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Alkali-activated cementitious material and concrete – Specification

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Foreword

Publishing information

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Figure B.1 is taken from BS EN 60812:2006. The complete British Standard can be purchased from the BSI online shop: http://shop.bsigroup.com/ProductDetail/?pid=000000000030101028

Hazard warnings

WARNING. This PAS calls for the use of substances and/or procedures that can be injurious to health if adequate precautions are not taken. It refers only to technical suitability and does not absolve the user from legal obligations relating to health and safety at any stage.

Product certification/inspection/testing

Users of this PAS are advised to consider the desirability of third-party certification/inspection/testing of product conformity with this PAS. Users seeking assistance in identifying appropriate conformity assessment bodies or schemes may ask BSI to forward their enquiries to the relevant organizations.

Assessed capability

Users of this PAS are advised to consider the desirability of quality system assessment and registration against the appropriate standard in the BS EN ISO 9000 series by an accredited third-party certification body.

Test laboratory accreditation

Users of this PAS are advised to consider the desirability of selecting test laboratories that are accredited to BS EN ISO/IEC 17025 by a national or international accreditation body.

Use of this document

It has been assumed in the preparation of this PAS that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions of this PAS are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is "shall".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. "organization" rather than "organisation").

Requirements in this PAS are drafted in accordance with *Rules for the structure and drafting of UK standards*, sub-clause **J.1.1**, which states, "Requirements should be expressed using wording such as: 'When tested as described in Annex A, the product shall ...'". This means that only those products that are capable of passing the specified test will be deemed to conform to this PAS.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a PAS cannot confer immunity from legal obligations.

Particular attention is drawn to the following legislation:

- Carcinogens and Mutagens Directive 2004 (2004/37/EC) [1];
- Chemical Agents Directive 1998 (98/24/EC) [2];
- CLP Regulation 2008 [3];
- Commission Regulation (EC) No 1907/2006 (REACH) [4] and associated amending and enforcement regulations;
- Control of Substances Hazardous to Health (Amendment) Regulations 2004 [5];

- Control of Substances Hazardous to Health (Amendment) Regulations (Northern Ireland) 2005 [6];
- Construction Products Regulation 2013 [7];
- Health and Safety at Work etc Act 1974 [8];
- Personal Protective Equipment Regulations 2002 [9];
- Pregnant Workers Directive 1992 (92/85/EEC) [10];
- Protection of Young People at Work Directive 1994 (94/33/EC) [11];
- Provision of Health and Safety Signs Directive 1992 (92/58/EEC) [12];
- REACH Enforcement Regulations 2008 [13].

0 Introduction

The UK's *Construction 2025: Industrial strategy for construction – government and industry in partnership* [14] sets a range of targets, including*:*

- lower emissions – a 50% reduction in greenhouse gas emissions in the built environment;
- lower costs – a 33% reduction in the initial construction and whole life cost of built assets;
- faster delivery – a 50% reduction in the overall time, from inception to completion, for new build and refurbished assets; and
- improvement in exports – a 50% reduction in the trade gap between total exports and total imports for construction products and materials.

Low carbon cements using alkali activators have been and continue to be developed in the UK. These cements can assist in reaching all of the targets in this strategy by:

- reducing the quantity of carbon dioxide released during the manufacture of cement and concrete;
- avoiding increasing costs associated with energy sources and the capture and storage of carbon from cement production processes and potentially reducing other production costs;
- providing an alternative range of materials for precasting products, as this mode of production can enable faster delivery; and
- helping UK product developers bring their products to market and develop exports.

In addition to these benefits, concrete produced using alkali-activated cementitious material (AACM) can have performance benefits [15] such as improved chemical and fire resistance and/or lower permeability to water and aggressive agents. The properties are influenced by the specific type of AACM used.

Major projects in the UK are actively looking for ways to meet the targets set out by *Construction 2025* [14], particularly in the sector of publicly-funded infrastructure development.

The primary objective of this PAS is to specify performance requirements of AACMs and the resulting concretes, and to facilitate and encourage their use in construction projects, where appropriate.

These new AACM products do not generally fit into the standard framework for traditional concretes and common cements covered by BS EN 197-1, BS EN 206, BS 8500-1 and BS 8500-2. While many of the tests and considerations relevant to traditional concretes and common cements may broadly be applied to AACMs, some of the details do not and this may impede the use of AACMs when the existing standards are specified for a project.

To specify a concrete, it is normally necessary to specify a combination of its performance requirements and any prescribed constituents. By definition an AACM Concrete is required to include AACM, and Clause **4** of this PAS sets out requirements for AACM. Clause **5** of this PAS sets out the requirements for AACM Concrete. Clauses **6** and **7** relate to both AACM and AACM concrete.

This PAS aims to facilitate the use of AACMs within construction by providing alternative specification approaches. It is intended to help specifiers, product manufacturers, materials suppliers and construction clients understand how AACMs can be incorporated into construction projects having confirmed the suitability of an AACM for the intended use. It is important to note that the group of materials described as AACMs covers a wide range of materials, and the

AACM manufacturers will generally need to be consulted to identify the most appropriate AACM and working methods.

Annex A provides guidance for executing a project using these materials.

For some intended uses of an AACM, the risk and opportunities assessment may indicate a need for additional durability tests. It is also noted that this PAS does not include explicit requirements for determination of long-term properties such as creep or drying shrinkage under service conditions, and in circumstances where such properties are critical, additional testing beyond the scope of this PAS may be required. Such additional tests would need to be agreed in writing between the specifier, the AACM manufacturer and the user, as necessary.

1 Scope

This PAS specifies the performance requirements for alkali-activated cementitious material comprising aluminosilicate main constituents and an alkali activator. An AACM (including the activator) may contain Portland cement only at a content of less than 5% mass of binder solids, and may contain subsidiary constituents not exceeding 25% of the mass of the cementitious material. It also specifies a means of assessing concrete obtained through the use of such cementitious material for performance and durability, and sets requirements for the alkali-activating component and the aluminosilicate powder component of these concretes.

NOTE 1 The term "geopolymer" is not used in this PAS, but this does not exclude its use for descriptive purposes in conjunction with alkali-activated cementitious materials.

This PAS does not:

- set detailed requirements for the composition of the alkali-activated cementitious material;
- specifically address applications for such materials as renders, screeds, mortars or repair materials, although it does not exclude the possibility that such materials could be used for such purposes; or
- cover the use of any material classified as hazardous waste.

NOTE 2 Hazardous waste is defined in the Technical Guidance of the UK Environment Agency (https://www.gov.uk/how-to-classify-different-types-of-waste) and includes radioactive materials [16].

This PAS is for use by manufacturers of alkali-activated cementitious material, producers of prefabricated concrete elements containing alkali-activated cementitious material and producers of concrete containing alkali-activated cementitious material which is to be precast, delivered ready-mixed, or mixed in situ. It is also of interest to designers and specifiers as it provides a means of assessing the suitability of AACM concrete mixtures for typical construction uses.

NOTE 3 Attention is drawn to The Personal Protective Equipment Regulations 2002 [9] and The Health and Safety at Work etc Act 1974 [8].

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

BS 8500-1, *Concrete – Complementary British Standard to BS EN 206 – Method of specifying and guidance for the specifier*

BS 8500-2:2015, *Concrete – Complementary British Standard to BS EN 206 – Specification for constituent materials and concrete*

BS EN 196-1:2005, *Methods of testing cement – Determination of strength*

BS EN 196-2, *Methods of testing cement – Chemical analysis of cement*

BS EN 196-3:2005+A1:2008, *Methods of testing cement – Determination of setting times and soundness*

BS EN 196-9:2010, *Methods of testing cement – Heat of hydration – Semi-adiabatic method*

BS EN 197-1:2011, *Cement – Composition, specifications and conformity criteria for* common cements

BS EN 197-2:2014, *Cement – Conformity evaluation*

BS EN 206:2013, *Concrete – Specification, performance, production and conformity*

BS EN 413-2, *Masonry cement – Test methods*

BS EN 480-1:2014, *Admixtures for concrete, mortar and grout – Test methods – Reference concrete and reference mortar for testing*

BS EN 480-2:2006, *Admixtures for concrete, mortar and grout – Test methods – Determination of setting time*

BS EN 480-10, *Admixtures for concrete, mortar and grout – Test methods – Determination of water soluble chloride content*

BS EN 480-11, *Admixtures for concrete, mortar and grout – Test methods – Determination of air void characteristics in hardened concrete*

BS EN 932-3:1997, *Tests for general properties of aggregates – Procedure and terminology for simplified petrographic description*

BS EN 934-1:2008, *Admixtures for concrete, mortar and grout – Part 1: Common requirements*

BS EN 934-2:2009+A1:2012, *Admixtures for concrete, mortar and grout – Part 2: Concrete admixtures – Definitions, requirements, conformity, marking and labelling*

BS EN 1008, *Mixing water for concrete – Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete*

BS EN 1015-3, *Methods of test for mortar for masonry – Determination of consistence of fresh mortar (by flow table)*

BS EN 1015-4, *Methods of test for mortar for masonry – Determination of consistence of fresh mortar (by plunger penetration)*

BS EN 1504 (all parts), *Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity*

BS EN 12620:2002+A1:2008, *Aggregates for concrete*

BS EN 12350 (all parts), *Testing fresh concrete*

BS EN 12390-2:2009, *Testing hardened concrete* – Making and curing specimens for strength tests

BS EN 12390-3, *Testing hardened concrete – Compressive strength of test specimens*

BS EN 12390-7, *Testing hardened concrete – Density of hardened concrete*

BS EN 12390-8, *Testing hardened concrete – Depth of penetration of water under pressure.*

BS EN 12878:2014, *Pigments for building materials based on cement and/or lime – Specifications and methods of test*

BS EN 13055-1:2002, *Lightweight aggregates – Lightweight aggregates for concrete, mortar and grout*

BS EN 13369, *Common rules for precast concrete products*

BS EN 15804:2012+A1:2013, *Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products*

BS EN 60812:2006, *Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*

BS EN ISO 14025:2006, *Environmental labels and declarations – Type III environmental declarations – Principles and procedures*

DD CEN/TS 12390-10:2007, *Testing hardened concrete – Determination of the relative carbonation resistance of concrete*

DD CEN/TS 12390-11:2010, *Testing hardened concrete – Determination of the chloride resistance of concrete, unidirectional diffusion*

PAS 2050:2011, *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*

Other publications

[NR1] BRE Special Digest 1:2005*, Concrete in aggressive ground. Third edition.* Bracknell: BREPress, 2005.

[NR2] BRE Digest 330, *Alkali-silica reaction in concrete, Parts 1-4. Watford: BRE, Centre for Concrete Construction,* 2004*.*

[NR3] RILEM TC 219-ACS. *RILEM Recommended Test Method: AAR-3. Detection of potential alkali-reactivity – 38°C test method for aggregate combinations using concrete prisms. Bagneux: RILEM,* 2011.

[NR4] SIMS, I., and NIXON, P. *RILEM Recommended Test Method AAR-0: Detection of Alkali-Reactivity Potential in Concrete – Outline guide to the use of RILEM methods in assessments of aggregates for potential alkali-reactivity*. *Materials & Structures* 36: 472-479, 2003. (www.rilem.org/images/publis/1559.pdf)

[NR5] HENRICHSEN, A., LAUGESEN, P., GEIKER, M., PEDERSEN, E.J., and THAULOW, N. *HETEK*, *Method for test of the frost resistance of high performance concrete. Summary, conclusions and recommendations.* Report #97. Copenhagen: Road Directorate, Danish Ministry of Transport, 1997.

[NR6] ASTM C1012, *Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution ASTM International, West Conshohocken, 2015.*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this PAS, the following terms and definitions apply.

3.1.1 admixtures
chemical substances, often organic in nature, which have no cementitious value but are added to AACM concrete to manipulate its fresh or hardened state properties

3.1.2 aggregate
natural, artificial, reclaimed or recycled granular mineral constituent suitable for use in concrete

[SOURCE: BS EN 206:2013, **3.1.2.5**]

3.1.3 alkali-activated cementitious material (AACM)
substance consisting of an alkali activator and an AACM powder, or blend of such powders, with or without the inclusion of subsidiary constituents, with or without the incorporation of Portland cement, which under aqueous conditions, reacts to produce a hardened monolithic material

NOTE AACM might also be known as alkali-activated cementitious binder.

3.1.4 AACM concrete
substance formed by combining AACM (including less than 5% Portland cement by mass of binder solids either factory or within-mixer blended), with fine and

coarse aggregates, under aqueous conditions, with or without the incorporation of admixtures

3.1.5 AACM mortar
substance formed by combining AACM (including less than 5% Portland cement by mass of binder solids), with fine aggregates, under aqueous conditions, with or without the incorporation of admixtures

NOTE The Portland cement content may be either factory or within-mixer blended.

3.1.6 AACM powder
substance consisting of one or more powders as its main constituent, containing both aluminium and silicon as oxides, which can be induced to react and harden through the addition of an alkali activator to form an AACM

3.1.7 alkali activator
source of one or more elements in the alkali metals group (Group 1 of the Periodic Table), and/or magnesium, and/or calcium, which when incorporated in aqueous or solid form, induces a reaction, setting and hardening of an AACM

3.1.8 application
method by which an AACM or AACM concrete is to be used

3.1.9 binder solids
part of an AACM consisting of all solids and dissolved solids

NOTE Calculated by subtraction of the water content from the overall mass of the AACM.

