the French scientist and engineer Joseph Davidovits who coined the term ‘geopolymer’ in 1979 having patented several aluminosilicate formulations. The 1980s and 1990s saw other relevant investigations in the field of alkali activation. Still it is only in the last few years that the production of scientific AACB-related papers has ‘exploded’. Figure 1.1 shows that only in the twenty-first century has the accumulated number of papers exceeded 100. As a comparison, since 1993 almost 8,000 articles/reviews related to Portland cement were published in Scopus journals. The search also shows that the term ‘geopolymer’ has been much more popular than the term ‘alkali-activated materials’.

The University of Melbourne was the affiliation with the highest number of ‘geopolymer’-related papers while the Instituto de Ciencias de la Construcción Eduardo Torroja was responsible for the major part of ‘alkali-activated’ papers. Another interesting fact was that two Elsevier BV journals published the majority of AACB related papers. *Construction and Building Materials* has the highest number of ‘geopolymer’ papers while *Cement and Concrete Research* was the lead journal for alkali-activated papers.

At this stage it is important to mention that notes on the various terminologies used for categorizing AACB are deemed redundant in this chapter just because too much has already been written about it. Section 1.2 of the introductory chapter of the 2009 book by Provis and van Deventer (2009) provides a clear and up-to-date

Table 1.1 Bibliographic listing of some important events in the history of AACB

Author	Year	Significance
Feret	1939	Slags used for cement
Purdon	1940	Alkali-slag combinations
Glukhovsky	1959	Theoretical basis and development of alkaline cements
Glukhovsky	1965	First called 'alkaline cements'
Davidovits	1979	'Geopolimer' term
Malinowski	1979	Ancient aqueducts characterized
Forss	1983	F-cement (slag-alkali-superplasticizer)
Langton and Roy	1984	Ancient building materials characterized
Davidovits and Sawyer	1985	Patent of 'Pyrament' cement
Krivenko	1986	DSc Thesis, $R_2O - RO - SiO_2 - H_2O$
Malolepsy and Petri	1986	Activation of synthetic melilite slags
Malek <i>et al.</i>	1986	Slag cement-low level radioactive wastes forms
Davidovits	1987	Ancient and modern concretes compared
Deja and Malolepsy	1989	Resistance to chlorides shown
Kaushal <i>et al.</i>	1989	Adiabatic cured nuclear wastes forms from alkaline mixtures
Roy and Langton	1989	Ancient concretes analogs
Majundar <i>et al.</i>	1989	$C_{12}A_7$ – slag activation
Talling and Brandstetr	1989	Alkali-activated slag
Wu <i>et al.</i>	1990	Activation of slag cement
Roy <i>et al.</i>	1991	Rapid setting alkali-activated cements
Roy and Silsbee	1992	Alkali-activated cements: an overview
Palomo and Glasser	1992	CBC with metakaolin
Roy and Malek	1993	Slag cement
Glukhovsky	1994	Ancient, modern and future concretes
Krivenko	1994	Alkaline cements
Wang and Scrivener	1995	Slag and alkali-activated microstructure
Shi	1996	Strength, pore structure and permeability of alkali-activated slag
Fernández-Jiménez and Puertas	1997	Kinetic studies of alkali-activated slag cements
Katz	1998	Microstructure of alkali-activated fly ash
Davidovits	1999	Chemistry of geopolymeric systems, technology

Table 1.1 (Continued)

Author	Year	Significance
Roy	1999	Opportunities and challenges of alkali-activated cements
Palomo	1999	Alkali-activated fly ash – a cement for the future
Gong and Yang	2000	Alkali-activated red mud–slag cement
Puertas	2000	Alkali-activated fly ash/slag cement
Bakharev	2001–2002	Alkali-activated slag concrete
Palomo and Palacios	2003	Immobilization of hazardous wastes
Grutzeck	2004	Zeolite formation
Sun	2006	Sialite technology
Duxson	2007	Geopolymer technology: the current state of the art
Hajimohammadi <i>et al.</i>	2008	One-part geopolymer
Provis and van Deventer	2009	Geopolymers: structure, processing, properties and industrial applications

Notes: According to Provis (2010), this table forgot to list the ‘extremely valuable 2006 book of Shi *et al.* (2006)’. Moreover, Li *et al.* (2010) should have credited the ‘one-part geopolymer’ concept to Kolousek *et al.* (2007) because their paper was submitted to review process on March 19, 2007 and published online on 27 July, 2007, before the paper of Hajimohammadi *et al.* was submitted to review process on April 28, 2008 and accepted on September 23 and published only on October 29, 2008.

