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Standardization and Legislation

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Abstract Because building materials are intended to provide durable and safe structures, they are subject to strict regulations designed to ensure that they do not pose a hazard during their use. But they must also not be harmful to humans or the environment at the end of their life cycle, regardless of whether they are reused, recycled, or disposed of in a landfill. The requirements that building materials/products must meet

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vary around the world, but all countries have at least some minimum requirements, whether through regulations, mandatory standards, certification procedures, and/or monitoring at construction sites. In Europe, regulations and standards are based on what is known as the "materials-based" approach, meaning that standards define not only the technical requirements, but also the materials from which products are made. Other parts of the world use the so-called "performance-based approach", meaning that products must have a certain performance regardless of the materials from which they are made. The "materials-based" approach could present some obstacles or barriers for alkali activated products when it comes to providing the documentation needed to bring such products to the market, as there are no EN standards for alkali-activated products so far. The aim of this chapter is to provide information on the legislation for building materials in general but with a focus on alkali activated materials (AAM) around the world and to provide guidance on how to approach the subject.

Keywords Standardization · CPR · hEN · EAD · Alkali activated material (AAM)

1 Introduction

The construction sector is strictly regulated by standards, regulations, conformity certification systems, and so on. Therefore, it is necessary to keep all the regulations behind them in mind when developing new products, in order to evaluate the products appropriately and enable a successful market entry. Especially in EU projects, it is often reported that the lack of standardization in the field of alkaline activated products could hinder their successful positioning on the market.

The aspect of standardization is very important for both the manufacturers of novel products and for the researchers and developers. In research nowadays a higher technological readiness (TRL) is required. This means that a pilot product should be developed as part of the project and the development of a market entry strategy is expected. Such a market strategy necessarily includes an adequate consideration of standardization and legislative activities. However, it also applies to society as a whole, as the commitment to a circular economy requires the recognition of such barriers and policies to overcome them. Barriers and obstacles to the implementation of the circular economy have different backgrounds; they can be cultural, sectoral, financial or regulatory. But among many of these, standardization issues are always identified as a major issue [1–3].

The lack of standardization activities in EU projects was also recognized by CEN, which launched "Bridget" and "Bridget 2" (Bridging the Gap between Research and Standardization), an initiative aimed at improving the link between research and standardization. It was recognized that standardization should become an integral part of the research and innovation cycle of product or process development. The project was funded by the European Commission as part of the FP7 and later Horizon 2020 programs. It represents an important effort to improve the link between research

and standardization by promoting the integration of research results into standardization activities [4]. A similar initiative has been developed under the H_Europe project "HSbooster", which supports research and innovation projects to exploit results through standardization and address the urgent issues identified in the "EU Strategy for Standardization" [5].

It has been recognized that R&D stakeholders should generally be more aware of the rules, not only during research, as compliance with the requirements of standards ensures that the developed products are competitive or compatible with those already on the market, and especially because pre-normative activities can significantly reduce the time to market. In international business, the issue of standardization can also boost or slow down the economy [6, 7].

2 European Legislation for AAM

2.1 EU Procedure for Attestation of Conformity

Standards are voluntary documents that either specify requirements for a particular item, material, component, system, or service, or describe a particular method or procedure. They thus facilitate the trade of products and services and bring benefits to both companies and customers, and establish a common foundation that ensures consistency, compatibility, and mutual understanding across industries and market [8].

However, standards can also become mandatory through European or national regulations, as is the case with construction products. Manufacturers of construction materials must comply with EU Regulation No. 305/2011 (Construction Products Regulation or CPR) [9], which sets the technical requirements and legal procedures for placing construction products on the EU market. This stringent regulation aims to ensure the safety, stability and sustainability of construction works through the proper fulfilment of eight basic requirements (Table 1):

Revised CPR 3110/2024 which was published in EU Official Journal on 18 December 2024, and entered into force on 7 January 2025 envisages 15 years of transition period before full implementation.

A product that is labelled CE meets the basic requirements that are important for its intended use. These procedures are described in detail in the harmonized European standards (hEN) for most construction products. The hEN means that they address the basic requirements from the building and product regulations and that the products also meet these requirements. This procedure, defined in hEN also foresees which product can bear the CE mark and defines the attestation of conformity system. It specifies the tasks (tests and factory production control) to be performed by manufacturers or by a notified independent body.

Such harmonised standards exist for practically all traditional building products, from bricks and cement to aggregates, roof tiles, etc. Only concrete is an exception,

Table 1 Basic requirements from CPR-2011 and CPR-2024

CPR-2011	CPR-2024
1. Mechanical resistance and stability	1. Structural integrity
2. Safety in case of a fire	2. Fire safety
3. Hygiene, health and the environment	3. Protection against adverse hygiene and health impacts
4. Safety and accessibility in use	4. Safety and accessibility
5. Protection against noise	5. Resistance to the passage of sound and acoustic properties
6. Energy economy and heat retention	6. Energy efficiency and thermal performance
7. Sustainable use of natural resources.	7. Emissions into the outdoor environment of construction works
	8. Sustainable use of natural resources

as the EN 206 standard provides a structure that is in line with the CPR but is adapted to national application by local regulations. This is also the reason why the use of alternative binders, even if they are already CE marked, cannot be used in concrete without going through the European or national procedure.