3.1.10 CEM (I, II, III, IV, V)
common cements as defined in BS EN 197-1

3.1.11 cradle-to-gate
life cycle stages from the extraction or acquisition of raw materials to the point at which the product leaves the facility in which it is manufactured, or is otherwise placed into service

3.1.12 cradle-to-grave
life cycle stages from the extraction or acquisition of raw materials to recycling and disposal of waste

3.1.13 demineralized water
water with a conductivity of less than 0.2 µS/cm and a silica (SiO_2) content of less than 0.02 mg/l

3.1.14 designer
person or body that prepares or modifies a design for any part of a construction project or who arranges or instructs someone else to do it

3.1.15 effective water content
difference between the total water content and the water absorbed by the aggregates, i.e. water available to the mix constituents, excluding any that has been absorbed by the aggregate or other inert components

3.1.16 exposure class
category of environmental actions that pose a risk of damage to concrete or its reinforcement

3.1.17 fresh concrete
concrete which is fully mixed and still in a condition that is capable of being compacted by the chosen method

[SOURCE: BS EN 206:2013, **3.1.3.7**]

3.1.18 hardened concrete
concrete that is in a solid state and which has developed a certain strength

[SOURCE: BS EN 206:2013, **3.1.4.2**]

3.1.19 heat of reaction
quantity of heat released by the reaction of an AACM within a specified period of time from the start of mixing

3.1.20 intended use
purpose indicated by a manufacturer or producer for which an AACM or AACM concrete is intended to be used

3.1.21 intended working life
assumed period for which a structure or a part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary

NOTE This might also be known as "design working life".

3.1.22 main constituent
powder, usually aluminosilicate, which is present in an AACM in a proportion exceeding 5% by mass of the binder solids

3.1.23 manufacturer
the company (or other legal entity) that assembles the AACM from a range of ingredients

3.1.24 mixing protocol
process for combining the components of AACM, AACM concrete or mortar as defined by the manufacturer

3.1.25 Portland cement clinker
hydraulic material made by sintering a precisely specified mixture of raw materials (raw meal, paste or slurry) containing elements, usually expressed as oxides, CaO, SiO_2, Al_2O_3, Fe_2O_3 and small quantities of other materials

*NOTE Refer to BS EN 197-1:2011, **5.2.1**, for a full description of Portland cement clinker.*

3.1.26 precast AACM concrete
AACM concrete cast and cured in a place other than the final location of use, e.g. factory produced or site manufactured

[SOURCE: BS EN 206:2013, **3.1.1.8**, modified]

3.1.27 producer
company (or other legal entity), which creates fresh concrete using an AACM

[SOURCE: BS EN 206:2013, **3.1.1.11**, modified]

3.1.28 ready-mixed AACM concrete
AACM concrete delivered in a fresh state by a person or body who is not the user; in this PAS it is also:

a) AACM concrete produced off site by the user;

b) AACM concrete produced on site, but not by the user

[SOURCE: BS EN 206:2013, **3.1.1.13**, modified]

3.1.29 reference concrete
concrete of established performance, created for direct comparison with an AACM concrete sample

NOTE Further information is given in Annex B.

3.1.30 specifier
person or body establishing the specification for fresh and hardened concrete

[SOURCE: BS EN 206:2013, **3.1.1.18**]

3.1.31 subsidiary constituent (SC)
component of an AACM which is not an activator, admixture, main constituent, water, or Portland cement, permitted to be present in a proportion not exceeding 5% by mass of binder solids, or 25% total by mass of binder solids for all SCs

3.1.32 total water content
amount of added water, plus water already contained in the aggregates and on the surface of the aggregates, plus water in the admixtures, liquid activators and in additions used in the form of a slurry, plus water resulting from any added ice or steam heating

3.1.33 user
person or body using fresh AACM concrete in the execution of a construction or an element

3.2 Abbreviations

For the purposes of this PAS, the following abbreviations apply.

AACM	alkali-activated cementitious material
CLP	classification, labeling and packaging
CPR	Construction Products Regulation
DC	design chemical class as defined in BRE Special Digest 1:2005 [NR1]
ETA	European Technical Assessment
FMEA	failure modes and effects analysis
GGBS	ground granulated blast furnace slag
LH	low heat
PPE	personal protective equipment
SC	subsidiary constituent
VLH	very low heat
X0	exposure class for no risk of corrosion or attack
XC	exposure classes for risk of corrosion induced by carbonation
XD	exposure classes for risk of corrosion induced by chlorides other than from sea water
XF	exposure classes for freeze/thaw attack
XS	exposure classes for risk of corrosion induced by chlorides from sea water

4 Alkali-activated cementitious material

The AACM manufacturer shall provide recommendations regarding the mixing protocol to be applied for correct utilization of the AACM.

NOTE The formulation of the AACM according to this mixing protocol may involve:

- *a dry-mix powder or blend of powders which is combined with aggregates and water; or*
- *as a powder or blend of powders which is combined with a liquid activator and the aggregates, and optionally additional water.*

4.1 Main constituents

The main constituents of an AACM shall be selected from the following classes of material:

a) granulated blast furnace slag (S), in accordance with BS EN 197-1:2011, **5.2.2**;

b) pozzolanic material (P,Q), in accordance with BS EN 197-1:2011, **5.2.3**, with the modification that the requirement for a minimum reactive silicon dioxide content is removed;

c) fly ash (V,W), in accordance with BS EN 197-1:2011, **5.2.4**, with the modification that the requirement for a minimum reactive silicon dioxide content is removed;

NOTE 1 Optionally, fly ash which is outside the allowable compositional range described in BS EN 197-1:2011, but which is compliant with BS EN 14227-4:2013, may be used by mutual written agreement between the AACM manufacturer, the specifier and the user.

d) burnt shale (T), in accordance with BS EN 197-1:2011, **5.2.5**;

e) limestone (L,LL), in accordance with BS EN 197-1:2011, **5.2.6**; and

f) silica fume (D), in accordance with BS EN 197-1:2011, **5.2.7**.

NOTE 2 Limestone (L, LL) or silica fume (D) are permitted as main constituents only when there is also at least one other main constituent from the other listed categories (S, P, Q, V, W, T), as it is necessary for the main constituents to supply both aluminium and silicon as oxides to form an AACM.

4.2 Water

Water added during the mixing of an AACM, AACM mortar or AACM concrete shall conform to BS EN 1008.

NOTE This does not apply to water which is provided as part of the alkaline activator or as part of an admixture, if these are added as aqueous solutions.

4.3 Alkali activator

The alkali activator shall consist of one or more components containing alkali metals, and/or magnesium, and/or calcium, and shall be the primary source of alkali metals within the AACM. The alkali activator shall be selected or formulated to provide an elevated pH to induce the reaction of the main constituents to form a solid.

Alkali metals (with the exception of francium) shall be used individually or in combination, and also with alkaline earth cations such as magnesium and calcium, if desired, in the presence of various anions, to provide an activator which generates an AACM with the desired properties.

NOTE 1 Francium is excluded from use in AACM manufacture due to its radioactive nature.

NOTE 2 Examples of activator components include sodium silicate, potassium silicate, sodium hydroxide, potassium hydroxide, sodium carbonate, and sodium sulfate. Excessive activator doses are known to induce efflorescence in AACMs, and so it is imperative that the activator dose is no higher than is necessary to achieve the desired mechanical performance. The exact activator dose which can induce problematic efflorescence depends on the mix design, curing conditions and service environment, and so no specific limit on activator content is specified in this PAS, but this does necessitate caution when designing and specifying the formulation of an AACM.

NOTE 3 The activator may be introduced to the system as a solid powder blended with the main constituents in a dry state, or pre-dissolved in an aqueous solution, or via both routes if multiple activating constituents are used.

4.4 Portland cement component

Where a Portland cement component is included in an AACM, this shall be less than 5% by mass of the binder solids.

NOTE 1 This component may be either Portland cement conforming to the CEM I classification of BS EN 197-1, or ground Portland cement clinker without addition of calcium sulfate. The 5% limit is to avoid conflict with the provisions of BS EN 197-1.

If Portland cement containing calcium sulfate or minor additional constituents is used, the quantity of calcium sulfate and minor additional constituents shall be determined, and this shall be acknowledged in the product information (see Clause **7**) as a subsidiary constituent (SC) of the AACM.

NOTE 2 The determination of the calcium sulfate content of the cement may be conducted by wet chemical analysis, set out in BS EN 196-2:2013, ***4.4.2****, or by X-ray fluorescence, set out in BS EN 196-2:2013, Clause* ***5****.*

4.5 Subsidiary constituents (SCs)

The total content of each SC shall not exceed 5% of the AACM solids by mass and the sum of all SCs shall not exceed 25% by mass of the AACM solids.

NOTE 1 SCs, after appropriate preparation and on account of their particle size distribution, improve the physical properties of the AACM (such as workability or water retention). They may be inert or have slightly hydraulic, latent hydraulic or pozzolanic properties. However, no requirements are set for them in this respect in this PAS. SCs may contain inorganic and/or organic constituents, and may be added in solid or liquid form to the AACM.

SCs shall not include alkali metals (lithium, sodium, potassium, rubidium, caesium) at any concentration above 5% by mass of the SC; all sources of alkali metals exceeding such concentrations shall be considered as components of the activator.

SCs shall not include any material classified as *hazardous waste* as defined in the Technical Guidance of the UK Environment Agency [16], and shall not include any compound which is known to the manufacturer to be deleterious to the performance of the material under relevant service conditions. In particular the SC, whether considered individually or collectively, shall not increase the water demand of the AACM appreciably, impair the resistance of the concrete or mortar to deterioration in any way or reduce the corrosion protection of the reinforcement.

NOTE 2 It may be possible to adapt the methodologies described in either BS EN 480-14:2006 or BS EN 15183:2006 to the assessment of reinforcement corrosion protection in materials or products based on AACMs.

SCs shall be selected, homogenized, dried and comminuted depending on their state of production or delivery.

NOTE 3 The established practice for preparation and performance assessment of "minor additional constituents"' used in common cements under BS EN 197-1 is also recommended for SCs. It is recommended that the water demand be assessed with reference to the quantity of water addition required to achieve standard consistence as defined in BS EN 196-3:2005+A1:2008, ***5.2.3*** *if a paste test is preferred, or BS EN 413-2:2005,* ***5.2*** *if a mortar test is preferred.*

4.6 Production control

The procedures, equipment and materials used in the production of AACM shall be subject to control as specified in BS EN 197-2:2014, Clause **4**, with the modification that all references to "cement" shall be replaced by "AACM". AACM manufacturers shall review these production control specifications and define any tighter controls that are needed in order to achieve the performance requirements of this PAS and claimed for their product. Where this (non-commercially confidential) information is needed by others, e.g. AACM concrete producers, then this shall be made available.

NOTE Other information required for AACM manufacturing purposes, which may be considered commercially confidential, is not required to be divulged. However, such manufacturing information may need to be divulged in confidence, to certification organizations.

4.7 Chloride content

The total chloride content of the AACM constituents shall be determined in accordance with the methodology described in BS 8500-2:2015, Table 5, with the modification that the activator shall be analysed in accordance with BS EN 480-10, and subsidiary constituents shall be analysed in accordance with BS EN 196-2.

4.8 Performance assessment

The performance of AACMs shall be assessed by the manufacturer on a regular basis in accordance with the requirements and test methods defined in **4.8**. The testing frequencies shall be in accordance with BS EN 197-1:2011, Table 6 for early strength, standard strength, initial setting time, soundness (expansion), sulfate content, chloride content, and composition. The testing frequency specified in BS EN 197-1:2011, Table 6 for heat of hydration of low heat common cements shall be applied for the heat of reaction of AACMs to be classified as low heat or very low heat.

Conformity criteria shall be in accordance with BS EN 197-1:2011, Clause **9**, with the modification that all references to "cement" shall be replaced by "AACM".

4.8.1 Mechanical and physical requirements

AACMs shall be classified by the manufacturer into strength classes in accordance with the physical requirements given in Table 1.

Table 1 **Mechanical and physical requirements given as characteristic values**

Strength class [A]	**Compressive strength / MPa**				**Initial setting time (min)**	**Soundness (expansion) (mm)**
	Early strength		**Standard strength**			
	2 days	**7 days**	**28 days**			
22.5*			≥ 22.5	≤ 42.5	≥ 75	
32.5 L		≥ 12.0				
32.5 N		≥ 16.0	≥ 32.5	≤ 52.5	≥ 75	
32.5 R	≥ 10.0					
42.5 L		≥ 16.0				≤ 10
42.5 N	≥ 10.0		≥ 42.5	≤ 62.5	≥ 60	
42.5 R	≥ 20.0					
52.5 L	≥ 10.0					
52.5 N	≥ 20.0		≥ 52.5		≥ 45	
52.5 R	≥ 30.0					

[A] Strength class 22.5 is only allowed for very low heat AACMs, see **4.8.2**

NOTE 1 The strength classes and associated requirements described in Table 1 are harmonized with those defined for common cements in BS EN 197-1:2011, Table 3 for strength classes 32.5 and higher, and for very low heat special cements in BS EN 14216:2004 for strength class 22.5.