Source: Reprinted from Li *et al.* (2010). Copyright © 2010, with permission from Elsevier. Based on the previous table of Roy (1999).

overview on that issue. One fact, however, deserves to be emphasized: the several names used by different authors (e.g., geopolymers, mineral polymers, inorganic polymers, inorganic polymer glasses, alkali-bonded ceramics, alkali ash material, soil cements, hydroceramics, zeocements, zeoceramics, among others) have made it more difficult for AACB to become an alternative to OPC. This reflects the concern to find the most scientific name but at the same time also reflects the lack of commercial good sense of the scientific community.

Although the exponential increase of articles on AACB makes it very difficult to choose the most relevant ones in order to update Table 1.1, this author thinks that three of them merit that distinction: Shi *et al.* (2011), van Deventer *et al.* (2012) and Provis (2014). This is not only because the first two have been widely cited and the author of the third won the RILEM Robert L’Ermite medal, but most importantly because they contain very important insights on the future of AACB research. Also it was not until the twenty-first century that the first Technical Committee in the area of alkali activation was formed. The RILEM Technical Committee on Alkali-activated Materials (TC 224-AAM) was initiated in 2007 and concluded its work in 2012 and the state-of-the-art report was published recently (Provis and van Deventer, 2013).

Fortunately the participants had the good sense to embrace the alkali-activated terminology even though some had published the majority of their research on geopolymers (low calcium alkali-activated systems).

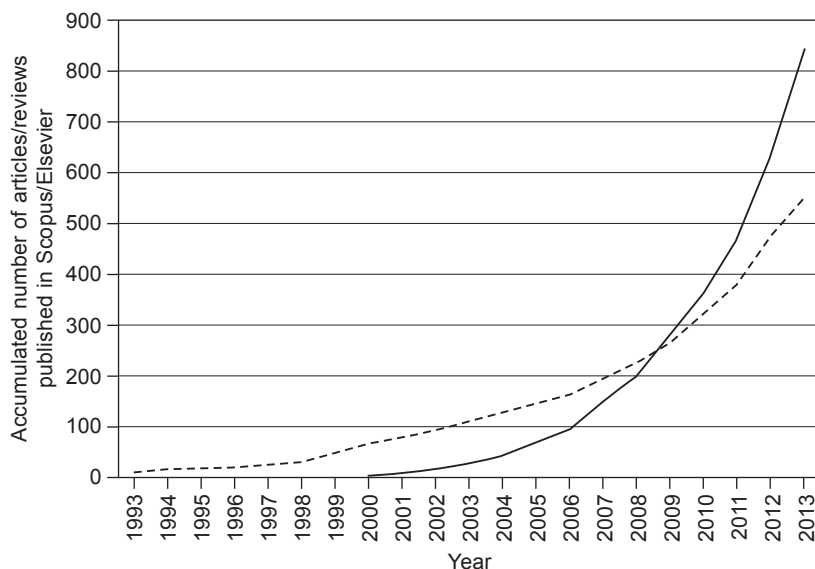


Figure 1.1 Evolution of the accumulated number of articles/reviews published in Scopus/Elsevier journals by the keyword ‘alkali-activated’ (dotted line); and the keyword ‘geopolymer’ (solid line) searched in the sections title, abstract or keywords.

The TC 224 constitutes an important landmark for AACB in tackling the lack of uniformly accepted standards which are ‘critical to the acceptance of alkali-activated materials in the industrialized world’. In their 2012 insightful paper, van Deventer *et al.* had already emphasized the importance of the development of new standards as pivotal to the commercialization of these materials.

A subsequent Technical Committee (247 DTA) was initiated in 2012 with a five-year work plan focusing on ‘Durability testing on alkali-activated materials’. The aim of this TC is to provide recommendations regarding appropriate test methodologies and protocols for the analysis of AACB. This is a relevant issue because the durability of AACB is still a subject of some controversy (Pacheco-Torgal *et al.*, 2012a).

