

Alternative binder systems for lower carbon concrete – Code of practice

September 2024 Version 2



BSI Flex 350 v2.0:2024-09



Publishing and copyright information

The BSI copyright notice displayed in this document indicates when the document was last issued.

© The British Standards Institution 2024. Published by BSI Standards Limited 2024.

ISBN 978 0 539 25863 9

ICS 13.020.40, 91.100.30

No copying without BSI permission except as permitted by copyright law.

BSI's Flex standards provide a new, flexible way to develop consensus-based good practice that dynamically adapts to keep pace with fast-changing markets. For more information, go to: <https://www.bsigroup.com/en-GB/our-services/standards-services/flex>

Publication history

Version 1 October 2023

Version 2 September 2024

Contents

Foreword iii

0 Introduction..... vi

1 Scope..... 1

2 Normative references 2

3 Terms, definitions and abbreviated terms 4

3.1 Terms and definitions..... 4

3.2 Abbreviated terms 5

4 Alternative binder systems 6

4.1 Main constituents..... 6

4.2 Performance assessment..... 6

4.3 Emissions..... 8

5 ABS concrete materials..... 9

5.1 Aggregates 9

5.2 Water 9

5.3 Admixtures 9

5.4 Other constituents 9

5.5 Chlorides..... 10

6 ABS concrete properties 11

6.1 General 11

6.2 Fresh properties..... 12

6.3 Mechanical properties 12

7 Durability of ABS concrete 18

7.1 General 18

7.2 Corrosion testing 18

7.3 Corrosion induced by carbonation (XC1, XC2, XC3, XC4)..... 18

7.4 Corrosion induced by chloride (XS1, XS2, XS3, XD1, XD2, XD3) 19

7.5 Freeze/thaw attack with or without de-icing agents (XF1, XF2, XF3, XF4) 19

7.6 Chemical attack [aggressive chemical environment for concrete classification (ACEC) exposure class]..... 20

7.7 Mechanical abrasion (XM1, XM2, XM3) 21

Annexes

Annex A (normative) Supply of ABS concrete..... 22

A.1 General..... 22

A.2 Plant and equipment..... 22

A.3 Batching 22

A.4 Placing and finishing..... 23

A.5 Early protection and curing 23

Annex B (normative) Reference concrete 24

Bibliography 26

List of figures

Figure 1 – Relative strength compared to 28 day for different strength development classes based on BS EN 1992-1-1:2023, 5.1.3 13

List of tables

Table 1 – Mechanical and physical requirements of ABS given as characteristic values 7

Table 2 – Recommended limits on chloride content of ABS concrete 10

Table 3 – 28 day tensile strengths derived from BS EN 1992-1-1 related to compressive strength class after Bamforth et al. 2008 14

Table B.1 – Design of reference concrete for Example 1 25

Table B.2 – Design of reference concrete for Example 2 25

Foreword

This BSI Flex was sponsored by the Institution of Civil Engineers (ICE). Its development was facilitated by BSI Standards Limited and it was released under licence from The British Standards Institution. It came into effect on 30 September 2024.

Acknowledgement is given to the following organizations that funded this BSI Flex:

- AMTEST UK
- DB Group
- Environment Agency
- I3P
- Laing O'Rourke
- Mineral Products Association (MPA) Cement
- Network Rail
- Wagners (EFC Green Concrete Technology UK Ltd)

Acknowledgement is given to James Aldred, Concrete Future, as the technical author, and the following organizations that were involved in the development of this BSI Flex as members of the Advisory Group:

- AKT II
- AMCRETE UK
- ARUP
- B/517
- CEMEX
- Concrete Future
- ConcreteZero
- Environment Agency
- GPT
- Institution of Civil Engineers (ICE)
- Laing O'Rourke
- Material Evolution
- Mineral Products Association (MPA) Cement
- Mott MacDonald
- OTB Concrete
- Paul Scherrer Institut
- Ramboll Buildings
- Skanska Costain STRABAG Joint Venture (SCS JV)
- The Institution of Structural Engineers (IstructE)
- University of Birmingham

The British Standards Institution retains ownership and copyright of this BSI Flex. BSI Standards Limited, as the publisher of the BSI Flex, reserves the right to withdraw or amend this BSI Flex on receipt of authoritative advice that it is appropriate to do so.