The strength of AACM shall be tested as follows:

a) compressive strength is determined in accordance with BS EN 196-1:2005, with the following modifications:

   1) the AACM mortar specimen is formulated at an effective water content measured to achieve standard mortar consistence, determined in accordance with BS EN 413-2:2005, **5**;

   2) the mass ratio of 3 parts CEN Standard Sand (BS EN 196-1:2005, **6.1**) to 1 part cement, as specified in BS EN 196-1:2005, is replaced by a ratio of 3 parts CEN Standard Sand (BS EN 196-1:2005, **6.1**) to 1 part AACM binder solids; and

   *NOTE 2 The overall batch compositions are likely to deviate from those specified in BS EN 196-1:2005, but the mass ratio of 3 parts CEN Standard Sand (BS EN 196-1:2005, **6.1**) to one part AACM binder solids shall be retained.*

   3) the mixing protocol shall be applied in accordance with the recommendations of the manufacturer of the AACM.

b) initial setting time shall be determined in accordance with BS EN 196-3:2005+A1:2008, Annex A, with the following modifications: the mixing protocol shall be applied in accordance with the recommendations of the manufacturer of the AACM;

   NOTE 3 With reference to BS EN 196-3:2005+A1:2008, Annex A, the "alternative" method where testing is conducted under high humidity rather than with the sample immersed in water, is more applicable than the "normal" protocol described for Portland cement. This is because immersion is often detrimental to the setting of AACMs.

   *NOTE 4 In some instances, the viscosity and other rheological characteristics of an AACM paste means that the determination of initial setting time set out in BS EN 196-3:2005+A1:2008 is impractical. In such cases, initial setting time may instead be determined employing the information given in BS EN 480-2:2006, Clause **5**, with the modification that the mortar is formulated as described in **4.8.1 a)**.*

c) soundness shall be determined in accordance with BS EN 196-3:2005+A1:2008.

4.8.2 Heat of reaction

The heat of reaction of an AACM shall be measured by semi-adiabatic calorimetry in accordance with BS EN 196-9:2010. The water/binder solids ratio shall be specified by the manufacturer of the AACM, appropriate to the planned use of the material.

AACMs shall be marked, for example, on the packaging or data sheet, as low heat (LH) or very low heat (VLH) if the measured heat of reaction does not exceed the respective limits shown in Table 2.

Table 2 **Heat of reaction limits for marking of AACMs as low heat or very low heat**

Classification	Heat of reaction at 7 days not exceeding
Low heat (LH)	270 J/g binder solids
Very low heat (VLH)	220 J/g binder solids

NOTE 1 The quantity defined as heat of reaction for an AACM is directly analogous to the heat of hydration of a hydraulic cement; the difference in terminology simply reflects the fact that the hardening of an AACM does not necessarily involve a hydration process.

NOTE 2 The limits in Table 2 are harmonized with the limits given in BS EN 197-1:2011 for LH common cements, and in BS EN 14216 for very low heat special cements.

Cements with heats of reaction exceeding these values can be appropriate for many applications, but should not be identified as low or very low heat.

NOTE 3 Further guidance on quality management aspects is given in Annex C.

5 AACM concrete

5.1 Concrete formulation

5.1.1 Alkali-activated cementitious material

The AACM used in the production of concrete shall conform to Clause **4**.

NOTE Further guidance on quality management aspects is given in Annex C.

5.1.2 Admixtures

In addition to the SC component of the AACM, if a concrete producer incorporates chemical admixtures to aid in controlling the properties of the concrete, these admixtures shall conform to BS EN 934-1:2008, Clause **4** and Clause **5,** regarding composition and corrosion behaviour. Any added component which contains alkali metals and which causes a reduction in initial setting time (determined in accordance with BS EN 480-2:2006, Clause **5**, using an AACM mortar formulated as described in **4.8.1 a)** and mixed in accordance with the recommendations of the manufacturer of the AACM) by more than 30 minutes (compared to an otherwise identical AACM mortar without this added component) shall be considered to be an activator, and thus subject to **4.3** of this PAS.

If an admixture is specified as one of the specific types of admixtures defined for concretes, mortars and grouts in BS EN 934-2:2009+A1:2012, Clause **4**; it shall conform to the requirements of BS EN 934-2:2009+A1:2012, Clause **4,** with respect to its performance in the concrete. In testing for compliance with these requirements, the provisions of BS EN 934-2:2009+A1:2012, Clause **4**, regarding the use of a reference concrete (or mortar) described by BS EN 480-1:2014, shall be replaced with a direct comparison between two otherwise-identical AACM concretes (or mortars), one with and one without addition of the admixture.

NOTE 1 Concrete properties which can be influenced by the use of admixtures include, but are not limited to: flow properties (e.g. yield stress, viscosity, slump/slump flow, pumpability); segregation or bleeding; air entrainment; setting and hardening (accelerating or retarding).

NOTE 2 Because of the differences in chemistry between AACMs and the majority of common cements, particularly the alkaline and high-ionic strength liquid environment induced by the presence of the activator, it is very likely that the admixtures which are currently in widespread use for concretes based on common cements may not display similar effectiveness in AACM concretes. It is recommended that the AACM manufacturer provides guidance where possible to the concrete producer, indicating which admixtures are likely to provide acceptable performance in combination with their AACM. It is the responsibility of the concrete producer to ensure the compatibility of any admixture used.

5.1.3 Aggregates

The producer of an AACM concrete shall use either:

a) aggregates conforming to BS EN 12620:2002+A1:2008; or

b) lightweight aggregates conforming to BS EN 13055-1:2002.

The aggregate used shall be classified as low or normal reactivity for alkali-silica reaction in accordance with BS 8500-2:2015, Annex B. Performance testing shall be carried out by or on behalf of the aggregate supplier for any expansive effects due to alkali-silica reaction, see **5.3.3.4.1**.

NOTE Further information regarding the avoidance of alkali-silica reaction is given in Annex B.

Aggregates classified as demonstrating high reactivity or extreme reactivity in alkali-silica reaction in accordance with BS 8500-2:2015, Annex B, shall not be used in AACM concrete.

5.1.4 Other constituents

It is acceptable to incorporate fibres (metallic, mineral, glass, synthetic organic, natural organic, or carbon-based) into the concrete, subject to the restriction that the addition of these fibres shall not have a deleterious effect on the performance of the material in the desired application. If glass fibres are added, they shall be of an alkali-resistant glass type.

NOTE 1 Glass fibres which are not alkali-resistant are prone to expansion via a process similar to the alkali-silica reaction involving reactive aggregates, and thus are considered deleterious in this application. ASTM C1666 [17] provides one example of a specification for alkali-resistant glass fibres.

The diversity of types and purposes of fibres that can be added to concrete mean that the producer shall consult the manufacturer and specifier regarding the applications in which the concrete is to be used, and shall validate the performance of the fibre-concrete combination in accordance with **5.3** to identify potentially deleterious effects.

Pigments conforming to BS EN 12878:2014 shall also be included subject to the approval of the AACM manufacturer.

The total chloride content of the concrete constituents shall be determined in accordance with the relevant method described in BS 8500-2:2015, Table 5, with the modification that the AACM shall be analyzed in accordance with **4.7**. The total chloride content shall be calculated on the basis of the total composition of the AACM concrete, and the total chloride content shall not exceed the limits provided in Table 3.

Table 3 **Limits on chloride content of AACM concrete**

Type of concrete	% chloride by mass of AACM binder solids
Unreinforced concrete containing no embedded metal other than corrosion-resistant lifting devices	0.50
Containing steel reinforcement or other embedded metal	0.20
Prestressed; heat-cured in contact with steel	0.10

*NOTE 2 These limits are harmonized with the limits in BS 6349-1-4:2013, **Table 5**, and are more conservative than the limits applied to concretes produced from common cements under BS 8500-1.*

5.2 Concrete mixing, placement and curing

AACM concrete shall be mixed, placed and cured in accordance with the instructions of the AACM manufacturer. The precise procedures shall be agreed in writing between the manufacturer, AACM concrete (including ready-mixed) producer, specifier and user. Recommended procedures shall be included in the specification supplied to the producer.

NOTE 1 This includes precast and sprayed concrete as well as in situ concreting works. Some AACM concretes are known to be more sensitive to variations in curing environments than Portland cement concretes, including both temperature and the availability of moisture, and so it is imperative that the materials are treated appropriately following casting or placement. The manufacturer is encouraged to provide detailed instructions in this regard, including guidance regarding the likely implications of deviation from these instructions. Many AACM concretes are designed for elevated temperature curing under precasting conditions; it is noted that this is not believed to introduce issues related to delayed ettringite formation, as this phenomenon has not, to date, been reported in AACMs.

Unless otherwise instructed by the manufacturer, no water, activator or admixture shall be added during transport or at delivery of ready-mixed AACM concrete.

The quantity of any additional water, alkali activator or admixture added to a mixer after batching of the designed components shall be recorded by the party requesting its addition, and reported to the user.

NOTE 2 In special cases, one or more of water, activator and admixtures may be added where:

a) this is under the responsibility of the producer and used to bring the consistence to the designed value;

b) the limiting values of water, activator and admixtures, permitted by the manufacturer and the specification are not exceeded; and

c) the additional water, activator and admixtures are included in the design of the concrete.

If more water or admixtures are added to the concrete in a truck mixer on site than is permitted by the specification or the AACM manufacturer's instructions, the concrete batch or load shall be recorded as "non-conforming". The party who authorized this addition is responsible for the consequences and the identity of this party shall be recorded on the delivery ticket.

5.3 Concrete testing

5.3.1 Test schedule

Conformity testing shall be carried out in accordance with BS EN 206:2013, Clause **8**.

Identity testing shall be carried out in accordance with BS 8500-1:2015, Annex B with the modification that all references to "concrete" shall be replaced by "AACM concrete", and all test methods shall be those defined in this PAS.

NOTE 1 When required, additional performance testing may be agreed in writing between the manufacturer, user and specifier.

*NOTE 2 The properties to be determined, and associated testing methods to be applied, are listed in **5.3.2** to **5.3.3**.*

5.3.2 Fresh concrete properties

A minimum of one of the following properties shall be determined to the tolerances shown in Table 4:

1) slump (in accordance with BS EN 12350-2);

2) compactability (in accordance with BS EN 12350-4) or;

3) flow value (in accordance with BS EN 12350-5).

Table 4 **Conformity criteria for target values of slump, compactability and flow**

Slump			
Target value (mm)	≤ 40	50 to 90	≥ 100
Tolerance (mm)	± 10	± 20	± 30
Degree of compactability			
Target value	≥ 1.26	1.25 to 1.11	≤ 1.10
Tolerance	± 0.13	± 0.11	± 0.08
Flow diameter			
Target value (mm)	All values		
Tolerance (mm)	± 40		
NOTE 1 Alternatively, for slump and/or flow the specifier and AACM concrete producer may refer to BS 8500-1:2015, Annex B.			
[SOURCE: BS EN 206:2013]			

Where required, the following properties shall also be determined:

a) for ready-mixed AACM concrete, density in the fresh state (in accordance with BS EN 12350-6); and

b) if required for the specified application, air content (in accordance with BS EN 12350-7).

NOTE 2 If self-compacting properties are required by the user, the relevant tests (given in BS EN 12350, Parts 8-12) may be conducted and the outcome recorded.

The density and air content shall be measured at sampling intervals as described in **5.3.1** if target values for these parameters are specified, or less frequently by mutual written agreement between the specifier and producer if these values are to be used only in an informative manner.

Sampling of AACM concrete shall be carried out in accordance with BS EN 12350-1, with the modification that all references to “concrete” shall be replaced by “AACM concrete”.

Density shall be measured in the fresh state for ready-mixed AACM concrete, and in either the fresh or the hardened state for precast AACM concrete (see **5.3.3.3**).

5.3.3 Hardened concrete properties

5.3.3.1 General

The following properties of the hardened concrete shall be tested and assessed:

a) compressive strength (see **5.3.3.2**);

b) for precast concrete, density in the fresh or hardened state (see **5.3.3.3**); and

c) durability (see **5.3.3.4**).

NOTE 1 Plastic density is the preferred method for determination of density in case of any disputes.

NOTE 2 Optionally, and by mutual written agreement between the manufacturer and specifier, additional tests may be carried out using the respective BS EN methods:

a) flexural strength (see BS EN 12390-5);

b) tensile splitting strength (see BS EN 12390-6);

c) *depth of penetration of water under pressure (see BS EN 12390-8);*

d) *secant modulus of elasticity (see BS EN 12390-13);*

e) *reaction to fire (see BS EN 13501-1:2007+A1:2009) or fire resistance (see BS EN 1363-1);*

f) *creep (in accordance with BS ISO 1920-9); and*

g) *drying shrinkage (see BS ISO 1920-8).*

Sampling of AACM concrete shall be carried out in accordance with BS EN 12350-1 with the modification that all references to "concrete" shall be replaced by "AACM concrete".

Curing of test specimens shall be carried out in accordance with BS EN 12390-2, **5.5** with the modification that all references to "concrete" shall be replaced by "AACM concrete" and with the exclusion of Note 1 of that Clause, as curing in water is not always appropriate for AACM concretes (as per **5.3.3.2**, Note 3).

NOTE Additional tests may be specified by mutual written agreement between the manufacturer and the specifier, depending on the intended use of the concrete.

5.3.3.2 Compressive strength

Compressive strength shall be tested in accordance with BS EN 12390-3. Whether the compressive strength is to be assessed on the basis of cube or cylinder tests shall be declared by the producer in advance of delivery (BS EN 206:2013, **5.5.1.2**).

NOTE 1 Unless specified otherwise, the compressive strength is determined on specimens tested at 28 days for compatibility with established national and international practice for Portland cement-based concretes.

NOTE 2 Where cube samples are used, BS EN 206 requires these to be 150 mm, but permits other sizes provided that a correlation or safe relationship has been established and documented between the chosen size and the reference size.

NOTE 3 Curing in a chamber at (20 ± 2) °C and relative humidity ≥ 95% (see BS EN 12390-2) may be preferred over curing with immersion in water.