Alkali-activated materials (AAM) are innovative construction products that do not yet fall within the scope of any hEN. Their legal access to the EU market is therefore regulated differently and follows the European Technical Assessment procedure (ETA) governed by EOTA [10], which requires the preparation of a corresponding European Assessment Document (EAD) defining the relevant essential characteristics in accordance with the basic requirements of the CRP. Such procedures are already available for many products, but if not, manufacturers may also request an EAD from a designated TAB (Technical Assessment Body), which will develop an EAD in collaboration with other members of the European Organization for Technical Assessment (EOTA). The proposed EAD draft is then circulated within the EOTA until all comments have been addressed to satisfaction. The EAD will then be published and used to harmonize technical specifications. An ETA is drafted following the requirements of the EAD. It therefore addresses the basic CPR requirements and contains information on the intended use and performance of a product. It also defines the use of the CE marking. The procedure is shown schematically in Fig. 1.

While placing construction products on the market is regulated at the European level, the use of products in construction is under the jurisdiction of the individual member states.

AAM have the potential to be widely used in the construction sector if the performance required for the intended use is achieved. The scope of research on AAM has increased in many countries around the world, while their large-scale production has been successfully started in countries such as the Ukraine, Australia and China. Hence the research results can be successfully implemented at the industrial level, which is of great importance for both the economy and the environment. The products introduced to the market include concrete, bricks, fire-resistant geopolymer foam, fire-resistant paint and fibre-reinforced mortar for structural rehabilitation

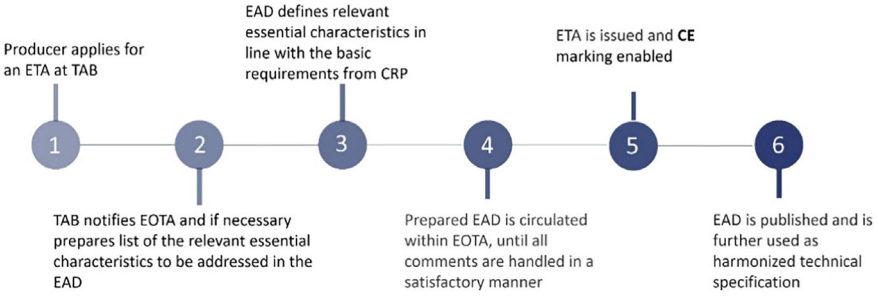


Fig. 1 Schematic presentation of the procedure for acquiring an ETA

and surface reinforcement (discussed further in Chap. "Applications"). A building called the Global Change Institute was constructed in Australia using AAM structural concrete in 2013 at the University of Queensland [11] (www.geopolymer.org) and the aircraft pavements at Brisbane West Wellcamp Airport were made of AAM concrete in 2014 [12]. These successfully applied cases provide some guarantee of the long-term performance of AAM. In Europe, adoption of AAM into practice is progressing slowly. As noted above, one of the reasons could be that the standardisation environment in Europe is "product/material based" rather than "performance based" and that there are no harmonised standards yet for such products, while other ways (EAD, national assessment), even if available, cost more time and money.

2.2 Some National Routes for Attestation of Conformity

Innovative products can also enter the European market through national assessment regulations, but only if there is no hEN available. Based on national approval, it can also be only sold locally. However, if manufacturers want to expand their market outside of their country, they can enter the EU market based on the mutual recognition document (REGULATION (EC) No. 764/2008) [13]. The use of such recognition in another EU Member State may require additional specific tests, e.g. on earthquake resistance or frost resistance. Manufacturers can obtain such information through national contact points [14].

Some selected national routes for assessment procedures are presented below.

Procedure in Slovenia: In Slovenia, the national procedure is similar to the EU procedure. A manufacturer applies for national approval to a designated institute (TAB) with a description of the product and its intended use. TAB then establishes a test program based on the basic CRP requirements (including harmful substances), and after positive test results, a national technical assessment is issued with an accompanying program for factory production control and attestation conformity system. CE labelling is not allowed if following this procedure.

Procedure in the Netherlands: The Netherlands are the first EU country which implemented a national approach for structural geopolymer/alkali activated concrete. So far, two main geopolymer applications are covered:

Architectural concrete based on geopolymer binders (tile, pavers, curbs etc.).

Ready mixed concrete/precast and applications based on geopolymer binders.

For both applications, the industry needs to validate and certify to main aspects:

Technical production and product performance.

Environmental performance related to element leaching. This is organized between the producer and the customer, validated by an independent certification body and covered by a covenant agreement.

For the environmental aspect a (NL) national product assessment guide is constructed named BRL 5077 [15]; in these documents the geopolymer concrete performance (building material) is validated/ linked to the Dutch national law on element leaching which is described in the Besluit Bodem kwaliteit.

Procedure in Finland: In Finland, national procedures can be applied for products not covered by hEN, ETA based on the *Act on Type Approval of Certain Construction Products* (Laki eraeiden rakennustuotteiden tuotehyvaeksynnaestae 954/2012) [16], which came into force in July 2013.

There are three voluntary national procedures for the approval of construction products:

Type approval

Test verification certificate

Production quality control certification

Only one of the procedures can be used for the same group of products.

Type approval is a voluntary approval procedure for construction products listed in the Ministry of Environment's Regulation on Type Approval of Certain Construction Products, and is carried out by an authorized body.

A verification certificate allows the manufacturer to prove that the product can be used in construction because it meets the requirements specified by law. With a test verification certificate, the builder can prove that the product is suitable for the intended use when applying for a building permit or in connection with building supervision. Compared to type approval, the test verification certificate is a less administratively complex procedure for approving a construction product.

A certification of production quality control can be used to confirm that the construction product is suitable for the intended use if no type approval has been granted or no test certificate can be issued. Further information on the procedures can be found at the Finnish National Contact Point [17].