This BSI Flex is not to be regarded as a PAS or British Standard.

The BSI Flex process enables a standard to be rapidly developed, on an iterative basis, in order to fulfil an immediate stakeholder need. A BSI Flex can be considered for further development as a PAS or British Standard, or constitute part of the UK input into the development of a European or international standard.

The content in this version is part of an iterative process. It is likely to change from time to time with subsequent iterations.

Supersession

This version of BSI Flex 350 supersedes BSI Flex 350 v1.0 2023-10, which is withdrawn.

Information about this document

This is Version 2 of BSI Flex 350, which is the last planned version of the document. All comments received will be reviewed to inform the future direction of this document. Interested parties are encouraged to check the BSI website for updates regarding any future plans.

This publication can be withdrawn, revised, partially superseded or superseded. Information regarding the status of this publication can be found in the Standards Catalogue on the BSI website at knowledge.bsigroup.com, or by contacting the Customer Services team.

Where websites and webpages have been cited, they are provided for ease of reference and are correct at the time of publication. The location of a webpage or website, or its contents, cannot be guaranteed.

Relationship with other publications

Upon release of this version of BSI Flex 350, PAS 8820 is to be withdrawn.

Use of this document

As a code of practice, this BSI Flex takes the form of recommendations and guidance. It is not to be quoted as if it were a specification. Users are expected to ensure that claims of compliance are not misleading.

Users may substitute any of the recommendations in this BSI Flex with practices of equivalent or better outcome. Any user claiming compliance with this BSI Flex is expected to be able to justify any course of action that deviates from its recommendations.

Presentational conventions

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

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

The word "should" is used to express recommendations of this document. The word "may" is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word "can" is used to express possibility, e.g. a consequence of an action or an event.

Notes and commentaries are provided throughout the text of this document. Notes give references and additional information that are important but do not form part of the recommendations. Commentaries give background information.

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

Contractual and legal considerations

This publication has been prepared in good faith, however no representation, warranty, assurance or undertaking (express or implied) is or will be made, and no responsibility or liability is or will be accepted by BSI in relation to the adequacy, accuracy, completeness or reasonableness of this publication. All and any such responsibility and liability is expressly disclaimed to the full extent permitted by the law.

This publication is provided as is, and is to be used at the recipient's own risk.

The recipient is advised to consider seeking professional guidance with respect to its use of this publication.

This publication is not intended to constitute a contract. Users are responsible for its correct application.

Compliance with a BSI Flex cannot confer immunity from legal obligations.

WARNING. Where skin is in contact with fresh alternative binder systems (ABS) concrete, skin irritations are likely to occur if the ABS is highly alkaline. The abrasive effects of sand and aggregate in ABS concrete can aggravate the condition. Potential effects range from dry skin, irritant contact dermatitis, to – in cases of prolonged exposure – severe burns. Take precautions to avoid dry ABS entering the eyes, mouth and nose when mixing mortar or concrete by wearing suitable protective clothing. Care is necessary to prevent fresh ABS concrete from entering boots and use working methods that do not require personnel to kneel in fresh ABS concrete. Unlike heat burns, alkali burns might not be felt until sometime after contact with fresh ABS concrete if the ABS is highly alkaline, so there might be no warning of damage occurring. If ABS or ABS concrete enters the eye, immediately wash it out thoroughly with clean water and seek medical treatment without delay. Wash wet ABS concrete off the skin immediately. Barrier creams can be used to supplement protective clothing but are not an alternative means of protection.

0 Introduction

The UK consumes 11.7 million metric tonnes of Portland cement per year according to the European Ready Mixed Concrete Organisation, and as quoted in the ICE Low Carbon Concrete Routemap (2022) [N1]. This results in the emission of approximately 9 million metric tonnes of CO₂ equivalent or nearly 90% of the greenhouse gas emissions associated with concrete production. Alternative binder systems (ABS) can be used to significantly reduce the emissions from the concrete binder compared to Portland cement while continuing to provide the many benefits of concrete construction. ABS are expected to play an increasingly important role in achieving the target of net zero by 2050 in concrete construction.