The characteristic strength of the concrete shall be equal to, or greater than, the minimum characteristic compressive strength for the specified compressive strength class given in Table 5. The specifier and concrete producer shall refer to BS 8500-1:2015, **B.5** for identity testing for compressive strength, with the modification that all references to "concrete" shall be replaced by "AACM concrete".

5.3.3.3 Density

Density shall be measured in the fresh state for ready-mixed concrete (**5.3.2**), or in the fresh or hardened state for precast concrete. If measured in the hardened state, density shall be tested in accordance with BS EN 12390-7.

5.3.3.4 Durability

The durability of AACM concretes shall be assessed in accordance with the approach summarized in Table 6.

Table 5 **Compressive strength classes for AACM concretes**

Compressive strength class	Minimum characteristic cylinder strength $f_{ck, cyl,}$ (MPa)	Minimum characteristic cube strength $f_{ck, cube,}$ (MPa)
C8/10	8	10
C12/15	12	15
C16/20	16	20
C20/25	20	25
C25/30	25	30
C30/37	30	37
C35/45	35	45
C40/50	40	50
C45/55	45	55
C50/60	50	60
C55/67	55	67
C60/75	60	75
C70/85	70	85
C80/95	80	95
C90/105	90	105
C100/115	100	115

NOTE These strength classes are harmonized with those specified for concretes based on common cements in BS EN 206.

Table 6 **Tests required for AACM concretes**

Concrete type	Test	Reference	
All	Alkali-silica reaction	see **5.3.3.4.1**	
	Freeze-thaw	see **5.3.3.4.2**	
	Sulfate resistance	see **5.3.3.4.3**	
Reinforced		**Up to 60 years intended working life**	**Exceeding 60 years intended working life**
	Carbonation	See **5.3.3.4.4**	Procedure to be determined by the specifier
	Chloride ingress	See **5.3.3.4.5**	

NOTE 1 The recommendations in BS 8500-1:2015 for an intended working life of at least 50 years include structures with a working life of up to 60 years.

Procedure(s) for any other tests shall be determined by mutual written agreement between the AACM manufacturer and the specifier.

Durability of elements with an intended working life up to 60 years shall be validated according to comparison against the performance of a concrete based on common cements covered by BS EN 197-1:2011 which is used as a reference. The durability properties of the concretes shall be tested, and the reference concrete selected, according to the exposure class for which the concrete is designed; see Annex B for detailed guidance. The performance of the AACM concrete shall meet or exceed the performance of the reference concrete in each case, within testing precision. The reference concrete shall comply with BS 8500-1, with the cement type being selected to maximize chemical similarities with the main constituent(s) of the proposed AACM. The reference concrete shall have the same target consistence as the AACM concrete allowing for permitted tolerances in BS EN 206:2013.

Additional durability testing, necessary to cover the intended application, e.g. abrasion or acidic environments, and the procedures to be applied for assessing durability under such conditions, shall be agreed in writing by the AACM manufacturer and the specifier, following as far as is possible any relevant British Standards.

*NOTE 2 The approach described in Clause **5** is intended to parallel in part the Equivalent Durability Procedure described in PD CEN/TR 16563:2013. A comparative method involving a reference concrete is the only feasible way in which durability performance requirements can be set for AACM concretes, in the absence of extensive data describing the correspondence between laboratory test results and field performance of AACM concretes under different exposure class conditions. There is a clear and direct need for such data to be generated and made available.*

NOTE 3 The main constituent(s) of the AACM should provide an indication of the closest permitted cement type to be adopted in the reference concrete. It is generally recommended that a concrete containing not less than 50% replacement of Portland cement by ground granulated blast furnace slag (GGBS), or not less than 25% replacement of Portland cement by pozzolan, should be used as the reference concrete where allowed for the relevant exposure class under BS 8500-1, see Annex B for detailed discussion. The cement replacement in the reference concrete may be achieved through the production of a within-mixer blended concrete (CII, CIII or CIV) or through the use of a factory-blended cement (CEM II, CEM III or CEM IV).

NOTE 4 The specifier should assess the comparative performance of the AACM concrete and reference concrete to determine the suitability of the concrete for the application. Differences in composition and performance should be taken into account when applying the durability recommendations of existing codes or standards to the AACM concrete.

NOTE 5 Given the absence of extensive field data describing the long-term durability performance of AACM concretes under different exposure conditions, the potential consequences of failure of the material should be considered when specifying these materials for safety-critical applications.

5.3.3.4.1 Alkali-silica reaction

The aggregate combinations proposed for use with the AACM shall be classified for alkali reactivity in accordance with BRE Digest 330 [NR2] by petrographic examination in accordance with BS EN 932-3:1997.

The proposed combination of aggregate and AACM shall be subject to testing in accordance with the RILEM AAR-3 [NR3] concrete prism method [1)], with the following modifications:

a) "cement" shall be replaced with "AACM";

b) the alkali content of the AACM shall be in accordance with the instructions of the AACM manufacturer;

   NOTE This usually yields a concrete alkali content which exceeds the 5.5 kg Na_2O-equivalent per cubic metre of concrete described in the test.

c) the AACM concrete mix design, including water content and aggregate grading, shall be in accordance with the instructions of the AACM manufacturer;

[1)] *This is an amended version of the document published as a draft for comment under the same test name: RILEM Recommended Test Method AAR-3 (formerly TC-106-03) "Detection of Potential Alkali-Reactivity of Aggregates: B – Method for Aggregate Combinations using Concrete Prisms", Materials & Structures 33 (229) (2000) 290-293. The 2011 revised version of the test is the method specified in this PAS.*

d) concrete specimens shall be cast and cured in accordance with the instructions of the AACM manufacturer; and

e) the test shall be conducted for both fine and coarse test aggregates (option (i) in **5.3.1** of Sims and Nixon [NR4]).

The expansion of the concrete prisms, after 12 months of storage under the specified testing conditions, shall not exceed 0.05%.

NOTE 1 The criterion of a maximum expansion of 0.05% follows the recommendation of Sims and Nixon [NR4] for the application of this test, where an expansion less than this value is considered likely to indicate a non-reactive combination of materials.

*NOTE 2 The total alkali content of an AACM concrete usually exceeds the maximum limits specified in BRE Digest 330 [NR2] and those used in BS 8500-2:2015, Annex B, by a large margin. Experience with field performance of AACM concretes [15] has shown that these high alkali contents are able to be accommodated without undue risk of alkali-silica reaction processes, subject to appropriate aggregate selection, and this is the basis for the specification of a performance test set out in **5.3.3.4.1**. Further details are given in Annex D.*

5.3.3.4.2 Freeze-thaw

The resistance of AACM concrete to freeze-thaw shall be determined in accordance with the Danish HETEK adaptation of the Borås test [NR5], as described in Annex E. The performance of the AACM concrete shall be assessed by comparison with a reference concrete as described in Annex B.

The performance of the AACM concrete shall be considered acceptable if the degree of scaling is no higher than the performance of the reference concrete.

The reference concrete shall be designed to comply with BS 8500-1:2015, Table A.1 for the exposure class (XF1, XF2, XF3 and XF4) for which the AACM concrete is intended to be used.

Annex E defines two test methods. Method A (with NaCl solution) shall be used when the AACM concrete is designed for exposure classes XF2 or XF4; method B (with demineralized water) shall be used when the AACM concrete is designed for exposure classes XF1 or XF3.

The strength class and aggregate used shall be appropriate to the exposure. AACM concrete in exposure class XF4 shall be air-entrained, and the air void characteristics of the reference and AACM concretes shall be assessed in accordance with BS EN 480-11.

*NOTE By mutual written agreement between the AACM manufacturer and the specifier, the test described in **5.3.3.4.2** may be replaced by an alternative testing protocol for freeze-thaw processes. Potential alternative methods include DD CEN/TS 12390-9:2006 and ASTM C666 [18], although these methods require some modification for optimal application to AACM concretes, and such modifications must also be agreed if these tests are to be used. In all cases, a reference concrete as described in **5.3.3.4** shall be tested in parallel with the AACM specimens; the performance of the AACM specimens shall be deemed to be satisfactory if it is equal to or better than the performance of the reference concrete.*

5.3.3.4.3 Sulfate resistance

For materials to be exposed to sulfate environments of classes AC-2 or higher, the resistance to sulfate attack shall be assessed by testing the expansion of AACM mortar specimens exposed to a sodium sulfate solution, and by testing of the physical resistance of the AACM concrete to water penetration.

A reference mortar shall be produced in accordance with BS EN 196-1:2005.

The AACM mortar shall be formulated as described in **4.8.1 a),** and mixed in accordance with the recommendations of the manufacturer of the AACM. The AACM shall correspond to that in the intended AACM concrete mix design.

The chemical sulfate resistance shall be assessed in accordance with ASTM C1012 [NR6] with the following modifications:

a) reference and AACM mortar specimens shall be prepared to standard consistence in accordance with BS EN 413-2;

b) AACM mortar specimens shall be cured in accordance with the instructions of the manufacturer;

c) the cement type of the reference mortar shall be selected to maximize chemical similarities with the main constituent(s) of the proposed AACM, allowing for the recommendations in Annex B and BRE Special Digest 1, Table D1 and Table D2 [NR1] for the relevant exposure class (AC-2 to AC-5). These reference specimens shall be tested in parallel with the AACM specimens; the performance of the AACM mortar shall be deemed to be satisfactory if the AACM specimens fall in the same or better class compared to the reference specimens:

   1) high resistance: six-month expansion ≤ 0.05%;

   2) moderate resistance: six-month expansion ≤ 0.10%; and

   3) low resistance: six-month expansion > 0.10%.

The permeability of the concrete shall be assessed by water penetration in accordance with BS EN 12390-8. The reference concrete for water penetration shall be designed in accordance with the recommendations in Annex B and BRE Special Digest 1, Table D1 and Table D2 [NR1] for the relevant exposure class (AC-2 to AC-5) and the cement type being selected to maximize similarities with the proposed AACM. The physical resistance of the AACM concrete shall be deemed acceptable if the water penetration is less than or equal to that of the reference concrete.

NOTE 1 The rate of sulfate attack on concrete is primarily dependent on the chemical composition of the cementitious binder, permeability of the concrete and the concentration and type of sulfates. The testing is intended to establish the effect of the composition of the AACM on sulfate attack of a representative mortar assessed by expansion.

*NOTE 2 By mutual written agreement between the AACM manufacturer and the specifier, the test described in **5.3.3.4.3** may be replaced by an alternative testing method, applying the recommendations summarized in Clause **6** of PD CEN/TR 15697:2008 to test the AACM under conditions which are relevant to the environment and ground exposure classes to which the material is expected to be exposed. For example, sodium sulfate is commonly used in the ASTM C1012 [NR6] test, but may not provide a representative indication of the resistance to other sulfate salts, e.g. magnesium sulfate.*

NOTE 3 The scientific literature, as summarized in Chapter 8 of the State of the Art Report of RILEM TC 224-AAM) [15], has reached a consensus that the majority of AACM formulations are resistant to common modes of sulfate-related degradation. Nonetheless, performance testing is required if the materials are to be placed into service environments which are classified as AC-2 or higher on the basis of sulfate concentrations.

NOTE 4 The testing does not address acidic conditions or conditions with elevated magnesium or ammonium concentrations (e.g. DC3-z or DC4-m in BRE Special Digest 1 [NR1]). If exposure to such conditions is expected, then a procedure for assessing durability should be agreed in writing by the specifier and the AACM manufacturer.

NOTE 5 The risk of thaumasite sulfate attack in AACMs is considered to be very low based on the high proportion of aluminous main constituents used in AACMs, and so no specific test for this mechanism of degradation is included in this PAS.

5.3.3.4.4 Carbonation

For exposure classes XC1, XC2, XC3 and XC4 when the concrete contains reinforcement or embedded metal, the natural carbonation rate shall be measured in accordance with DD CEN/TS 12390-10:2007, with the following modifications:

a) "cement" shall be replaced with "AACM";

b) the reference concrete shall be designed as described in **5.3.3.4**, and shall comply with the requirements stated in BS 8500-1:2015, Table A.4, for the exposure class (XC1, XC2, XC3 or XC4) for which the AACM concrete is intended to be used.

NOTE 1 This testing does not address the onset or rate of corrosion of reinforcement or embedded metal.

NOTE 2 Testing of compressive strength retention following carbonation exposure may also be desirable, if agreed in writing between the manufacturer and specifier.

5.3.3.4.5 Chloride ingress

For concretes designed for exposure classes XS1, XS2, XS3, XD1, XD2 and XD3 when the concrete contains reinforcement or embedded metal, the resistance to chloride diffusion shall be determined in accordance with DD CEN/TS 12390-11:2010, with the following modifications:

a) sampling depth intervals in DD CEN/TS 12390-11:2010, Table 1, shall be used;

b) "cement" shall be replaced with "AACM".

A reference concrete shall be tested in parallel with the AACM specimens; the performance of the AACM specimens shall be deemed to be satisfactory if the chloride diffusion coefficient of the AACM concrete is equal to, or lower than, that of the reference concrete.

The reference concrete shall be designed in accordance with Annex B, to meet the requirements stated in BS 8500-1:2015, Table A.4, for the exposure class (XS1, XS2, XS3, XD1, XD2 or XD3) for which the AACM concrete is intended to be used.

NOTE 1 It is acknowledged that the pre-saturation in calcium hydroxide solution specified in DD CEN/TS 12390-11:2010 is not directly representative of the pore solution chemistry of AACM as is the case for Portland cement-based materials. Nonetheless, this pre-saturation protocol places all samples into a state in which their pore solution chemistry is directly comparable across specimens, and is thus considered appropriate for this test.