Procedure in the United Kingdom: Steps toward standardisation of AAMs in the UK reached the attention of the civil engineering with the publication of the British Standards Institute (BSI) publicly available specification (PAS) 8820:2016 [18] which describes a procedure for the validation of the characteristics and performance of AAM cements and the concretes produced from them. This document was sponsored by a major asset owner and an AAM producer, drafted through a BSI committee and peer review process including an open public comment period, and approved for use in the UK. A PAS document is not intended to be a standard,

but rather acts as a pre-standardisation step that defines good practice and sets the expectations for how the materials within its scope are to be formulated and tested.

The AAMs covered by the scope of PAS 8820:2016 are produced by combining an alkaline activator (defined very broadly as a constituent that raises the pH to induce reaction, containing alkali metals, magnesium, and/or calcium) with "main constituents" which are selected from among the well-established supplementary cementitious materials (SCMs) defined and used in EN 197-1 [19] cements and EN 206 [20] concretes: GGBFS, natural pozzolans (calcined or uncalcined), fly ash, or burnt shale. Limestone and silica fume are also permitted to be included, but only in conjunction with one of these other main constituents. Portland cement content is limited to 5%, to prevent overlap in scope with the CEM III/C class of common cements in EN 197-1, rather than for any specific reason related to the performance or characteristics of AAM cements containing higher than this level of Portland cement content.

The PAS 8820:2016 approach includes classification of the AAM at a cement/mortar level, according to fresh-state and strength properties, giving a set of classes that are intended to be closely aligned to the classification given in EN 197-1. The test methods that are specified are in general as close as possible to established UK practice for testing of conventional cement-based materials, with modifications as needed to enable their application to AAMs.

The concrete testing also involves qualification by strength grade and fresh properties, as well as durability testing which is conducted comparatively with concretes that are of established satisfactory performance according to the tabulated prescriptive requirements of BS 8500 [21] (which is the UK national counterpart to EN 206). The candidate AAM concretes are tested under selected durability methods, in parallel with the conventional concretes and if the performance of the AAM concrete is at least equivalent to that of the conventional concrete, then it is classified as acceptable for that exposure class scenario under PAS 8820. However, it is worth noting that the selection of the control/conventional concrete should be representative of accepted practice for a specific application. Tests are required for all concretes for ASR, freeze-thaw, and sulfate attack; concretes to be used with reinforcement are also tested for carbonation and chloride ingress. Durability tests are selected from established UK practice, using the EN catalogue where these were available at the time of publication, or alternative well-proven tests otherwise (i.e. ASR by a RILEM method, freeze-thaw by a Swedish method, sulfate by an ASTM method). Where possible, non-accelerated or minimally-accelerated tests are specified, but scope if provided for more accelerated methods to be chosen by mutual agreement between key stakeholders.

Industry feedback on the practical application of PAS 8820:2016 focused on the difficulty in completing the required tests within a realistic timeframe, the need to invest in building up a significant database of reference concrete test results for comparative purposes, and some challenges in defining the actual precision of the test methods. Discussion that followed the release of this document, as well as the findings of RILEM TC 247-DTA [22–24] led to further understanding of the industrial needs and practical applicability of the various test methods and approaches

to proving performance, as well as identifying additional information related to structural characteristics and material properties that are required by engineering designers and specifiers. From this basis, rather than converting PAS 8820 directly into a full BSI standard (which is often the intended outcome of a PAS development process), the UK community instead decided to evolve standards development for AAMs using a new pathway that had been introduced by BSI, of a "Flex Standard", with an accelerated drafting and review procedure but carrying more weight than a specification-style PAS. Nevertheless, it is worth noting that for both BSI PAS and BSI Flex documents do not provide the liability coverage that a typical standard document carries, and this can often be a reason for AAMs not being preferred in the industry.

To this end, BSI Flex 350:2023: Alternative binder systems for lower carbon concrete. Code of Practice, [25] was developed, and initially published in 2023. BSI Flex 350:2023 has undergone the first stage of public consultation and new version BSI Flex 350 v2.0:2024-09: (2024) was accepted in 2024 and replaced PAS 8820.

This standard carries through many things that were learned in the development and application of PAS 8820 and also integrates additional information that was derived from Australian and other international experience in AAM standardisation and commercialisation. The specific details of the Australian standards framework as applied to AAMs will be presented in Sect. 4, and that experience provided very valuable input into the process of evolving PAS 8820 into Flex 350. While the scope of Flex 350 pertains to other potentially lower carbon concrete and cement systems, it is very much designed around AAMs.

A major change in the focus of Flex 350 is the fact that the low-carbon credentials of the material must be demonstrated as a key aspect of the accreditation process; Flex 350 declares that its applicability is specifically for low-carbon concretes, based on the classifications given in the Low Carbon Concrete Group's Low Carbon Concrete Routemap [26], which was developed by, and is strongly influential within, UK industry. However, the classification going forward is expected to be based on other influential systems for concrete embodied carbon, such as the Universal Classification [27, 28]. The scope of Flex 350 includes terminology of "Alternative Binder Systems" (ABS) rather than specifically being scoped to describe only AAMs, but AAMs are given as a key example of the ABS concept throughout the document. It is also less restrictive on the selection of precursor materials than was PAS 8820, with materials outside the established SCMs standards being accepted as long as consistent quality of both the precursor materials and the resulting concretes can be demonstrated.

Compared to PAS 8820, the emphasis of the testing and analysis conducted under Flex 350 is much more strongly at concrete, rather than binder/mortar, level. This is in large part in recognition of the fact that a performance-based philosophy is most usefully applied to a concrete (as the ultimate end-product), without necessarily benefiting from placing too many requirements on the intermediate stages (i.e. binder formulation). There is the option for a producer to supply a separate ABS binder to be used in producing concretes, and if this is done then the binder should be tested and classified for strength as is conventional for common (and other) cements, but this step is not strictly required if ABS (including AAM) concretes are produced directly.