Duxson *et al.* (2007) recognized that durability is the most important issue in determining the success of these new materials. On the other side Juenger *et al.* (2011) argue that ‘*The key unsolved question in the development and application of alkali activation technology is the issue of durability*’ and more recently van Deventer *et al.* (2012) stated that ‘*whether geopolymer concretes are durable remains the major obstacle to recognition in standards for structural concrete*’. The importance of the durability of AACB (as well as the importance of alkali-activation technology itself) can be seen by the fact that recently the European Research Council approved a Starting Grant for a research project entitled ‘Durability of geopolymers as 21st century concretes’. This project which is coordinated by John Provis was initiated in September 2013 and goes up to September 2018.

Another relevant issue regarding AACB concerns their CO₂ emissions. According to Davidovits *et al.* (1990) geopolymers generate just 0.184 tons of CO₂ per ton of

binder. It is important to remember that this alleged extraordinary environmental performance over OPC fueled the growing interest in AACB that took place in the following decades. The majority of AACB-related papers used to make very impressive statements on the role of the activation technology in contributing to greatly reduced overall CO₂ emissions of the binder industry. Unfortunately the astonishing numbers of Davidovits were not confirmed by other authors.

Duxson *et al.* (2007) stated that although the CO₂ emissions generated during the production of Na₂O are very high, still the production of AACB is associated to a level of CO₂ emissions lower than the emissions generated in the production of OPC. An independent study made by Zeobond Pty Ltd concluded that the latter had 80% lower CO₂ emissions (Duxson and van Deventer, 2009).

Weil *et al.* (2009) compared OPC concrete and AACB concrete with similar durability reporting that the latter have 70% lower CO₂ emissions. McLellan *et al.* (2011) reported a 44–64% reduction in greenhouse gas emissions of Australian AACB when compared to OPC. However, the information on the performance of AACB is scarce and it is not easy to comprehend why sodium silicate-free mixtures did not show the lowest emissions.

Habert *et al.* (2011) confirmed that they have a lower impact on global warming than OPC but on the other hand they have a higher environmental impact regarding other impact categories. More recently, Turner and Collins (2013) showed that the CO₂ footprint of a 40 MPa AACB concrete was approximately just 9% less than comparable concrete containing 100% OPC binder (328 kg/m³), the major part being due to sodium silicate.

The OPC concrete mixture used in this study could even have a much lower carbon footprint (below the geopolymers concrete) if fly ash had been used as partial replacement of Portland cement. A similar 40 MPa 28 days compressive strength could easily be achieved with a mixture of just 200 kg/m³ Portland cement type II 42.5 plus 300 kg/m³ fly ash (Azevedo *et al.*, 2012). These results confirm that in some situations AACB can show ‘an emissions profile worse than that of Portland cement-based concretes’ (Provis, 2014) constituting a crucial argument for the search for AACB that are sodium silicate free. Of course current two-part low calcium silicate-based AACB technology will continue to play an important role in the construction industry for niche applications, especially fire resistant ones and also in other innovative applications.

Unfortunately, although hundreds of papers have been published on AACB with low CO₂ emissions, (low cost) alkaline activators were not at the heart of the investigators’ concerns. One exception is the recent paper by Kim *et al.* (2013) which shows promising results on the use of CaO as a low cost alternative to classic alkali activators (sodium hydroxide and sodium silicate) leading to mixtures with around 42 MPa compressive strength after 28 days curing. Still further investigations regarding durability and environmental performance are needed to confirm the viability of this activator. Instead the majority of the published investigations deal with interesting but low commercial relevance scientific aspects. That is why the comments in the introductory chapter of the 2009 book by Provis and van Deventer are worth

remembering ‘a material that is well characterized but not used in the real world is in effect useless’.

The efflorescences problem is another example of the misguided priorities of the AACB scientific community. As Zheng *et al.* (2007) rightly put it, since ‘the alkaline and/or soluble silicates cannot be totally consumed during geopolymerization ... this causes severe efflorescence ... and high permeability and water absorption due to the movement of alkali together with water to the geopolymer surfaces’. However, in the several hundred AACB-related papers published on Scopus/Elsevier journals, only less than ten addressed in some way the efflorescence problem and of those only three focus directly on that problem.