NOTE 2 If an electrically-accelerated chloride migration test is preferred by both the manufacturer and specifier to enable more rapid analysis, an alternative testing method may be selected by mutual written agreement. Potential alternative testing methods have been standardized by international organizations including NordTest (NT Build 492) [19] and ASTM (ASTM C1202) [20]. In all cases, comparison against a reference concrete is required, as the definition of absolute performance levels for materials based on AACM for these tests is not yet available, and the relationship between test and field performance is not yet established. Similarly, alternative ponding test methods including ASTM C1543 [21] and NordTest NT Build 443 [22] are available, and may also be used by mutual written agreement between the manufacturer and specifier. The results of these tests are expected to be similar to those obtained by DD CEN/TS 12390-11:2010, as these test methods are conceptually similar although differ in the details of the procedures applied.

NOTE 3 This testing does not address the onset or rate of corrosion of reinforcement or embedded metal.

5.4 Production control of AACM concrete

The procedures, equipment and materials used in the production of AACM concrete shall be subject to rigorous control.

AACM concrete producers shall review the production controls as specified in BS EN 206:2013, Clauses **8** and **9** with any relevant tests modified as specified in this PAS. They shall define any tighter controls that are needed in order to achieve both the performance requirements of this PAS and the performance claimed for their AACM concrete.

NOTE Where this information is needed by others, e.g. AACM concrete specifiers or users, then this should be made available. Information required for concrete production purposes may be considered commercially confidential and is not required to be divulged, excepting when needed and in confidence, to certification organizations.

5.5 Actions to be taken in the event of non-conformity of the AACM concrete to its specification

The producer shall:

a) check validity of conformity test results;

b) where the test result is invalid, take action to address the root cause of test result invalidity;

c) if non-conformity is confirmed, e.g. by confirmation of the measurement system's capability, repeatability and reproducibility and retesting, take corrective actions including a management review of relevant production control procedures;

d) where there is confirmed non-conformity with the AACM concrete specification that was not obvious at delivery, give notice and provide relevant information to the specifier and user in order to avoid or allow mitigation of any adverse impact; and

e) record actions on items a) to d).

If more water or admixtures are added to the concrete in a truck mixer on site than is permitted by the specification or AACM manufacturer's instructions, the concrete batch or load shall be recorded as "non-conforming". The party who authorized this addition is responsible for the consequences and the identity of this party shall be recorded on the delivery ticket.

6 Intended use specific testing and trials for AACM concrete

6.1 Laboratory testing

The concrete producer shall liaise with the manufacturer to undertake laboratory tests to establish the relevant characteristics of each proposed AACM concrete, including, as a minimum:

a) consistence over the consistence retention time;

b) fresh concrete density;

c) air content;

d) compressive strength development (1, 3, 7, 14, 28 and 56 days);

e) durability (consistent with intended application and exposure conditions);

f) dimensional stability (shrinkage); and

g) if required, colour and efflorescence (for exposed concrete surfaces).

The sample for colour and efflorescence shall be of a size appropriate to the final product or construction, and cured in the same way as is intended for the final application.

The definition of AACM covers a wide range of materials. The performance of AACM concrete depends on numerous factors including the choice of AACM and other constituents. The AACM manufacturer or AACM concrete producer shall therefore establish the suitability of AACM concrete for the intended use.

NOTE 1 Alternative means of demonstrating suitability may be agreed in writing between the specifier user and AACM manufacturer.

NOTE 2 Efflorescence is sometimes observed as a white "bloom" on the surface of an AACM concrete, and is considered to be a symptom of excessive alkali content in the formulation.

NOTE 3 The AACM manufacturer may previously have undertaken a number of relevant tests to the satisfaction of the user.

6.2 Plant suitability trials

Plant suitability trials shall be undertaken by the AACM concrete producer using the materials, batch size, batching facility, plant, equipment and methods intended for production.

The suitability trials shall include as a minimum:

a) consistence over the consistence retention time;

b) fresh concrete density;

c) air content;

d) compressive strength (7 and 28 days); and

e) trial element where specified.

Before commencing concrete works, the user shall prepare a trial element of a suitable size (i.e. for the construction project or precast product) that demonstrates that the required compaction, uniformity and surface finish achieved using the intended materials, plant and methods are met. The element of AACM concrete shall contain reinforcement representative of the intended reinforcement sizes and spacings in the works.

The definition of AACM covers a wide range of materials. The performance of AACM concrete depends on numerous factors including the plant and the ambient conditions. The AACM concrete producer shall therefore establish the suitability of plant for the production of AACM concrete.

NOTE 1 Alternative means of demonstrating suitability may be agreed in writing between the specifier, user and manufacturer.

NOTE 2 The AACM manufacturer may have developed a suitable, standard AACM concrete production system for its product.

7 Information and marking [2)]

7.1 General

The AACM manufacturer shall provide detailed instructions to the AACM concrete producer, specifier and user regarding the appropriate protocols for mixing, placement and curing of the AACM concrete.

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2) Marking PAS 8820:2016 on or in relation to a product represents a manufacturer's declaration of conformity, i.e. a claim by or on behalf of the manufacturer that the product meets the requirements of the PAS. The accuracy of the claim is solely the claimant's responsibility. Such a declaration is not to be confused with third-party certification of conformity.

The AACM manufacturer and the AACM concrete producer shall maintain, for at least six years or the declared warranty period of their product (whichever is the longer), configuration details for each batch or production process run.

NOTE 1 Although this can be classified as commercially confidential, the manufacturer or producer might be required to make this information available in confidence if called upon to contribute to future quality investigations relating to their products.

Where different AACM and AACM concrete configurations are used, the AACM manufacturers and AACM concrete producers shall provide supporting test information, which is relevant to them.

NOTE 2 Identification of AACM delivered and traceability of AACM manufacturing and AACM concrete production information should be considered. Guidance is provided in Annex C.

NOTE 3 It is advisable that the constructor of a facility using an AACM should record where the AACM is used in the "as constructed" record in a manner that would enable production traceability information to be accessed should the need arise.

NOTE 4 REACH regulations referred to throughout this PAS have different requirements for "different activities carried out and the position in the supply chain". It should be noted that the use of the term "manufacturer" in this PAS could be different to that used in REACH. REACH has different requirements for "manufacturers of substances, importers of substances, formulators of mixtures, industrial end-users of substances as such or in mixtures, professional end-users of substances as such or in mixtures, article producers and re-fillers[3)]". As "a company that has a downstream user role may also have other roles under REACH, such as a manufacturer, importer or distributor role" it is important that each company makes its own assessment of its role(s) and requirements.

7.1.1 AACM and AACM concrete information

7.1.1.1 Flow of information before supply

Where requested by the specifier or user, the AACM manufacturer shall review their specification for the intended use.

The AACM manufacturer shall provide the specifier or AACM concrete producer with the information defined in BS 8500-1:2015, Clause **5** and BS EN 206:2013, Clause **6** with the following modification: "heat development during hydration" shall be replaced with "heat of reaction".

7.1.1.2 Flow of information during supply

The AACM manufacturer shall provide the receiver of its product the following information before or at the point of supplying the product:

a) where the AACM was manufactured;

b) production date (and batch number for batch manufacture);

c) a use-by date;

d) storage condition requirements (e.g. temperature and humidity ranges);

e) a product configuration code (that enables the manufacturer to trace how the product has been made);

f) details of the physical characteristics (e.g. particle size distribution) and chemical composition of the main constituents;

g) chloride content;

h) CE mark, if applicable;

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3) See http://www.echa.europa.eu/web/guest/guidance-documents/guidance-on-reach.

i) any standards that the AACM conforms to, where applicable;

j) any standards that the manufacturing process conforms to, where applicable;

k) performance expectations of the AACM (see **4.8**), including AACM strength class;

l) instructions on how to prepare the AACM for its intended use;

m) environmental conditions within which the AACM is expected to perform; and

n) warnings and exclusions of use such as material hazards and personal protective equipment (PPE) requirements.

The marking of the strength class (see **4.8.1**) of the AACM shall be preceded by reference to this PAS.

As health and safety and PPE issues are AACM specific, the manufacturer shall provide clear health and safety recommendations, including PPE use, for their specific product.

NOTE 1 This information could be provided electronically or on paper, for example.

NOTE 2 Attention is drawn to:

a) The Control of Substances Hazardous to Health (Amendment) Regulations 2004 [5];

b) The Control of Substances Hazardous to Health (Amendment) Regulations (Northern Ireland) 2005 [6]);

c) The CLP regulation 2008 (1272/2008) [3]; and

d) The worker protection directives:

1) Chemical Agents Directive 1998 (98/24/EC) [2];

2) Carcinogens and Mutagens Directive 2004 (2004/37/EC) [1];

3) Provision of Health and Safety Signs at Work Directive 1992 (92/58/EEC) [12];

4) Pregnant Workers Directive 1992 (92/85/EEC) [10]; and

5) Protection of Young People at Work Directive 1994 (94/33/EC) [11].

NOTE 3 The manufacturer may, at their discretion, provide a list of all chemicals included in the product and the proportions that they represent within it.

NOTE 4 Attention is drawn to the need for the manufacturer of AACM to provide the user, or purchaser, a safety data sheet for each product supplied in accordance with Commission Regulation (EU) No 453/2010 amending Regulation (EC) No 1907/2006 (REACH) [4].

7.1.2 AACM intended uses

The AACM manufacturer shall complete risk and opportunity assessments for the intended uses listed for their product.

Where the risk and opportunity assessment for an intended use is carried out by a third party, the third party shall consult the AACM manufacturer for any additional information needed to complete the assessment.

NOTE 1 For example, information about the AACM's likely performance in that context and gaps in knowledge that may indicate a need for further tests or trials.

NOTE 2 The risk and opportunity assessment may be carried out by a third party in circumstances where the AACM is used for a use outside of those intended uses listed by the AACM manufacturer.

NOTE 3 Where the risk and opportunity assessment is carried out by a third party, that third party is responsible for the completeness of the assessment.

*NOTE 4 The FMEA process (see **C.2**) is one possible means of carrying out the risk assessment for either the product or the production process.*

7.1.3 Marking

The manufacturer shall mark individual AACM containers (including the alkali activator) with the following information:

NOTE 1 Examples of containers might be sacks, bins, intermediate bulk containers, silos and tankers.

a) where the AACM was manufactured;

b) production date (and batch number for batch manufacture);

c) a use-by date;

d) storage condition requirements (e.g. temperature and humidity ranges);

e) a product configuration code (that enables the manufacturer to trace how the AACM has been made);

f) details of the physical characteristics (e.g. particle size distribution) and chemical composition of the main constituents;

g) CE mark, if applicable;

h) any standards that the AACM conforms to, where applicable;

i) guidance for how to mix the AACM powder, the alkali activator and curing condition requirements;

j) the health and safety and PPE requirements; and

k) information on how to obtain additional information.

NOTE 2 At the time of writing this PAS, there is not a harmonized European standard for AACMs which means that there is no legal requirement to CE mark this type of product. Under *the Construction Products Regulation (CPR) [7], it is possible for a company to apply for a voluntary European Technical Assessment (ETA) enabling them to apply the CE mark to their specific product that has passed the ETA. Whether this can be done on a self-assessment basis or whether it requires independent certification depends upon the risk assessment that is required to be carried out by the AACM manufacturer under the requirements of the CPR.*

7.2 Ready-mixed AACM concrete

7.2.1 Product information

The AACM concrete producer shall provide the user or purchaser (if different) with the product information either:

- on delivery to the user or purchaser prior to transportation to the intended site of use; or
- on delivery to the user or purchaser after transportation.

The product information provided by the AACM concrete producer shall include:

a) name of the ready-mixed AACM concrete plant;

b) reference number of delivery;

c) date and time of first contact between the alkali activator and other components of AACM (see **4.1, 4.2, 4.4** and **4.5**);

d) truck number or vehicle identification, if applicable;

e) name of purchaser;

f) name and location of the site;

g) details or references to specifications, e.g. the AACM concrete producer's product code number;

h) the AACM concrete producer's AACM purchase order number;

i) amount of concrete in cubic metres;

j) the specific type of AACM that has been used, ideally including the AACM manufacturer's configuration code for the specific AACM used, and details of the physical characteristics (e.g. particle size distribution) and chemical composition of the main constituents;

k) binder solids content in kg/m^3;

l) declaration of conformity to PAS 8820:2016;

m) time at which the concrete arrives at the site;

n) time of the beginning of unloading;

o) time of the end of unloading;

p) strength class of AACM concrete;

q) exposure classes;

r) chloride content;

s) consistence class or target value;

t) limiting values of concrete composition, if specified;

u) strength class of AACM, if specified;

v) types of admixtures and additions, if specified;

w) special properties, if required;

x) maximum nominal upper aggregate size; and

y) in case of light-weight or heavy-weight concrete, density class or target density.

As health and safety and PPE issues are AACM concrete specific, the producer shall provide clear health and safety recommendations, including PPE use, for their specific AACM concrete.

AACM shall be mixed and cured by the AACM concrete producer as specified by the manufacturer.

The user shall be responsible for complying with the AACM manufacturer's instructions.

NOTE 1 Concrete mix design protocols based on the use of a specified mass of binder solids per cubic metre of concrete may require modifications in application to concrete based on AACM, as the density of the majority of AACM might differ from the density of common cements. This means that a given mass of AACM might provide a different paste volume fraction to the concrete, compared to the same mass of a common cement. Mix design protocols based on the provision of a specified paste volume, rather than mass, are more likely to offer direct applicability to concretes based on AACM.