Although the binder certainly does form a key part of the concrete formulation, it is more productive to treat the concrete as a whole when classifying and qualifying performance.

Procedure in Switzerland: In Switzerland, alkali-activated binders are partly covered by the SIA Guideline MB 2049 [29] which describes a procedure to obtain approval for a cementitious binder outside the specifications of the EN 197 series. Alkali-activated binders could comply to the cement type "HSN" (CH-blast furnace composite cement), in case blast furnace slag and/or calcined oil shale (main constituents S and T, respectively) according to EN 197-1 are present in contents between 80 and 100% mass-% of the binder. Portland cement clinker may be present up to 20 mass-%. The manufacturer needs to supply to the certification body quite extensive results related to binder, mortar and concrete properties including durability, and the conformity of the product needs to be surveyed regularly. Currently, no alkali-activated binder is certified according to SIA 2049.

The guideline was replaced by a Swiss national Standard, SIA 215-1 [30], and became effective in May 2025. The possible compositions of the cement type "HSN" were extended. The Portland cement clinker was limited to max. 5 mass-%, and 80–100% mass-% of the binder should contain other main constituents as specified by the EN 197 series; at least 50 mass-% should be blast furnace slag. Up to 20 mass-% main constituents outside the specifications of the EN 197 series may be added. Minor constituents including the activator are limited to 5 mass-%. The certification process will be similar as in the case of MB 2049.

2.3 Environmental Aspect

In addition to fulfilling the technical requirements, it should be noted that special attention should be paid to fulfilling the basic requirement #3 (hygiene, health and environment). The characteristics are in fact not defined uniformly throughout Europe. Some hEN/EAD documents address this aspect and prescribe methods of determination and sometimes even limit values for hazardous substances, but in most of these documents the decision on harmful substances is left to each member state.

If tests are not specified (i.e., which method, which limit values), it is usually assumed that construction products can become waste at the end of their life cycle and hence meet certain requirements of the Waste Framework Directive (WFD). The main objective of the WFD is a proper management of waste to prevent pollutants (potentially toxic elements or substances) from entering the environment where they may pose a risk to health, i.e. to reduce potential negative impacts on the environment, in particular on surface water, groundwater, soil, air and human health. Leaching tests are generally considered to be the most appropriate laboratory methods for assessing the release of contaminants, ensuring compliance with regulatory limits, and evaluating potential health or environmental risks resulting from waste disposal. Leaching results must comply with the requirements and provisions of the WFD

(2018/851) [31] and the Landfill Directive 1999/31/EC [32]. Table 2 provides an overview of the requirements of the WFD for different types of waste.

In some countries, the provisions of the WFD are directly adopted to assess construction products with regard to pollutants. Other countries provide national regulations that may impose stricter requirements than the WFD. Some countries have enacted specific legislation for products manufactured on the basis of waste materials. Information on pollutants can also be obtained (if not from the relevant ministries) from the EOTA and/or TAB involved in the preparation of the European Technical Assessment, where this specific basic requirement should be duly taken into account.

In **Slovenia**, for example, a waste regulation [33] was updated in June 2022 (http://www.pisrs.si/Pis.web/pregledPredpisa?id=URED8482), which specifies that additional leaching requirements are imposed on the reuse of waste in construction products. Table 3 provides a comparison between the limit values specified in the WFD and the requirements of the Slovenian national regulation.

In the **Netherlands** the regulation Soil Quality regulation—BWBR0023085 [32] prescribes limit for heavy metals, selected anions, as well as organic components in building materials/products, as given in Table 4 and Table 5 respectively.

The document provides also requirements for organic parameters. For further details, please check the original document.

In **Belgium** the so-called VLAREMA document [35] defines requirements for use of waste as building materials. Requirements for heavy metals are given in Table 6; the document provides also requirements for organic parameters. For further details, please check the original document.

In **Switzerland**, regarding environmental issues including limits for hazardous materials, the upcoming national standard on alternative cements (SIA 215/1) [30] refers to the national VVEA and Chemical Risk Reduction regulations. Some possible binder constituents (hard coal fly ash, paper ash, wood ash, granulated blast furnace slag, electric arc furnace slag) are on the VVEA positive list, enabling their use in cementitious binders without further testing regarding the possible presence of hazardous constituents.

As can be seen from these examples limits for use of certain materials in the building sector varies from country to country. Such new regulations (or stricter ones) are also expected to come into force in other countries. In particular for AAM products, where alkaline components are added to the mixture, those may be released into the leachate if they are not fully consumed for the alkali-silica reaction, resulting in a higher dissolution of certain elements or a less effective binding of elements due to the partially amorphous nature of the AAM microstructure [36, 37]. Hence special attention should be paid to this aspect, because only a proper mixture design can control this aspect [37, 38].

Table 2 Leaching limit values for different types of landfills according to the WFD [31]

Component	Inert waste			Non-hazardous waste/ hazardous waste acceptable at non-hazardous waste landfill			Hazardous waste		
	L/S = 2 L/kg	L/S = 10	C_0^1	L/S = 2 L/kg	L/S = 10	C_0^1	L/S = 2 L/kg	L/S = 10	C_0^1
	mg/kg	Dry substance	mg/L	mg/kg	Dry substance	mg/L	mg/kg	Dry substance	mg/L
As	0.1	0.5	0.06	0.4	2	0.3	6	25	3
Ba	7	20	4	30	100	20	100	300	60
Cd	0.03	0.04	0.02	0.6	1	0.3	3	5	1.7
Cr total	0.2	0.5	0.1	4	10	2.5	25	70	15
Cu	0.9	2	0.6	25	50	30	50	100	60
Hg	0.003	0.01	0.002	0.05	0.2	0.03	0.5	2	0.3
Mo	0.3	0.5	0.2	5	10	3.5	20	30	10
Ni	0.2	0.4	0.12	5	10	3	20	40	12
Pb	0.2	0.5	0.15	5	10	3	25	50	15
Sb	0.02	0.06	0.1	0.2	0.7	0.15	2	5	1
Se	0.06	0.1	0.04	0.3	0.5	0.2	4	7	3
Zn	2	4	1.2	25	50	15	90	200	60
Cl^-	550	800	460	10000	15000	8500	17000	25000	15000
F^-	4	10	2.5	60	150	40	200	500	120
SO_4^{2-}	560[a]	1000[a]	1500	10000	20000	7000	25000	50000	17000
Phenol index	0.5	1	0.3	–	–	–	–	–	–
DOC[b]	240	500	160	380	800	250	480	1000	320
TDS[c]	2500	4000	–	40000	60000	–	70000	100000	–