The most interesting efflorescence-related article is the one by Škvára *et al.* (2012) who state that Na,K is bound only weakly in the nanostructure of the (N,K)–A–S–H gel and is leachable almost completely. This lack of research effort is even more odd considering that almost 7 years ago some authors (Zheng *et al.*, 2007) have already acknowledged the fact that AACB were prone to severe efflorescence. These unresolved issues help us to understand why AACB are still far from being able to compete commercially against OPC.

Interestingly, and not without some irony, some authors (Shi *et al.*, 2011) have recently admitted that the global replacement of Portland cement by any kind of binder (AACB included) is virtually impossible. As a consequence they suggested that a future trend in the field of binder materials could encompass the dilution of Portland cement in high volumes of SCMs in hybrid Portland cement–alkali-activated aluminosilicate. More recently relevant publications address this new trend (Garcia-Lodeiro *et al.*, 2013a, 2013b).

Since the high strength of these new mixtures is only attainable if sodium silicate is used, it remains to be seen if these formulations are more competitive than OPC ones concerning eco-efficiency and cost-efficiency. Besides, this trend may raise some concerns regarding the chemical durability (alkali-silica reaction) just because the same research team recognized that the guarantee for the absence of expansive products by ASR is precisely a low calcium content (Fernandez-Jimenez and Palomo, 2009).

A 2007 international patent by Zeobond Research PTY Ltd (WO 109862 A1) on a dry-mix cement composition already recommended the use of as much as 30% Portland cement (Zheng *et al.*, 2007). This fact and the statement by van Deventer *et al.* (2012) that calcium is pivotal for the strength and durability of geopolymers do not anticipate a bright future in the cement industry for low calcium alkali-activated systems. The patented new formulation (WO 109862 A1) attempts to overcome the problems of ‘two-part’ mix AACB, namely the difficulty of handling caustic solutions, poor workability, quality control and ‘most important’ the problem of efflorescence.

van Deventer *et al.* (2012) cite an updated US patent on this dry-mix cement composition (van Deventer *et al.*, 2010). This new formulation commercially termed E-CRETETM, is allegedly associated with very low CO₂ emissions (Figure 1.2).

The commercial LCA conducted by NetBalance Foundation reported 60–80% reduction in CO₂ emissions. However, no LCA studies have been published in major

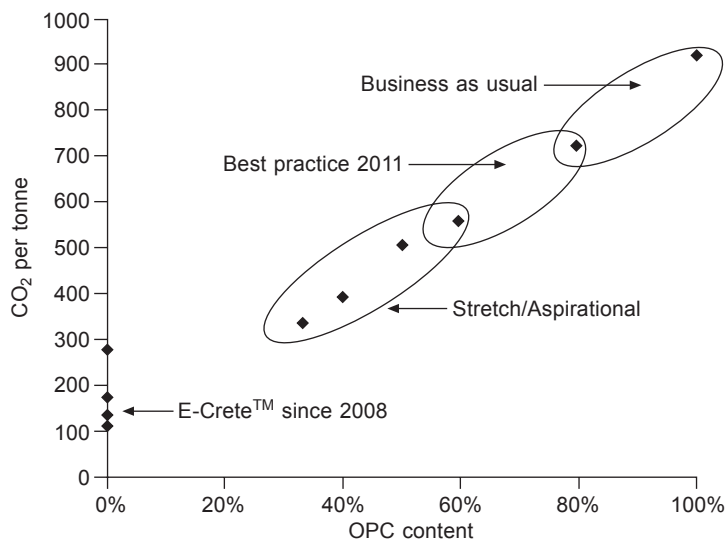


Figure 1.2 CO₂ emissions of various cement binders as a function of OPC content (reprinted from van Deventer *et al.*, 2012. Copyright © 2012, with permission from Elsevier).

journals that confirm that statement and could help to understand which compositions were evaluated.