NOTE 2 The manufacturer should draw attention to aspects where AACMs differ from conventional Portland cement concretes such as with respect to de-moulding agents or the cleaning of equipment.

NOTE 3 AACM concrete is ordinarily designed concrete, unless adequate information exists to support the use of proprietary or prescribed concrete methodologies.

NOTE 4 This product information could be provided electronically or on paper, for example.

NOTE 5 The AACM manufacturer may, at their discretion, provide a list of all chemicals included in the AACM and the proportions that they represent within it.

NOTE 6 Attention is drawn to the need for producers of AACM concrete to provide to the user or purchaser a safety data sheet for each product supplied in accordance with Commission Regulation (EU) No 453/2010 amending Regulation (EC) No 1907/2006 (REACH) [4] and their role(s) as defined in the Regulation.

7.2.2 Application of the AACM concrete on site

The AACM manufacturer shall specify the method of application of the AACM concrete on site, including appropriate curing regimes.

As health and safety and PPE issues are AACM concrete specific, the producers shall provide clear health and safety, recommendations, including PPE use, for their specific AACM concrete.

AACM shall be mixed and cured by the producer and user, respectively, as specified by the manufacturer.

The producer and user shall be held responsible for complying with the instructions of the AACM manufacturer.

NOTE 1 The possible methods of application may include direct placement from a mixing truck or stationary mixer, precasting, spray application, or others.

NOTE 2 Some AACM concretes are known to be more sensitive to variations in curing environments than Portland cement concretes. It is therefore necessary in these cases to take particular care regarding both temperature and humidity during curing of AACMs, as the effects of drying on AACMs can be damaging through the generation of surface cracks. Elevated temperature curing at early age can sometimes be beneficial but the compatibility of the curing regime, AACM concrete and required early age and longer-term performance should be verified.

*NOTE 3 Production of AACM for repair purposes, using such methods as listed in **7.2.2**, Note 1, should be undertaken with consideration of the provisions of BS EN 1504.*

7.3 Precast AACM concrete – product information

For bespoke AACM concrete orders, the producer shall provide product information to the purchaser either:

- prior to transportation to the intended site of use (subject to the information existing at that time); or
- on delivery to the purchaser after transportation.

The marking of precast products and the accompanying information and technical documentation shall be in accordance with the applicable product standard, such as those for unreinforced concrete paving blocks, kerb stones, drainage pipes, etc. and the general requirements set out in BS EN 13369, Clause **7** and Clause **8**.

The product information provided by the producer shall also include (where not required by the product standard):

a) reference number of delivery;

b) truck number or vehicle identification, if applicable;

c) name of purchaser;

d) name and location of the site;

e) details or references to specifications, e.g. producer's AACM concrete type code number or name and the order number; and

f) declaration of conformity to PAS 8820:2016 from the AACM manufacturer and also from the precast AACM concrete producer.

As health and safety and PPE issues are AACM concrete specific, the precaster shall provide clear health and safety, recommendations, including PPE use, for their specific precast product.

AACM shall be mixed and cured by the precaster as specified by the manufacturer.

The concrete producer and user shall be held responsible for complying with the AACM manufacturer's instructions.

NOTE 1 This product information could be provided electronically or on paper, for example.

NOTE 2 The precaster may, at their discretion, provide a list of all chemicals included in the precast product and the proportions that they represent within it, subject to the information made available to them by the AACM manufacturer.

NOTE 3 Attention is drawn to the need for the precaster of AACM concrete components to provide to the user or purchaser a safety data sheet for each product supplied in accordance with Commission Regulation (EU) No 453/2010 amending Regulation (EC) No 1907/2006 (REACH) [4].

7.4 AACM designation

The designation of an AACM shall always start with reference to PAS 8820.

The following designations (parallel to those in BS EN 197-1:2011) shall be adopted for AACMs:

- strength classes for AACM products shall be denoted 22.5, 32.5, 42.5 or 52.5 according to **4.8.1**, Table 1;
- N, R or L denotes early strength as per **4.8.1**, Table 1; and
- LH or VLH denotes low or very low heat of reaction as per **4.8.2**, Table 2.

NOTE 1 An example of a complete AACM designation is:

PAS 8820, product name, 28 day strength rating, early strength rating, with a low heat of reaction, e.g. PAS 8820, Product X, 32.5 N LH

NOTE 2 The strength categories and other requirements, such as heat of reaction, parallel those defined in BS EN 197-1:2011, but do not correspond directly to the requirements in that standard.

NOTE 3 AACMs may also be selected for uses where performance criteria other than those listed in this PAS are required.

7.5 AACM concrete designation

The designation of an AACM concrete shall include the concrete strength class specified in **5.3.3.2**, Table 4, and the designation of the AACM as defined above.

7.6 Life cycle assessment of greenhouse gases

The AACM manufacturer shall produce an Environmental Product Declaration (EPD) which complies with:

a) BS EN ISO 14025:2006; and

b) BS EN 15804:2012+A1:2013.

The AACM manufacturer shall develop a greenhouse gas life cycle assessment for each AACM in accordance with the processes set out in PAS 2050:2011.

NOTE 1 PAS 2050 may be applied on either a cradle-to-gate or cradle-to-grave basis. It requires that a carbon dioxide equivalent (CO_2e) value be calculated per functional unit of product. It allows manufacturers to self-declare the life cycle greenhouse gas CO_2e result, provided the calculations are accurate, clear and not misleading, and conforming to international and national regulations on consumer protection. Clients and users may, however, require third-party certification of the analysis by an accredited organization.

NOTE 2 There is no requirement for confidential information to be disclosed other than to an independent assessor if that is the route the manufacturer decides to take. The manufacturer should ensure that such an assessor is covered by appropriate confidentiality clauses in their contract and that there is not a conflict of interest that risks compromising the manufacturer's intellectual property.

NOTE 3 It is recommended that the manufacturer record and be prepared to make available information for assessing whole life cost (see BS ISO 15686-5:2008). Detailed guidance on the use of the standard is available in the companion document PD 156865:2008.

7.7 Handling and storage

The manufacturer of AACM or the producer of AACM concrete shall supply the following information to the organization being supplied:

a) instruction for handling and storage of the materials (AACM, activator and other constituents where not pre-mixed) prior to use, together with any special requirements for extreme weather conditions;

b) where pre-bagged, a use-by date, after which the material should be safely discarded; and

c) instruction on the correct mixing, placing and curing methods, plus additional advice for placement in extreme weather conditions (e.g. avoidance of frost damage or exposure of uncured material to direct rain).

NOTE 1 This applies to AACM manufacturers, AACM concrete producers and purchasers of AACM products.

NOTE 2 This is essentially the same as the information required for conventional cement-based systems, although there may be additional requirements for the safe disposal of silicate-based activators.

NOTE 3 Attention is drawn to Annex XVII, Note 47 of REACH for legislative requirements regarding control of chromium (VI) [13].

7.8 Service life maintenance

The AACM manufacturer shall provide guidance on how concrete made with their AACM could be repaired if damaged in service. Such guidance shall be in accordance with BS EN 1504.

NOTE 1 It is recognized that the appropriate monitoring and maintenance of concrete structures, including those manufactured with AACMs, might result in longer service life and reduced longer-term intervention. The precise nature of the monitoring and maintenance activities can be dependent upon the use, and exposure environment, but is likely to include regular period visual inspection for signs of displacement, delamination or cracking and the local reinstatement of damage, whether due to physical or chemical attack, with a compatible material.

NOTE 2 Risk-based condition monitoring employing embedded sensors and other devices can allow the early identification of damage and distress and facilitate early intervention to minimize the need for extensive repairs or replacement. Such monitoring can be particularly useful for aggressive environments and critical structures, or those structures that are difficult to access.

NOTE 3 General guidance on the use of repair methods and products, together with the monitoring and management of concrete structures, is given in BS EN 1504-9:2008. The suitability of repair products should be reviewed for the specific AACM concrete and intended use.

7.9 Claiming conformity of AACM, ready-mixed AACM concrete or precast AACM concrete with this PAS

To claim conformity with this PAS, the manufacturer of any AACM product shall use the designation:

"This product conforms to PAS 8820 for the following intended uses: (insert list of assessed intended uses)" if, and only if, all of the requirements of PAS 8820:2016 have been met.

Determining whether a manufacturer may self-certify or instead requires independent certification shall be undertaken by the manufacturer in the same way as determining the certification requirements for CE marks in the CPR.

NOTE The risk assessment is likely to lead to third party verification for most construction uses.

Annex A (informative) Guidance for project teams

A.1 Planning

As the term AACM covers a wide range of materials, it is important to examine the planning aspects specific to the intended AACM and its intended use, rather than use assumptions based on different materials or uses.

Further practical guidance is given, particularly for materials based on siliceous fly ash but with broader applicability to many other AACMs, in the Concrete Institute of Australia, Geopolymer Recommended Practice Handbook Z16 [23]. AACM manufacturers should be able to provide project-specific advice on how to apply their products based upon current knowledge.

A.1.1 Laboratory tests and plant trials

If laboratory tests are required on a particular project, these should be planned at an early stage.

*NOTE 1 The scope of the laboratory test (i.e. for aspects not previously tested) may need to be initiated earlier than would be normal for materials based on Portland cement, if some aspects of durability requiring longer test durations are to be included (see **5.3.3.4**). These data and other product information may also require time to collate and review (see **7.2.1**).*

NOTE 2 Laboratory tests are likely to require a minimum of 3 months. Durability tests may require an additional 6 to 12 months.

Plant trials using the intended plant and equipment types are essential prior to production (see **6.2**), as some of the constituent materials and the fresh and hardened characteristics of AAM concrete differ from those of concrete based on common cements. In particular, batching, mixing, pumping, spraying, slip-forming, finishing and curing may require changes from normal procedures, including the ability to clean out mixing and delivery equipment where other cementitious material is being used.

Personnel should be fully briefed and equipped with the correct PPE for the tasks involved, in line with the AACM manufacturer's instructions.

NOTE 3 These materials are similar to traditional concretes in many ways but can be different in important areas. For *example, AACM, AACM concrete, or the AACM activator may have a significantly higher pH than Portland cement-based concrete. It should not be assumed that what is appropriate for Portland cement-based concrete is necessarily appropriate for AACM.*

A.1.2 Batching and mixing

Admixtures, activators and powders need a safe means of being batched and introduced into the mixing cycle. Many of the common admixtures marketed for Portland cement-based materials, with the exception of air-entraining agents, have been observed to be ineffective or less effective in AACM concrete.

Where plants are being used to produce Portland cement-based concrete, extra care should be taken to reduce cross-contamination between deliveries. Small amounts of calcium-bearing materials, such as Portland cement, can shorten the setting time of AACM concrete.

Monitoring water in both the fine and coarse aggregate is essential, and covered bins and conveyors are recommended.

NOTE 1 Central batching plants with dual action (folding and high shear) are preferred for ease of adding constituents, effective mixing and assessment of the concrete. Where truck mixing is used, it may be necessary to provide staging for adding activators and admixtures.

NOTE 2 Liquid activators can be highly alkaline and corrosive, and need appropriate storage and handling procedures, including bunding against spillages and potentially agitation and temperature control. Materials such as silica fume and metakaolin, which can be used in AACM concrete, are sometimes dispersed into the concrete in a slurry form. This requires suitable storage with agitation and temperature control.

The batcher should become familiar with the appearance of AACM concrete. Mixes can become more fluid upon extended mixing but begin to lose workability as the reaction proceeds. The change in workability and optimum mixing procedure should be established by trials.

NOTE 3 This change in workability can be assessed from the mixer torque or power consumption.

The transit time between the plant and site should allow for any increase in workability loss.

*NOTE 4 Site addition of activator and/or admixture may be required to address this issue, subject to compliance with **5.5**.*

A.1.3 Fresh AACM concrete

AACM concretes may be used in different ambient temperature ranges: some may be lower than for Portland cement-based concrete and some may be higher. This in turn may extend or reduce the seasonal working window, which should be reflected in project delivery plans.

AACM concrete can be subject to very rapid loss of workability at the end of its working time. Therefore, working time should be accurately established by trials across the range of conditions expected in service.

Any variability in the constituent materials, such as the loss on ignition value of the fly ash, can significantly impact the required admixture dosage, and air content should be verified for concrete containing an air-entraining agent.

NOTE The particle size distribution of the AACM powders, in combination with reduced effectiveness of some admixtures and the need to keep the water content as low as possible, often leads to a mix which seems sticky or viscous. Low amplitude vibration is recommended to ensure full compaction.

Uncontrolled water should not be added to the mix, as this has a detrimental impact on the hardened concrete properties.

The low bleed of the AACM concrete may increase the risk of plastic shrinkage cracking, and aliphatic alcohol evaporation retarders may be required. Water should not be applied to the surface to aid finishing.

AACM concrete adheres strongly to steel. Equipment should be cleaned before the end of the working time. It is recommended that steel formwork is thoroughly treated with a thick coating of a viscous wax-based mould release agent.

The compatibility between the AACM and any chemical agents used for demoulding, curing and retarding the concrete should be established by trials. It is recommended that guidance be sought from AACM manufacturers prior to the use of such agents.

A.1.4 Hardened AACM concrete

The AACM concrete should be selected for the specific intended use. Some AACMs permit a higher strength gain at lower curing temperatures than traditional Portland cement-based concretes while others develop strength more slowly.