Remarks: Member states can determine which of the test methods and corresponding limit values should be used

[1] Percolation test

[a] If the waste does not meet these values for sulphate, it may still be considered as complying with the acceptance criteria if the leaching does not exceed either of the following values: 1500 mg/L as C_0 at L/S = 0.1 L/kg under initial equilibrium conditions, whereas the value at L/S = 10 L/kg may be determined either by a batch leaching test or by a percolation test under conditions approaching local equilibrium

[b] If these values are not met (at pH of waste), alternative testing conditions are L/S = 10 L/kg and a pH between 7.5 and 8.0: the results should be $\leq$500 mg/kg (inert waste) or $\leq$800 mg/kg (non-hazardous waste and hazardous waste)

[c] Values for total dissolved solids (TDS) can be used alternatively to the values for sulfate and chloride

Table 3 Comparison between limits given in WFD [31] and the limit on concentrations in recycled products from the Slovene decree on waste [33]

Element (mg/kg)	Cr	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg	Pb
Inert waste	10.0	/	10.0	50.0	50.0	2.0	0.5	10.0	3	0.7	100.0	0.20	10.0
Non-hazardous waste	0.5	0.03	0.4	0.5	2.0	0.1	0.6	0.5	0.025	0.3	5.0	0.005	0.5
Decree on waste (SLO)	0.5	/	0.4	2.0	4.0	0.5	0.1	0.5	0.04	0.06	20.0	0.01	0.5

Table 4 Limits for heavy metals and selected anion as given in Soil Quality regulation—BWBR0023085 [34]

Element	Cr	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba
Shaped (E_{64d} in mg/m^2)	120	60	81	98	800	260	4.8	144	3.8	8.7	1500
Unstyled (mg/kg dw)	0.63	0.54	0.44	0.9	4.5	0.9	0.15	1	0.04	0.32	22
IBC building materials (mg/kg dw)	7	2.4	2.1	10	14	2	3	15	0.06	0.7	100

Table 5 Limits for heavy metals and selected anion as given in Soil Quality regulation—BWBR0023085 [34] Cont

Element	Hg	Pb	Sn	V	Br	Cl	F	SO_4
Shaped (E_{64d} in mg/m^2)	1.4	400	50	320 [1]	670[2]	110000[2]	2500[2]	165000[2]
unstyled (mg/kg dw)	0.02	2.3	0.4	1.8 [1]	20[2]	616[1,2]	55[2]	1730[2,3]
IBC building materials (mg/kg dw)	0.08	8.3	2.3	20	34	8800	1500	20000

Notes

- Shaped is monolithic concrete and analysis is based on the tank test
- Unstyled-non-shaped is granular material and analysis is based on the column test

Table 6 Limits for heavy metals as given in VLAREMA [35]

Element	AS	Cd	Cr	Cu	Hg	Pb	Ni
Total conc. (in mg/kg dry matter)	250	10	1250	375	5	1250	1250

Notes (1) The concentration applies to the metal and compounds expressed as metal

(2) Determination of the total concentration of metals according to the methods in the Compendium of Sampling and Analysis (CSA)

3 Ukrainian Legislation for AAM

Standardization in Ukraine is carried out in three stages. In the first stage, the enterprise standards are created, in the second stage—the industry standards, and in the third stage—the national standards.

The transition from one standard to another is based on accumulated experience in production and application.

Alkali-activated slag cements and concretes have been used in construction since 1958 in the former Soviet Union. Alkali-activated slag cement and concrete possess many unique features compared with conventional Portland cements and concretes. The manufacture, applications and specifications for alkali-activated slag cement and concrete are different from those for ordinary Portland cement and concrete. Over 60 standards related to alkali-activated slag cements and concretes were developed in the Soviet Union.

The mentioned standards apply to cements, concretes, and recommendations on manufacturing technology. Taking into account extensive experience in production and application of alkali activated materials, Ukraine has created 4 national standards that cover cements (DSTU B V.2.7-181:2009 Alkaline cements. Specifications), concretes (DSTU B V.2.7-25:2011 Heavy weight alkaline concretes), recommendations (DSTU-N B V.2.7-304:2015 Manual on the production and use of alkali activated cements, concretes and structures from them), and norms (DBN G.1-3-95 Standard consumption rates for ground slag and alkaline component for manufacture of alkali-activated slag cement concretes, prefabricated and monolithic concrete and reinforced concrete structures and products) [39, 40].

Structure and content of the newly issued updated Ukraine national standard for AAC was brought closer to the structure of the EU standards (EN) by including the requirements set down, in particular, in EN 197 as to performance characteristics. Considerably, the number of aluminosilicate materials available for use in AACs through involvement of a wider range of by-products such as ash-slag mixtures—by-products of coal incineration process and natural materials such as basalt etc., was enlarged.