1.2 Potential contributions of AACB for sustainable development and eco-efficient construction

1.2.1 AACB with lower CO₂ emissions

Climate change is one of the most important environmental problems faced by Planet Earth (IPCC, 2007; Schellnhuber, 2008; Rockström *et al.*, 2009). This is due to the increase of carbon dioxide (CO_{2eq}) in the atmosphere for which the built environment is a significant contributor. In the early eighteenth century, the concentration level of atmospheric CO_{2eq} was 280 parts per million (ppm). At present it is already 450 ppm. Keeping the current level of emissions (which is unlikely given the high economic growth of less developed countries with consequent increases in emission rates) will imply a dramatic increase in CO_{2eq} concentration to as much as 731 ppm by the year 2130 leading to a 3.7°C global warming above pre-industrial temperatures (Valero *et al.*, 2011).

Global warming will lead to a rise in the sea level caused by thermal expansion of the water. If the sea level rises above 0.40 m it will submerge 11% of the area of Bangladesh and as a result almost 10 million people will be rendered homeless (IPCC, 2007). Another consequence of global warming is the occurrence of increasingly extreme atmospheric events. Global warming may also be responsible

for the thawing of the permafrost (permanently frozen ground), where approximately 1×10^6 million tons ($1000 \text{ GtCO}_{2\text{eq}}$) are still retained. This astonishing figure is equivalent to the current worldwide production ($34 \text{ GtCO}_{2\text{eq}}$) during 30 years. Even if all the greenhouse gas emissions suddenly ceased, the inertia associated to climatic systems would mean that the rise in the sea level, ocean acidification and extreme atmospheric events will continue at least for the next 100 years.

To make things worse, in the coming years the construction industry will keep on growing at a fast pace. China alone will need 40 billion square meters of combined residential and commercial floor space over the next 20 years, equivalent to adding one New York City every two years (Pacheco-Torgal and Jalali, 2011).

A recent forecast estimates that by 2030, urban land cover will increase by 1.2 million km^2 (equivalent to an area about the size of South Africa). This will be concomitant with an enormous infrastructure boom in road construction, water and sanitation, energy and transport, and buildings (Seto *et al.*, 2012).

The latest findings on silicate-based AACB do not confirm their carbon footprint advantage over OPC. Therefore the contribution of these materials to reduce the overall CO_2 emissions of the binder industry, thus ameliorating climate change, is not at all clear. However, it is hoped that in the next few years investigators in this field could be able to find low CO_2 emissions (low cost) alkaline activators that may permit such goal.

1.2.2 AACB for building energy efficiency

According to the *World Energy Outlook 2012* energy efficiency improvements show the greatest potential of any single strategy to abate global GHG emissions from the energy sector (IEA, 2012).

The building sector is the largest energy user responsible for about 40% of the EU's total final energy consumption (Lechtenbohmer and Schuring, 2011).

According to the *Energy Road Map 2050* (European Commission, 2011a) higher energy efficiency in new and existing buildings is key for the transformation of the EU's energy system. Of the several areas related to the built environment, energy efficiency and renewable energies are the only ones that will be funded under the HORIZON 2020 EU framework program (Pacheco-Torgal, 2014).

The European Energy Performance of Buildings Directive 2002/91/EC (EPBD) has been recast in the form of Directive 2010/31/EU by the European Parliament on 19 May 2010. One of the new aspects of the EPBD is the introduction of the concept of nearly zero-energy building (Pacheco-Torgal *et al.*, 2013a).

The use of thermal insulation materials constitutes the most effective way of reducing heat losses in buildings, thus reducing heat energy needs. These materials have a thermal conductivity factor, k (W/m.K) lower than 0.065 and a thermal resistance higher than $0.30 \text{ (m}^2\text{.K)/W}$. Current commercial insulation materials (expanded polystyrene, extruded polystyrene, rigid foam of poly-isocyanurate or polyurethane) are associated with negative impacts in terms of toxicity.

Polystyrene, for example, contains anti-oxidant additives and ignition retardants.

Additionally, its production involves the generation of benzene and chlorofluorocarbons. On the other hand, polyurethane is obtained from isocyanates, which are widely known for their tragic association with the Bhopal disaster. Besides, it releases toxic fumes when subjected to fire (Pacheco-Torgal *et al.*, 2012b).