According to Global Cement and Concrete Association (GCCA), alternative binders can reduce emissions in different ways. Some retain the slower setting belite phase of Portland cement mixed with rapid setting calcium sulfoaluminate cement (SAC) reducing the total CO₂ emitted during production. Others rely on different chemistries eliminating the need for Portland cement, such as alkali activated materials.

Some alternative binders set through carbonation (i.e. absorbing CO₂) rather than hydration, such as wollastonite-based cement. These effectively capture the CO₂ emitted during their production as they set and harden in concrete, creating a low-carbon or even carbon neutral construction material. Others use magnesium oxide instead of calcium oxide which captures more CO₂. ABS differ in their level of development. Some have a long history of use. An ABS based on vitreous slag was first patented by Whiting in 1895 [1] and described as providing performance “equal in quality to the best Portland or similar cement”. Xu et al (2008) [2] investigated the long-term performance of activated slag concretes from the former Soviet Union. The slag component had been activated by carbonates and by carbonate/hydroxide mixtures. The research found high compressive strengths that were significantly higher than the original design strength, and excellent durability after 35 years of field exposure. Xu et al (2008) [2] and Shi et al. (2006) [3] reported that the carbonation depths are relatively low for their age and no microcracks were observed after prolonged service.

Some ABS are used commercially but constitute a limited volume of the total market; some are more recent developments or require more study before their true potential can be assessed.

This BSI Flex provides a framework by which the performance of each type of ABS concrete is established by comprehensive assessment in accordance with Clause 6 and Clause 7. While this BSI Flex is focused on the application of ABS concrete within the United Kingdom, it provides a helpful guide for other countries when considering the use of ABS concrete.

Following on from PAS 8820:2016, *Construction materials – Alkali-activated cementitious material and concrete – Specification*, this BSI Flex recommends a framework for assessing ABS concretes to facilitate their acceptance as suitable alternatives to Portland cement-based concrete when designing and building structures.

Where ABS concrete has substantially lower strength or stiffness than traditional concrete, this BSI Flex recommends it be considered in less demanding applications when it is safe to do so and provides reduced emissions.

1 Scope

This BSI Flex gives recommendations for the assessment and use of alternative binder systems (ABS) in concrete when building concrete structures otherwise in accordance with BS 8500 (all parts) and BS EN 1992 (all parts). This is part of a strategy for meeting the proposed net zero 2050 target.

This BSI Flex covers properties of ABS and provides recommendations on testing and monitoring to demonstrate conformity with the recommended performance for different applications.

The types of ABS covered include, but are not limited to, alkali-activated materials. It does not cover the cement types covered in BS EN 197, BS EN 15743, BS EN 14216 or BS EN 14647.

This BSI Flex is not applicable to any other methods of concrete carbon reducing measures.

This BSI Flex is intended for use by both ABS and ABS concrete manufacturers/producers. It might also be of interest to engineers, designers, end users, contractors and other stakeholders.

It is intended that:

- a) all the recommended performance tests are conducted on a representative grade of ABS concrete on behalf of the producers to demonstrate acceptable properties of the ABS; and
- b) project specific testing and conformance testing are conducted on behalf of the engineer/designer/concrete contractor to demonstrate suitability of the specific ABS concrete mixes and quality control.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions, or limits the application, of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies¹⁾.