Like the European standard for cement EN 197, the newly issued standard specifies only strength classes and compressive strength after 2,7 and 28 days of hardening. In substantial composition and strength at an age of 28 days, the cements are classified as the following: slag alkali-activated cement, alkali-activated Portland cement, alkali-activated pozzolana cement, alkaline slag Portland cement, and alkali-activated composite cement, which differ in combination of such aluminosilicate components as granulated blast furnace slag, Portland cement clinker, ashes from coal combustion, and basalt, taken in combination with the alkaline activator. Compressive strength classes under the standard are: 300, 400, 400R, 500, 500R, 600, 600R, 700, 800, 900, 1000.

The procedure of standardisation of AAC concrete was in line with standardisation rules and international practice, according to which a standard could be issued in cases when extensive experience is collected and proven accordingly, from many years of

research and development and from wide practical application. One variety of these concretes, the alkali-activated slag cement concretes, found wide use in practice of construction on the territory of the former USSR and Ukraine. A priority was given to granulated blast-furnace slags because of the huge amounts available, low cost (for metal producers- for free, being their own by-product). That is why commercial scale production of alkali-activated slag cement concretes (both monolithic and precast) was organized near or on the territory of metallurgical plants (as "side production"-concrete factory).

High performance characteristics of the AAC concretes are supported by over 55-year service life of the AAC concrete structures, as well as by a number of certified tests that have been performed by leading institutions [39–41]. These high strength characteristics (classes from C8/10 to C110/125) guarantee highly advantageous special properties: freeze-thaw resistance (in excess of 1000 freeze/thaw cycles), resistance to water penetration (over 2 MPa), resistance in aggressive environments, inclusive of solutions of magnesium and sulfate salts, an ability to harden at low temperatures, and many others. All of this allows high performance properties of the AAC concretes and their retention in time (i.e., durability). This standard gives specification of basic quality characteristics: mean density; compressive strength; strength in axial tension; tensile strength in flexure; resistance to freezing/thawing; resistance to water penetration.

The third and fourth standards listed above are applicable to the manufacture and use of AACs, heavyweight and fine aggregate AAC concretes, as well as concrete and reinforced concrete structures produced from them, in accordance with Ukrainian basic building regulations for application in common and aggressive environments, common uses such as industrial, civil, agricultural, hydro-engineering, mining, etc., inclusive of those cast-in-situ concretes, taking into account their high water impermeability, corrosion resistance and other performance properties.

The above recommendations cover the requirements for alkali-activated cement concretes in the manufacture of both precast concretes and reinforced concrete products and structures, and cast-in-situ, requirements for winter concreting, as well as requirements for calculations and design of products and structures using normative characteristics.

The manufacturing process and quality of the AAC concrete products should be in compliance with the requirements of the Ukrainian building regulations in their parts concerning the alkali activated slag cements, as well as requirements of valid normative documents currently in force and working drawings for all types of products from heavyweight Portland cement concretes. It is not required to get any approval from the designer in order to substitute Portland cements by alkali activated ones, or to develop any additional technical specification for such products and structures.

4 Australian Legislation for AAM

In Australia, the terms "AAM" and "geopolymer" are used interchangeably, and no justification is presented here for the use of this terminology. In general, these terms are used for any concrete that is chemically activated.

AAMs have been applied at large scale in Australia since 2007, initially by Zeobond Pty Ltd in Victoria, subsequently by Wagners in Queensland, and then by other suppliers. Special permission was granted by regulatory authorities for early project-specific applications, which required close collaboration between technology providers, regulatory authorities, structural engineers and asset owners. Over time, as more confidence was gained in AAM, a need was identified to develop new specifications and standards, or to expand the existing framework to allow for AAM. In the early 2000s in Australia there was little focus on carbon reduction in construction, and the driver for early adoption of AAM was innovation in concrete technology as a niche feature within larger projects. Andrews-Phaedonos [42] provided a review of some of these early pioneering projects approved by VicRoads, the roads authority in the State of Victoria.

Due to confidence gained in these projects, as a pioneering step in Australia, four VicRoads Standard Specifications were amended in 2010 to incorporate provisions for the use of geopolymer concrete as follows:

Section 701—Underground Stormwater Drains, with geopolymer concrete for use in the manufacture of steel reinforced concrete pipes defined as an equivalent product to conventional concrete pipes [43].

Section 703—General Concrete Paving, with geopolymer concrete specified for use in kerb and channel, joint user paths, footpaths, driveways and other surfacing, defined as an equivalent product to conventional concrete for strength grades 20–32 MPa [44].

Section 705—Drainage Pits and Covers, with geopolymer concrete specified for use in the construction of both precast and in-situ drainage pits [45].

Section 711—Wire Rope Safety Barrier, with geopolymer concrete specified for use in the construction of anchor blocks, post footings, maintenance strips and other associated concrete works [46].

In addition, VicRoads also requires suppliers of geopolymer concrete to be approved, which usually involves disclosure of mix designs to VicRoads. Such disclosure has become an obstacle to commercial adoption, as suppliers fear loss of intellectual property because public bodies like VicRoads may be obliged to disclose confidential information under the Freedom of Information Act of 1982. With the increasing investment of suppliers in AAM and chemically activated concrete in Australia, there is a growing need for a performance-based specification framework, instead of the cumbersome requirement to disclose mix designs on a product or project-specific basis.