The information regarding hazardous substances is a crucial aspect in the new Construction Products Regulation (CPR) fully enforced since 1 July 2013. CPR links this subject to EC Regulation No. 1907/2006 (Registration, Evaluation, Authorisation and Restriction of Chemicals – REACH Regulation). Investigations into the development of thermal insulators based on AACB could constitute a lower toxicity alternative to some of the current commercial insulators.

1.2.3 AACB capable of reusing a high waste content

According to the Waste Management Acts 1996 and 2001, wastes can be defined as ‘any substance or object belonging to a category of waste which the holder discards or intends or is required to discard, and anything which is discarded or otherwise dealt with as if it were waste shall be presumed to be waste until the contrary is proved’. The milestone related to the recycling of other kinds of waste can be found in the *Roadmap to a Resource Efficient Europe*: ‘By 2020, waste is managed as a resource. Waste generated per capita is in absolute decline. Recycling and re-use of waste are economically attractive options for public and private actors due to widespread separate collection and the development of functional markets for secondary raw materials. More materials, including materials having a significant impact on the environment and critical raw materials, are recycled. Waste legislation is fully implemented. Illegal shipments of waste have been eradicated. Energy recovery is limited to non-recyclable materials, landfilling is virtually eliminated and high quality recycling is ensured.’ Improving the reuse of raw materials through greater ‘industrial symbiosis’ across the EU could save €1.4bn a year and generate €1.6bn in sales (European Commission, 2011b).

Construction and demolition wastes (CDW) deserve special attention in eco-efficient construction because the high volume of CDW constitutes a serious problem to be dealt with. CDW in the US is estimated at around 140 million metric tonnes (Yuan *et al.*, 2012). Eurostat estimates the total for Europe to be 970 million tonnes/year, representing an average value of almost 2.0 tonne per capita (Sonigo *et al.*, 2010).

Recycling of CDW is of paramount importance because it reduces environmental pressure. It prevents an increase of the area needed for waste disposal and also avoids the exploitation of non-renewable raw materials. Currently, the average recycling rate for EU-27 is just 47%. The need to recycle at least 70% of non-hazardous construction and demolition waste by 2020, expressed in *Roadmap to a Resource Efficient Europe* (European Commission, 2011b), was set by the Revised Waste Framework Directive 2008/98/EC (European Parliament, 2008) and does not include naturally occurring material defined in category 170504 (soil and stones not containing dangerous substances) in the European Waste Catalogue.

Eurostat estimates the total for Europe to be 970 million tonnes/year, representing

an average value of almost 2.0 tonne/per capita. As the current average recycling rate of CDW for the EU-27 is only 47%, achieving the 2020 target in just a decade seems an ambitious goal, further stressing the need for new and more effective recycling methods (Pacheco-Torgal *et al.*, 2013b). Moreover, in the next decades waste recycling will be increasingly challenging as a result of the zero waste scenario (Zaman and Lehmann, 2013).

Mining and quarrying wastes represent another worrying waste (more than 700 million tonnes/year just in Europe) that can be reused in construction materials. Mineral waste can be defined as the ‘residues, tailings or other non-valuable material produced after the extraction and processing of material to form mineral products’ (Harrison *et al.*, 2002).

In the recent past the failures of the Aznalcollar mine in Spain (1998), which contaminated 2656 ha of Donana Nature Park with pyrite sludge, and the Baia Mare mine (2000) in Romania clearly show that in the short term mine wastes represent a clear and present environmental danger (Pacheco-Torgal and Labrincha, 2013).

Given that most mining wastes have toxic substances, research efforts to find construction materials capable of immobilizing these wastes are needed. A recent COST action termed NORM4Building materials (in which the author participated in the initial proposal) was approved on 15 May 2013. NORM4Building intends to stimulate research on the reuse of industrial residues containing enhanced concentrations of natural radionuclides (NORM) in tailor-made building materials. Investigations on AACB are considered an emerging field under that COST action, which is why waste reuse is the subject of three chapters in this book.

1.3 Outline of the book

This handbook provides an updated state-of-the-art of the field of alkali-activated materials.

The first part encompasses an overview on the chemistry, mix design and manufacture of alkali-activated binders (Chapters 2–4).

Chapter 2 concerns the chemistry of the different types of alkali-activated binders. It reviews the physical-chemical principles governing alkali-activation processes in both high- and low-CaO aluminosilicate materials. It addresses factors such as starting material composition, reaction mechanisms, and the nature, composition and structure of the reaction products.