NOTE 1 The low heat of reaction of AACM concretes makes them suitable for control of early-age cracking in large pours, but may need planning for the supply of environmental control equipment, e.g. enclosures and insulating blankets, during winter months.

Curing by ponding or allowing large amounts of water to come in contact with the concrete surface is not recommended, as this risks the leaching of alkali activators, leading to a friable surface with poor abrasion resistance. Curing the concrete by sealing the surface is effective, providing that there is no loss of moisture leading to premature drying. Elevated temperature curing can be beneficial but should be undertaken carefully. Excessive heat applied in the pre-hardening period can result in a less dense matrix with reduced strength and durability.

Early strength gain is typically proportional to the curing temperature. The strength development should be established for the specific AACM concrete (particularly the AACM type and activator dosage), as this affects the curing and formwork striking times. The principles of CIRIA Report R136 [24] may be applied.

NOTE 2 AACM concrete containing GGBS may have a blue or green hue after curing. This fades after a few days exposure to the atmosphere and light. The final colour of the surface is dependent on the main constituents of the AACM, with fly ash producing a darker grey and GGBS producing a light grey colour than CEM I. Metakaolin as a main constituent may produce a white, pink, terracotta or red colour depending on its iron content.

Annex B (informative) Reference concrete

In determining an appropriate reference concrete for an intended use, as illustrated by Examples 1 and 2, the designer or specifier should carry out the following steps:

- assess the environmental and ground conditions;

  NOTE 1 These are typically classified using the exposure classes in BS 8500-1 and the additional guidance in BRE Special Digest 1, Concrete in Aggressive Ground [NR1].

- reconcile any different exposure classes that apply to different surfaces of a structure or element, when selecting the reference concrete;
- design the reference concrete for the same target consistence as the AACM concrete, allowing for permitted tolerances in BS EN 206:2013;
- consider the recommendations in BS 8500-1:2015 for an intended working life of at least 50 years to include structures with a working life of up to 60 years; and
- design the reference concrete so it should achieve a target mean strength of at least (f_{ck} + 8) MPa, and be formulated with a water/cement ratio 0.02 units lower, when compared with the basic requirements for the specified exposure class, as this concrete is more representative of concrete of established suitability with reference to PD CEN/TR 16563:2013.

  NOTE 2 Specifying the reference concrete via this approach means that normal variations in production are much less likely to reduce the durability of the AACM concrete below an acceptable level.

For buried concrete, the sulfate and magnesium ion concentrations in the soil or groundwater give the design sulfate class. The designer should take into account the "potential" sulfate that can arise from oxidation of sulfides, whether the site is natural soil or brownfield, mobility of the groundwater, and pH.

NOTE 3 This leads to the classification of Aggressive Chemical Environment for Concrete, which in combination with the intended working life, gives the Design Chemical Class.

There may be cases where the exposure does not readily fit the descriptions given in the exposure classes. In such situations, the designer should use judgement and/or experience of the performance of concrete in that use.

The designer should decide upon the minimum requirements for strength and durability. This should be decided based on the characteristic strength for structural design, exposure conditions and intended cover to reinforcement or other embedded steel. There may be other requirements that also need to be considered, such as maximum aggregate size for placing in congested sections, early strength gain, appearance and finish.

For the selected exposure class, intended working life and nominal cover, the designer should select the reference concrete target strength, cement type, and limiting mix proportions, e.g. maximum water/cement ratio.

The characteristics of the reference concrete should be selected to maximize similarities with the consistence, strength and composition of the proposed AACM concrete. In particular, the cementitious blend should reflect the main constituent(s) of the AACM.

EXAMPLE 1
A concrete is to be designed for a mass concrete foundation. The buried surfaces are exposed to AC-3 conditions, which in conjunction with an intended working life of 50 years gives a design chemical class DC-3. The proposed AACM comprises 75% GGBS by mass of binder solids and the concrete is expected to have a maximum aggregate size of 20 mm.

The requirements for this scenario from BS 8500-1 and BRE SD1 [NR1] are summarized in Table B.1, along with the recommendations for use based on the increased strength and reduced water/cement ratio compared to the limit values.

Table B.1 **Design of reference concrete for Example 1**

Parameter	**BRE SD 1**	**Reference concrete**
Exposure conditions	DC-3	XF2, DC-3
Minimum strength class	N/A	C32/40 (recommended target mean cube strength 48 MPa)
Maximum water/cement ratio	0.50	0.45 (recommended target w/c 0.43 or less)
Minimum cement content (kg/m^3)	340	340
Cement type	III+SR	III+SR (75% GGBS)

EXAMPLE 2
A concrete is to be designed for a reinforced precast concrete culvert with a characteristic strength of 50 MPa and a nominal cover of 40 mm minimum cover plus 5 mm deviation. The headwall is exposed to XD3 chloride exposure and XF2 freeze-thaw conditions. The buried surfaces are exposed to XD2 conditions and other surfaces are exposed to XC3/4 carbonation exposure. The culvert has an intended working life of 60 years.

The proposed AACM comprises 90% fly ash by mass of binder solids and the concrete is expected to have a maximum aggregate size of 14 mm.

The requirements for this scenario from BS 8500-1 and BRE SD1 [NR1] are summarized in Table B.2, along with the recommendations for use based on the increased strength and reduced water/cement ratio compared to the limit values.

Table B.2 **Design of reference concrete for Example 2**

Parameter	BS 8500-1	BS 8500-1	BS 8500-1	Reference concrete
Exposure conditions	XD3	XF2	XC3/4	XD3, XF2, XC3/4
Minimum strength class	C32/40	C40/50	C40/50	C40/50 (recommended target mean cube strength 58 MPa)
Maximum water/ cement ratio	0.40	0.45	0.45	0.40 (recommended target w/c 0.38 or less)
Minimum cement content (kg/m^3)	380	360	360	380
Cement type	IV/B-V	All in Table A.6 BS 8500-1	IV/B-V	IV/B-V (55% fly ash)
Nominal cover (mm)	45	NA	30	Dependent upon application

In some cases it may be necessary to have more than one reference concrete in order to represent the requirements for the different exposure conditions. For instance, if in Example 2, the exposure to freeze-thaw was to XF3 rather than XF2 conditions, this would exclude the use of the IV/B-V cement type. Therefore, the reference concrete for freeze-thaw exposure would be limited to a maximum of 35% fly ash (cement type II/B-V). The reference concrete for the other exposure conditions would retain the use of 55% fly ash (cement type IV/B-V).

Annex C (informative) Considerations when producing or specifying an innovative AACM or AACM concrete

C.1 Recommended production processes

C.1.1 Quality management system

A quality management system should be used to generate, record and analyse reliable product information.

C.1.2 AACM Product quality plans

Manufacturers of AACM products should consider the desirability of quality plans for:

a) each product category that they create;

b) production processes.

NOTE 1 Each different AACM would be a product just as each different type of AACM concrete would be a product or types of precast components would be a product.

NOTE 2 Following this system should allow manufacturers to conform to BS ISO 10005.

C.1.3 Identification and traceability

C.1.3.1 Identification and traceability of use

When introducing a new AACM, the manufacturer should have a clear identification of the specific AACM used for a project and how it has been manufactured. Should anything not perform as planned, it is advantageous for there to be relevant information available to the AACM manufacturer to enable a thorough root-cause analysis to be carried out and for other related uses of the same product to be identifiable. Similarly, the AACM concrete producers should maintain records of how the AACM concrete has been produced for a specific project and delivery batch.

*NOTE Identification and traceability are common aspects of quality management systems. For example, BS EN ISO 9001:2015, **8.5.2** states:*

- *"The organization shall use suitable means to identify outputs when it is necessary to ensure the conformity of products and services".*
- *"The organization shall identify the status of outputs with respect to monitoring and measurement requirements throughout production and service provision".*
- *"The organization shall control the unique identification of the outputs when traceability is a requirement, and shall retain the documented information necessary to enable traceability".*

Traceability records should be maintained where AACM is developed and manufactured and where AACM concrete is produced

C.1.3.2 Configuration management

Configuration management should be applied in both product development and product manufacturing life cycle stages.

NOTE 1 Configuration management is one tool for achieving achieving identiifcation and traceability with respect to managing changes to AACM formulation development and manufacture. It also provides a process for managing concessions (waivers or deviations) i.e. temporary permission, given by an authorized person or group within the organization, to use or release a product which does not conform to specified requirements for a specified quantity or time period.

NOTE 2 One such system for product identification and traceability is described in ISO 10007:2003. It defines Configuration Management as:

"a management activity that applies technical and administrative direction over the life cycle of a product, its configuration items, and related product configuration information. Configuration management documents the product's configuration. It provides identification and traceability, the status of achievement of its physical and functional requirements, and access to accurate information in all phases of the life cycle".

NOTE 3 As there is likely to be a range of variations of these new products emerging to optimize their uses for specific purposes, it is important that the AACM specifier, manufacturer and concrete producer record different configurations in a way that ensures reliable cross referencing to relevant product test results, and that any variations are introduced to the manufacturing process in a controlled manner. Furthermore, if the user has recorded identifying data in their construction record, they should be able to trace specific batch related information should variations in performance be observed.

C.2 Failure modes and effects analysis (FMEA)

The manufacturer of an AACM or the producer of an AACM concrete should complete an FMEA or similar risk analysis for:

a) each product and their intended use (for internal use only);

b) their manufacturing processes (for internal use only); and

c) the process of using their products, on site or in a precast manufacturing context.

NOTE 1 This is not required to disclose commercially sensitive information but is expected to be adequate to explain how the product may be used successfully, managing user related risks.

NOTE 2 The supporting risk analysis / FMEA report (for use of the product) does not need to be presented if the manufacturer wishes to provide the key information in a form more adapted to the user's requirements but should be available if the user wishes to review it.

NOTE 3 Those preparing and relying on the FMEA should ensure its assumptions are consistent with the intended use(s).

NOTE 4 Guidance on performing an FMEA is given in BS EN 60812:2006.

A typical FMEA should include (see Figure C.1):

a) description and function of the item;

b) failure mode;

c) possible cause of the failure;

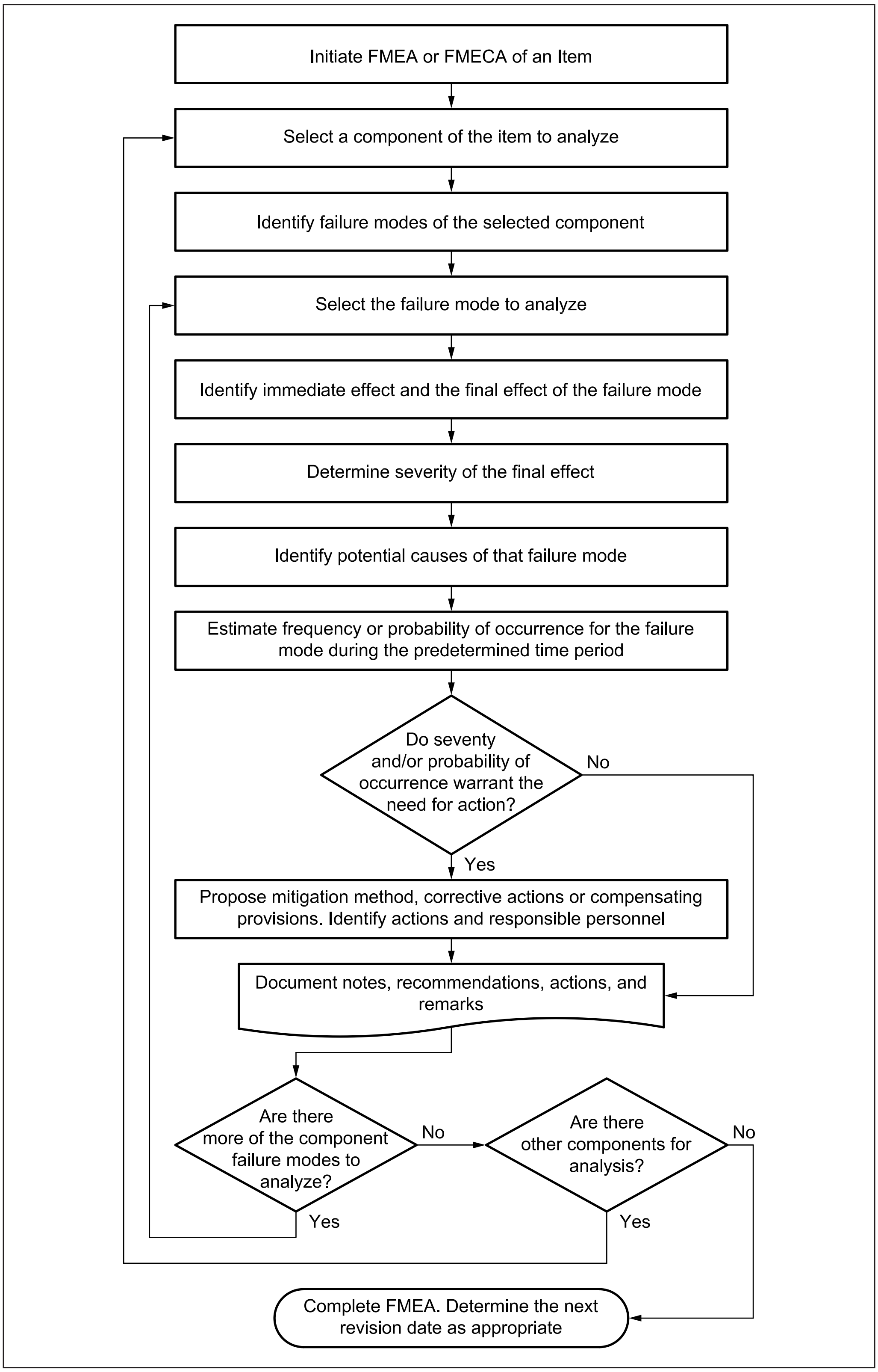
d) method of detection;

e) provision against failure;

f) severity class; and

g) frequency or probability of occurrence.