At present, the use of geopolymer concrete has not been allowed in VicRoads Standard Specification Section 610—Structural Concrete [47]. However, numerous lower risk structural applications have been approved by VicRoads on a case-specific

basis, as outlined by Andrews-Phaedonos [42]. VicRoads Section 610 (2020) sets maximum limits on the Volume of Permeable Voids (VPV), a measure advocated by Andrews-Phaedonos [48] as a permeability indicator of concrete durability. VPV is the key durability measure used by VicRoads and one of the measures used in other states in Australia, but it is not widely used internationally, with some experts disputing its relevance. Several structural grade AAM mixes do not meet the VPV criteria in VicRoads Section 610 [47], which is the reason why there is no blanket acceptance of AAM or geopolymers in this structural specification.

Other states in Australia have taken limited steps to follow the path of VicRoads in recognising geopolymer concrete. For example, the Government of South Australia's Department for Infrastructure and Transport, Division CC Concrete, Part CC27 Geopolymer Concrete [49] specifies geopolymer concrete with strengths 20–32 MPa. The Queensland Government's Department of Transport and Main Roads, Technical Specification MRTS270, Precast geopolymer concrete elements (Transport and Main Roads Specifications MRTS270 Precast Geopolymer Concrete Elements 2018) [50] specifies geopolymer concrete for non-structural applications with a design life less than 50 years.

A further promising development in Australia was the following series of publications by Austroads, which is the association of the Australian and New Zealand transport agencies, representing all levels of government:

Research Report AP-R531-16, Specification of geopolymer concrete: General guide, 2016 [51].

Technical Report AP-T318-16, Specification and use of geopolymer concrete in the manufacture of structural and non-structural components: Review of Literature, 2016 [52].

Technical Report AP-T329-17, Specification and use of geopolymer concrete in the manufacture of structural and non-structural components: Experimental work, 2017 [53].

These Austroads reports have expanded the awareness and knowledge of AAM and geopolymer concrete throughout government agencies and hence key regulatory agencies.

After several years of establishing confidence in AAM and geopolymer technology through large-scale industrial application with the support of suppliers and regulatory agencies, Standards Australia (SA) agreed to publish the following technical specification: SA Technical Specification 199:2023: Design of geopolymer and alkali-activated binder concrete structures [54]. This specification is written in a style that is largely educational and instructive, and it covers the design of AAM concrete structures. This extensive document is based on a large body of experimental results and in-service testing of AAM concrete structures in Australia. It is meant to be read and used in conjunction with Australian Standard AS 3600: Concrete Structures [55]. The document states that the structural behaviour of AAM and geopolymer concrete is different from that of blended PC concrete, therefore the design equations in AS 3600 need to be modified in some instances. Ultimately, AAM should be viewed as a continuum with blended PC concrete, so that AS 3600 should be expanded to cover

a wider range of binders. In the meantime, SA Technical Specification 199:2023 is a useful document that enables structural engineers to specify AAM concrete.

A key development in the adoption of AAM and the wider acceptance of a performance-based approach was the publication of Australian Standard AS 3582.4:2022: Supplementary cementitious materials (SCM) Part 4: Pozzolans—Manufactured, in 2022 [56]. This new Standard is complementary to the existing series AS 3582 Part 1: Fly ash (FA), Part 2: Slag-ground granulated blast-furnace (GBFS) and Part 3: Amorphous silica. This new standard specifies a reactivity test and an expansion test on any synthetic SCM, so it is largely a performance-based standard. Until recently, FA and GBFS were the only SCMs specified in structural concrete, such as in Australian Standard AS 3600. Implicitly, they were also the precursors specified in geopolymer specifications and standards. The new AS 3582.4:2022 effectively broadens the standards framework to include any future SCM or cementitious material in AAM or activated concrete. As the world progresses towards decarbonisation of energy generation and steel production, the current shortage of FA and GBFS will get worse, and future precursors in AAM will be synthetic rather than secondary products from other industries. The approach in AS 3582.4:2022 is not perfect and requires future revision, but it could serve as a model for other jurisdictions. The EN framework with its multiple classes remains largely prescriptive and still does not allow for radical innovation in cement and concrete production, hence this framework protects the incumbents and presents a barrier for alternative technologies like AAM.

The above developments in Australia are only the beginning along an exciting journey. The foundation has been laid for a performance-based framework of standards, but more work needs to be done at research and application level. Sutter and Hooton [57] outline the deficiency of the current standards regime and why a prescriptive approach is outdated, but at the same time why it remains a challenge to progress towards a performance-based approach. A key reason for the industry to continue with prescriptive standards is that it is easier to manage risk.

An ongoing debate in Australia concerns the development of laboratory test methods to quantify the durability and service-life of AAM and other activated concrete with ultra-low CO_2 emissions. This presents a hurdle that the AAM community must address as a matter of urgency. Increasingly, test methods for concrete permeability such as VPV are being accepted for AAM as predictors of service-life. In contrast, there is uncertainty about test methods for binder phase stability, because the tests must be tailored to the exposure conditions and the binder chemistry. Despite the uncertain relationship between accelerated carbonation testing and natural carbonation, SA Technical Specification 199:2023 specifies carbonation rates for AAM. However, high carbonation has been demonstrated to not always cause rapid corrosion of steel reinforcement [58]. Instead of measuring carbonation rate and/or chloride diffusion as predictors of steel corrosion, it is suggested that actual steel corrosion is measured in carbonated concrete as a more accurate predictor of service-life. It remains a challenge to relate laboratory corrosion tests to service-life, which should be an active area of academic research.

5 ASTM and ACI Standardization of AAM

The American Concrete Institute structural code, ACI 318-19, does not specifically refer to AAMs, but does include provisions for an "alternative cement" that can be used as a direct replacement for conventional cementitious materials. This code includes scope for case-by-case approval of the use of alternative cements—which could potentially include AAMs—if they are considered acceptable by the relevant officials. This acceptance could be achieved through demonstration of successful use under conditions with "essentially equivalent performance requirements" (although this means that first-of-its-type applications will always be challenging), or by developing proof that technical requirements can be met, including by using the advice of ACI Innovation Task Group 10 [59] who provided general guidance for the use of alternative cements.