Chapter 3 discusses the most prominent characteristics and properties of the two-part component of alkali-activated materials, i.e. solid aluminosilicates and alkaline activators. It includes the $[\text{CaO}]/[\text{SiO}_2]$ and $[\text{SiO}_2]/[\text{Al}_2\text{O}_3]$ ratios in the cementitious materials; the best activator for each solid precursor; and the effect of anions (OH^- (pH), silicates, carbonates and sulfates) and cations (Na^+ or K^+).

Chapter 4 analyses a case study related to the synthesis of a new activator like waterglass from waste glass reuse through processes of solubility. The feasibility

of using this solution as a potential alkaline activator for blast furnace slag cement pastes is also analysed.

The properties of AACB are the subject of Part Two (Chapters 5–10).

Chapter 5 is concerned with setting time, segregation and bleeding of alkali-activated binders. Setting time for three different precursors is analysed (ground granulated blast furnace slag, metakaolin and fly ash). Comments on the segregation and bleeding of alkali-activated binders are made.

Chapter 6 looks at rheology parameters of alkali-activated binders. The chapter is divided into three parts: the first relates to forming techniques, the second concerns scientific rheology aspects, and the third presents the results of rheological studies on different alkali-activated systems.

Chapter 7 covers the mechanical strength and Young's modulus of alkali-activated binders. The influence of the type of aluminosilicate precursors and synthesis conditions on compressive and flexural strength is discussed. Comments on tensile strength are given. Analyses of Young's modulus of alkali-activated binder (AAB) gels, paste, mortars and concretes are made. The mechanical performance of fibre reinforced AAB is also analysed.

Chapter 8 analyses a case study related to the prediction of the compressive strength of alkali-activated binders by neuro-fuzzy modelling. The model was constructed by 395 experimental data collected from the literature and divided into 80% and 20% for training and testing phases, respectively. Absolute fraction of variance, absolute percentage error and root mean square error of 0.94, 11.52 and 14.48, respectively in the training phase and 0.92, 15.89 and 23.69, respectively in the testing phase of the model were achieved, showing the relatively high accuracy of the proposed neuro-fuzzy model.

Chapter 9 analyses the pore structure of alkali-activated metakaolin and alkali-activated slag. Water permeability, absorption and chloride ion diffusion of AACB are also examined

Chapter 10 addresses shrinkage and creep of alkali-activated binders. It includes a discussion of the importance of shrinkage and creep as well as of the factors that affect these two parameters. An example of shrinkage and creep prediction is also included.

Part Three (Chapters 11–17) deals with the durability of AACB.

Chapter 11 reviews freezing and thawing resistance of alkali-activated binders. It describes frost damage mechanisms and significant parameters of frost action.

Chapter 12 analyses the resistance to carbonation of alkali-activated binders. The protocols followed to assess the carbonation susceptibility are presented. A critical overview of the role of testing conditions and chemistry of the binding phases on the results acquired from those tests is included.

Chapter 13 is concerned with the corrosion behaviour of reinforced steel embedded in alkali-activated mortar. A discussion on the influence between the passivating capacity and the nature and dosage of binder on the type of activator used and on the environmental conditions is presented. New palliative methods (inhibitors and stainless steel) to prevent reinforced concrete corrosion are presented.

Chapter 14 is concerned with resistance to chemical attack of alkali-activated

binders. Three cases merit the author's attention. Acid resistance of alkali-activated slags, acid resistance of alkali-activated pozzolan (ash, metakaolin, mine waste) and acid resistance of a hybrid Portland cement–alkali-activated aluminosilicate system. The decalcification resistance of alkali-activated granulated blast furnace slag and the resistance to alkaline solutions are also presented.

Chapter 15 is related to the resistance to alkali-aggregate reaction (AAR) of alkali-activated binders. The chapter starts with an overview on the visual and microscopic manifestations as well as on the mechanisms of ASR in Portland cement concrete. Analyses of AAR in alkali-activated slag, alkali-activated fly ash and alkali-activated metakaolin are included.