Figure C.1 **Analysis flowchart (reproduced from BS EN 60812:2006)**



C.3 Repair and recycling

C.3.4 Repair

The on-going maintenance and repair of structures or elements which use AACM concretes should be carried out with reference to BS EN 1504, including use of the established protocols and expertise of the asset owner for the specific conditions to which the material is exposed. Repair materials and techniques applied to concretes based on AACM should be tested and validated for compatibility with the specific chemistry of the AACM.

The high alkali levels of many AACM concretes might mean that some repair material systems do not function in the same way as when they are applied to Portland cement concrete. Testing of compatibility between the repair material and the material to be repaired is therefore imperative.

C.3.5 Recycling

Recycled AACM concrete should be regarded as being a potentially reactive aggregate, unless it has been specifically established to be non-reactive. Where the alkali content of the new concrete (or the cement therein) is being limited, the alkali content of the recycled AACM concrete aggregates should be determined and taken into account in calculations of total alkali content as per BS 8500-2:2015, Annex B.

The use of AACM concretes in the production of recycled aggregates has not yet been validated in the scientific literature or in practice. Prior to the use of crushed AACM concrete as a recycled aggregate, it is necessary to ascertain that the original concrete does not contain reactive (or reacting) aggregate.

NOTE The total alkali level in recycled AACM concrete is likely to be very high (i.e. more significant than being a reactive aggregate in itself). Consequently, tests for free alkali content as well as total alkali content could be usefully applied to better understand risks associated with recycling these materials as aggregates.

Annex D (informative) Avoidance of alkali-silica reaction

The majority of AACM concretes contain concentrations of alkalis which significantly exceed the guidance in BRE Special Digest 330 [NR1] and those used in BS 8500-2:2015 Annex B, by a large margin. Nonetheless, experience with field performance of AACM concretes has shown that these high alkali contents are able to be accommodated without undue risk of alkali-silica reaction processes, subject to appropriate selection of the combination of binder and aggregate. Further information is given in the report of RILEM Technical Committee 224-AAM, Chapter 8 [15], with more recent information available in a 2015 review paper [25] and several technical publications including Pouhet and Cyr, *Alkali-silica reaction in metakaolin-based geopolymer mortar [26]*, Shi, et al., *Comparison of alkali-silica reactions in alkali-activated slag and Portland cement mortars* [27] and Krivenko et al., *Mechanism of preventing the alkali-aggregate reaction in alkali activated cement concretes* [28].

The consensus in the academic literature regarding alkali-silica reaction in AACM mortars and concretes is that the alkaline component of the cement reacts with siliceous aggregates, but that the reaction does not seem to be deleterious or significantly expansive. The fact that the reaction is taking place is evident through the formation of rims of reaction products around the aggregate grains, which can be observed by scanning electron microscopy. However, the degree of expansion observed in specimens exposed to standard testing regimes is uniformly observed to be low; much less than would be expected from simple consideration of the alkali content and aggregate reactivity. The reason for this has been identified as being linked with the binder chemistry, and specifically the high content of reactive alumina present in most AACM formulations. As the alkaline pore solution etches the aggregate particles in an AACM, rather than forming the highly expansive and damaging gel products, which are observed in materials based on Portland cement, the reaction product is instead a non-expansive, cross-linked aluminosilicate gel. This gel resembles the key binding phase in low-calcium AACMs, and thus contributes to the strong binding of the aggregate particles into the AACM rather than introducing any deleterious effects.

This mechanism may be considered to be analogous to the well-known effect of alumina-rich supplementary cementitious materials in reducing the expansive effects of alkali-silica reaction in materials based on Portland cement, as described in BRE Special Digest 330 [NR2]. Although the alkali content of AACM concrete may be a factor of ten times or more above the maximum limits in BRE Digest 330 [NR2] field experience with these materials as outlined in Provis and Van Deventer, *Alkali-Activated Materials: State of the Art Report* [15] and Shi et al., *Alkali-activated cements and concretes* [29] has shown that any possible expansive effects of alkali-silica reaction are limited, and are generally not observable over the timescale on which elements have been analysed in the field, consistent with laboratory tests on mortars and concrete prisms.

Annex E (normative) Test method for determination of frost scaling resistance of AACM concrete (based on HETEK adaptation of the Borås method SS 137245 – Henrichsen et al. 1997 [NR5])

E.1 Introduction

This method is based on the Danish HETEK modifications to the Borås method SS 137245 [NR5], as described in Appendix 1 of Henrichsen et al. This methodology follows the methodology described in that report for pre-testing of concretes, with some modifications to the curing procedure to improve applicability of the test method to AACM concretes.

Method A describes the use of 3.0% by mass NaCl solution in the test to represent de-icing salts, representing exposure classes XF2 and XF4; Method B describes the use of demineralized water as the test solution, representing exposure classes XF1 and XF3.

E.2 Specimens

The test specimens (AACM and reference concretes) shall be slices of 50 ± 2 mm in thickness, sawn from concrete cylinders 150 mm in diameter. The slices shall be taken no less than 20 mm from the ends of the cylinders as cast.

Optionally, and with agreement between the AACM manufacturer and specifier, the test may be applied to slices sawn from cubic or prismatic specimens of not less than 100 mm in the smallest dimension. In such instances, the slices shall be 50 ± 2 mm in thickness, with the cut surfaces taken no less than 20 mm from the cast surfaces of the cube or prism.

Slices shall be made as soon as the concrete has achieved sufficient maturity, which depends upon the material. This is likely to be at least seven days after casting.

The AACM and reference concrete specimens shall be cured for 28 days prior to the commencement of testing. The AACM concrete specimens shall be cast and cured in accordance with the instructions of the AACM manufacturer;

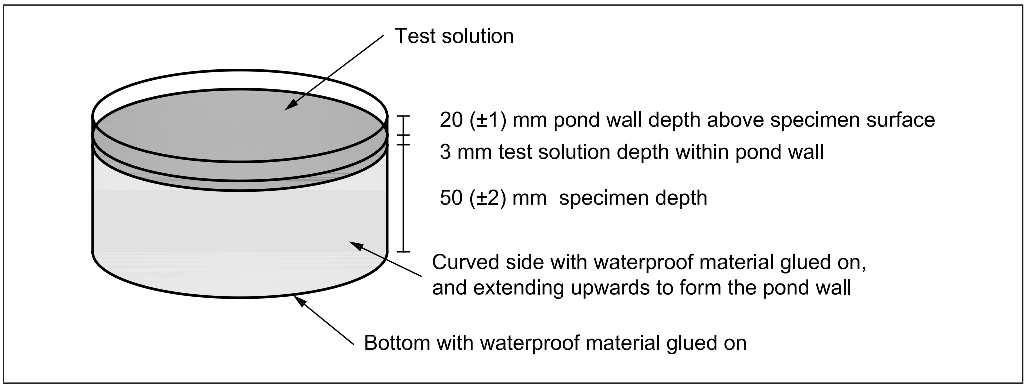
the reference concrete specimens shall be cast and cured in accordance with BS EN 12390-2. The test shall be carried out using no less than five specimens of each concrete (AACM and reference).

NOTE 1 Testing may be carried out at earlier or later ages, by mutual written agreement between the AACM manufacturer and specifier, if the key performance requirements on the AACM concrete are likely to be imposed at an age other than 28 days.

When the test specimens are sawn from the cast cylinders, they shall be rinsed with potable water, and any excess surface water removed with a damp cloth. The samples shall be made water-tight on the curved side and the bottom side, by gluing a waterproof sealant material to these sides. The waterproof material on the curved side shall extend upwards by 20 ± 1 mm to form a pond on top of the specimen.

NOTE 2 It is recommended that a bead of a silicone-based sealant is used to ensure water-tightness of the joint between the waterproof material and the edge of the top surface of the sample. The sample geometry is shown in Figure E.1.

Figure E.1 **Test specimen geometry and setup**



E.3 Conditioning

When the samples have been prepared, they shall be placed in a controlled environment chamber for conditioning at 20 ± 2°C and 65 ± 5% relative humidity, for seven days. Specimens shall be placed standing on the curved side, spaced by at least 50 mm between specimens to enable air circulation.

After seven days of conditioning under these conditions, demineralized water with a temperature of 20 ± 2 °C shall be poured into the pond to a depth of 3 mm. The top of the pond shall be covered with polyethylene film to seal, and the samples held at 20 ± 2 °C for 72 ± 2 hours.

E.4 Insulation

At the completion of this conditioning procedure, the demineralized water shall be discarded, and the samples shall be insulated on all sides except the top, using polystyrene foam with a minimum thickness of 20 mm, or an alternative insulating material with equivalent heat transfer properties.

E.5 Exposure

The insulated samples shall then be exposed to the test solution (3.0% by mass NaCl solution for Method A, or demineralized water for Method B), to a depth of 3 mm within the pond. The test solution shall be introduced to the specimen at a temperature of 20 ± 2 °C. The top of the pond shall then be sealed with polyethylene film. The sample shall remain in a horizontal position throughout the test duration.

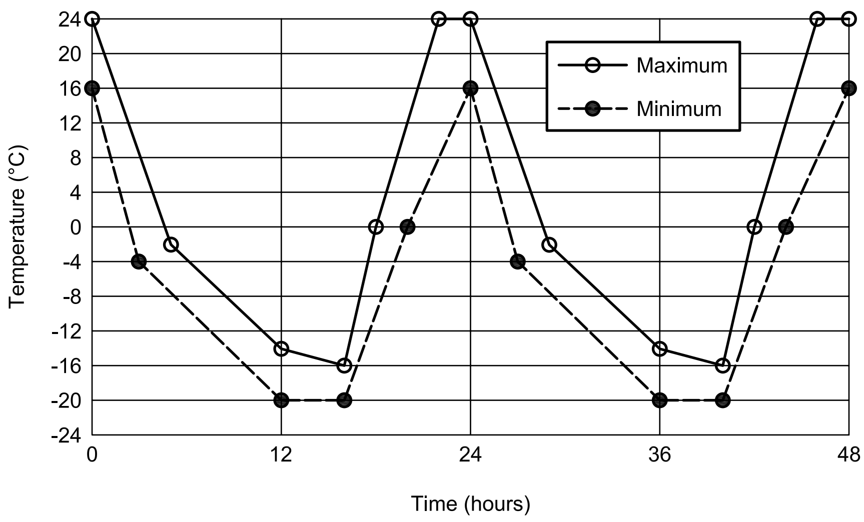
NOTE 53 mL of solution provides the correct depth of 3 mm for a 150 mm diameter cylindrical slice.

Within 15 minutes of the first contact between the specimen and the test solution, the specimens shall be placed into the test chamber. All specimens shall be located not less than 50 mm from any of the side walls of the test chamber. The chamber shall apply a cyclic freezing and thawing action, on a 24 hour cycle, as defined in Table E.1 and depicted in Figure E.2, where the time of loading the samples is defined as time 0. The temperature shall be recorded continuously at the midpoint of the surface of the test solution on at least one specimen in the chamber. The specimen used for temperature monitoring may, if desired, be a dummy specimen (i.e. neither an AACM concrete nor a reference concrete) of comparable or higher performance compared to the specimens under test.

Table E.1 **Temperature limits at specified points of each 24-hour cycle in the freeze-thaw chamber**

Upper limit		Lower limit	
Time (hours)	Temperature (°C)	Time (hours)	Temperature (°C)
0	24	0	16
5	-2	3	-4
12	-14	12	-20
16	-16	16	-20
18	0	20	0
22	24		

Figure E.2 **Maximum and minimum temperatures in the freeze-thaw chamber at specified times in the cycle (Table E.1)**



NOTE Two cycles of 24 hours each are depicted.

E.6 Performance assessment and reporting

At the completion of 7, 14, 28, 42 and 56 cycles, during the thawing phase between the 20-hour and 24-hour point of the respective cycle, the performance of each specimen shall be assessed as follows:

- the polyethylene film is removed, and the test solution discarded;
- material which has been detached from the exposed surface of each specimen by scaling is collected using a paintbrush and a suitable paper receptacle (e.g. coffee filter or filter paper) of known mass;
- the test solution is replaced on each specimen, and the specimens replaced in the exposure chamber;
- the material scaled from the surface of each specimen is oven-dried to constant mass at 105 ± 5 °C; and
- the mass of the dried scaled material after n cycles, M_n (g), is recorded to the nearest 0.1 g.

The mass loss per unit surface area (ML_n) shall be calculated for each specimen at each time interval as:

$$ML_n = 1000 \times M_n/A \text{ (kg/m}^2\text{)}$$

where A is the exposed specimen surface area in mm^2.

The test result at each time interval n shall be calculated as the mean value of ML_n for the five tested specimens of each concrete (AACM or reference). Results shall be reported to two decimal places, and the standard deviation for each result shall also be reported.

The performance of the AACM shall be considered acceptable if its mean ML_n values are less than or equal to the corresponding ML_n values for the reference concrete at the majority of testing intervals: i.e. the performance of the AACM must be better than or equal to the performance of the reference concrete for 3 or more of the measurements conducted at 7, 14, 28, 42 and 56 days.

When reporting the test results, the specimen dimensions and age, and the nature of the test solution (Method A or Method B) shall also be reported.

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