Under this approach, the requirement to demonstrate material performance appears to lie with the producer, but engagement with a suitably supportive specifier or end user can be of enormous value in bringing a first-of-its-type application to fruition; this is a more open scope than is available in many other major structural codes regarding the use of materials that are not specifically covered by relevant (or cascading) standards.

It should also be noted that the jurisdictions in which ACI 318 is commonly used are also heavily reliant on the standards catalogue of ASTM International, who are actively developing standards and specifications for AAMs. The first such standard to reach approval and publication is ASTM C1928/C1928M-23 [60] which describes the methodology for testing the compressive strength of AAM mortar cubes. This may seem at first glance a rather incidental aspect of the standardization of AAM concretes in practice, but in the ASTM standards structure it is essential that this is in place to enable other standards to move forward (for example, the currently (late 2024) open work item on a performance-based specification for AAMs in general [61]. There are details related to sample formulation and mixing procedures embedded in the Portland cement mortar cube testing standard, ASTM C109 [62] which are not applicable to the production and testing of AAM mortars, and so it was considered necessary to first standardize this test method to underpin an essential part of the performance-based approach that is being taken in the broader AAM specification. With the approval of ASTM C1928 in 2023, important further steps in AAM standardization has followed by publication of ASTM C 1948M-24: Standard Specification for Alkali-Activated Cementitious Materials in 2025 [71].

6 Chinese Legislation for AAM

AAM has been studied in China for over 40 years while its large-scale engineering application is still limited. This is primarily due to the challenges in developing standardized technical requirements and quality assessment criteria. Thus, it is crucial

to establish relevant standards for AAM to regulate its production, use, sales, and quality inspection, thereby facilitating its industrial-scale production. In the past 15 years, China has actively developed relevant standards to advance the engineering application of AAM and its products.

AAM generally exhibits excellent resistance to salt and acid-alkali corrosion, making it highly suitable for the production of corrosion-resistant cement products. To ensure the quality and durability of alkali-activated concrete products and to standardize the production and development of corrosion-resistant concrete in China, Jiaxing University led the compilation of the national standard GB/T 29423-2012 "Alkali-activated slag-fly ash concrete for anticorrosive cement products" in 2009 [63]. This is the first standard in China for AAM products. The standard outstands the characteristics of corrosion-resistant concrete products, specifically highlighting the performance requirements of alkali-activated slag-fly ash concrete, focusing on workability, mechanical properties and chemical corrosion resistance by: (1) clarifying the requirements for raw materials; (2) proposing a test method for the setting time of hard-dry concrete and (3) a test method for the chemical corrosion resistance of alkali-activated slag-fly ash concrete [64].

To standardize the engineering application of alkali-activated slag concrete, the local standard DBJ-50T-205-2014 "Technical specification for application of alkali-activated slag concrete" was implemented in 2015 [65]. Afterwards, Chongqing University took the lead in compiling the industry standard JG/T 439-2018 "Technical standard for application of alkali-activated slag" in 2016 [66]. This standard provides detailed specifications for the application requirements of alkali-activated slag concrete, covering aspects such as raw materials quality control, mix design, construction, and quality acceptance, filling the gap in the lack of design basis in the application of alkali-activated slag concrete. As an engineering construction standard, JG/T 439-2018 has been used to guide the construction of foundations, wall panels, and floor slabs in the Chongqing Jianke Building project, using more than 1,000 cubic meters of C20-C45 alkali-activated slag concrete [64].

Starting from the standardization of quality control of slag-based geopolymer concrete, Hunan University led the development of the association standard T/CECS 1556-2024 "Standard for quality control of slag-based geopolymeric concrete" [67]. This standard emphasizes the quality control requirements for the entire production process of slag-based geopolymeric concrete. It provides detailed specifications on mix proportion control, quality standards, preparation and transportation, pouring and curing, and quality inspection, which will further promote the production and application of alkali-activated slag concrete products in China. Moreover, it proposes, for the first time, the test methods for alkali-aggregate reaction, chloride ion permeability resistance, and carbonation resistance of slag-based geopolymeric concrete.

In addition, other standards for AAM, such as the local standard DBJ/T 50-286-2018 "Technical standard for application of alkali-activated slag anchoring material" [68], the industry standard JC/T 2603-2021 "Ecological concrete reef" [69] have been established, further promoting the application of AAM products in specific fields. Therefore, the Chinese standard system for AAM is gradually evolving. However,

there remains a need for the development of standards specifically addressing alkali-activated cementitious materials, structural design of alkali-activated concrete, and related aspects [64].

7 Conclusions

AAMs are being developed to the point where they can be (and have been) used in practice. However, these products must provide adequate long-term performance to be used in construction or in specific niche applications, which should be demonstrated by testing taking into account all relevant parameters. For products that are not covered by an hEN in Europe, the EOTA route can be followed or national assessment procedures can be used. In all cases, due consideration must be given to harmful substances and transparent information about the life-cycle environmental impact, which is further emphasized by the revised CPR (2024/3110) published in EU Official Journal on 18 December 2024, with an entry into force on 7 January 2025 [70]. Revised CPR will require the integration of environmental performance into the DoC (Declaration of Conformity)/DoP (Declaration of Performance) and third party verification.

In other parts of the world, some other (national) legislation is in force, where Australia in particular is driving standardization in the field of AAM much further forward.

As standardization for AAM is not yet uniform, not even in Europe, it is therefore very important that manufacturers check the (national) legislation, including environmental requirements, before placing a product on the market. This also applies to the legislation of all target countries in which they intend to market the product.

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