Chapter 16 analyses the resistance to fire of alkali-activated binders. The introduction reviews the risks arising from fires in construction; the principles of passive fire protection; the definition of the fire resistance of materials; the standard temperature–time fire curves used for the simulation of several fire incidents; and the potential of alkali-activated binders as fire resistant materials. A discussion on the theoretical principles governing the fire performance of alkali-activated binders is included as well as a review on fire resistant alkali-activated binders.

Chapter 17 closes Part Three with a closer look at the efflorescence control of alkali-activated binders. It starts with comments on general features, definitions, effects and consequences, types of efflorescence and formation mechanism. Methods to reduce efflorescence are described, including careful adjustment of chemical composition, curing conditions and utilization of special additives.

Part Four (Chapters 18–24) concerns current applications of AACB.

Chapter 18 examines the reuse of aluminosilicate industrial wastes in alkali-activated binders. It includes residues from industrial activities related to energy, metallurgy, mining, ceramics, construction and demolition, chemical and petrochemical industries and agro-industry. Mechanical and microstructural properties of paste, mortar or concrete prepared by alkali activation of these residues are presented.

Chapter 19 covers the reuse of recycled aggregates in alkali-activated concretes. A brief discussion on recycled aggregates is included. The properties of alkali-activated recycled aggregate concrete are discussed, including normal strength, lightweight and pervious alkali-activated concrete. The performance of alkali-activated concrete containing recycled aggregates from other sources is also reviewed.

Chapter 20 looks at the use of alkali-activated binders for toxic waste immobilization. A discussion on the nature of the waste, in terms of mineralogy, alumina and silica contents, particle size, surface area and morphology and its influence on the reactivity of the waste is carried out.

Chapter 21 deals with alkali-activated mixtures for soil stabilization. The basic mechanisms of chemical soil stabilization are presented. Current materials and techniques for stabilization are reviewed. Recent results on the development of alkali-activated binders for soil stabilization are discussed.

Chapter 22 covers alkali-activated cements for OPC concrete coating. The properties (setting time and bond strength) and durability of metakaolin-based AACB used as inorganic coating for OPC concrete in the marine environment are presented. The

results of on-site trials over OPC concrete accropodes along the Shanghai Jinshan coast are also presented.

Chapter 23 looks at the performance of alkali-activated mortars for OPC concrete repair and strengthening. It provides a literature overview on concrete repair materials, highlighting current problems faced by them. The potential of alkali-activated mortars to overcome those limitations is analysed. Two specific cases are addressed: the case of concrete patch repair and the strengthening of concrete structures with fibre sheets.

Chapter 24 closes Part Four and covers the properties and durability of alkali-activated masonry units. Physical, mechanical properties and durability of alkali-activated binders based on different types of wastes are discussed.

Finally, Part Five concerns life cycle analysis (LCA) and novel applications of AACB (Chapters 25–28).

Chapter 25 looks at the LCA of alkali-activated cements and concretes. A revision of the theory on the compressive strength of concrete to define a functional unit that also includes the volume of the cement paste in the concrete to compare mixes was carried out. A new method to recalculate the cement equivalent of an alkali-activated concrete is presented. The global warming potential (GWP) of the mixes in the published LCA was calculated and compared to the current concrete alternative and the best available technology. Simulations on GWP of hybrid alkali-activated cements and one-part geopolymers are included.

Chapter 26 is concerned with the use of alkali-activated binders as inorganic thermal insulator materials. The chapter starts with an overview on general aspects and thermal phenomena in porous materials. It then reviews the various ways to prepare foam-based AACB, and analyses the influence of blowing agent and alkaline elements on the foam network, microstructure, porosity and thermal properties.

Chapter 27 addresses the photocatalytic degradation of water pollutants with alkali-activated cements.

Chapter 28 closes Part Five with important insights on innovative applications of low calcium alkali-activated binders (geopolymers). These include: potential for fast ion conductor applications, to act as photocatalysts for the photodegradation of pollutants, biological applications, to be used as solid-state humidity indicator, as chromatography media for separating mixtures of organic compounds, as low temperature ceramics, as carbothermal reduction and nitridation (CRN) precursors for wear-resistant engineering components, as stable host material for luminescent systems, as catalyst for organic reactions, and as solid-state hydrogen storage material.

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