Standards publications

ASTM C469/C469M – 22, *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*

BS 812-104, *Testing aggregates – Part 104: Method for qualitative and quantitative petrographic examination of aggregates*

BS 7542, *Method of test for curing compounds for concrete*

BS 8204-2:2003+A2:2011, *Screeds, bases and in situ floorings – Part 2: Concrete wearing surfaces – Code of practice*

BS 8443, *Specification for establishing the suitability of special purpose concrete admixtures*

BS 8500-1, *Concrete – Complementary British Standard to BS EN 206 – Part 1: Method of specifying and guidance for the specifier*²⁾

BS 8500-2:2023, *Concrete – Part 1: Complementary British Standard to BS EN 206 – Part 2: Specification for constituent materials and concrete*

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

BS EN 196-2, *Method of testing cement – Part 2: Chemical analysis of cement*

BS EN 196-3, *Methods of testing cement – Part 3: Determination of setting times and soundness*

BS EN 196-6, *Methods of testing cement – Part 6: Determination of fineness*

BS EN 197 (all parts), *Cement*

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

BS EN 206:2013+A2:2021, *Concrete – Specification, performance, production and conformity*

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 1990:2023, *Eurocode – Basis of structural and geotechnical design*

BS EN 1992 (all parts), *Eurocode 2: Design of concrete structures*

BS EN 1992-1-1:2023, *Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings, bridges and civil engineering structures*

BS EN 1992-1-2, *Eurocode 2: Design of concrete structures – Part 1-2: Structural fire design*

BS EN 12620, *Aggregates for concrete*

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

BS EN 12390-5, *Testing hardened concrete – Part 5: Flexural strength of test specimens*

BS EN 12390-6, *Testing hardened concrete – Part 6: Tensile splitting strength of test specimens*

¹⁾ Documents that are referred to solely in an informative manner are listed in the Bibliography

²⁾ This document also gives informative references to BS 8500-1:2023 and BS 8500-1:2015+A2:2019

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

BS EN 12390-10, *Testing hardened concrete – Part 10: Determination of the carbonation resistance of concrete at atmospheric levels of carbon dioxide*

BS EN 12390-11, *Testing hardened concrete – Part 11: Determination of the chloride resistance of concrete, unidirectional diffusion*

BS EN 12390-12, *Testing hardened concrete – Part 12: Determination of the carbonation resistance of concrete. Accelerated carbonation method*

BS EN 12390-13, *Testing hardened concrete – Part 13: Determination of secant modulus of elasticity in compression*

BS EN 12390-14, *Testing hardened concrete – Part 14: Semi-adiabatic method for the determination of heat released by concrete during its hardening process*

BS EN 12390-15, *Testing hardened concrete – Part 15: Adiabatic method for the determination of heat released by concrete during its hardening process*

BS EN 12390-16:2019, *Testing hardened concrete – Part 16: Determination of the shrinkage of concrete*

BS EN 12390-17, *Testing hardened concrete – Part 17: Determination of creep of concrete in compression*

BS EN 12390-18, *Testing hardened concrete – Part 18: Determination of the chloride migration coefficient*

BS EN 12390-19, *Testing hardened concrete – Part 19: Determination of electrical resistivity*

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

BS EN 14216, *Cement – Composition, specifications and conformity criteria for very low heat special cements³⁾*

BS EN 14227-4, *Hydraulically bound mixtures – Specifications – Part 4: Fly ash for hydraulically bound mixtures*

BS EN ISO 14067, *Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification*

BS ISO 1920-14, *Testing of concrete – Part 14: Setting time of concrete by resistance to penetration*

CEN/TR 15177, *Testing the freeze-thaw resistance of concrete – Internal structural damage*

PD CEN/TS 12390-9, *Testing hardened concrete – Part 9: Freeze-thaw resistance with de-icing salts – Scaling*

PD CEN/TR 16563, *Principles of the equivalent durability procedure*

SA TS 199:2023, *Technical Specification – Design of geopolymer and alkali-activated binder concrete structures*

Other publications

[N1] ICE. Low Carbon Concrete Routemap – Setting the agenda for a path to net zero⁴⁾

[N2] MPA CEMENT, MPA Fact sheet 18 Embodied CO₂e of UK cement, additions and cementitious material. Document No: ST/FS/18. September 2019

[N3] AASHTO T 336-11, Standard method of test for coefficient of thermal expansion of hydraulic cement concrete

³⁾ This BSI Flex also gives an informative reference to BS EN 14216:2004

⁴⁾ Available at https://www.ice.org.uk/media/200i0yqd/2022-04-26-low-carbon-concrete-routemap-final_rev.pdf (accessed 22/8/2024)

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

3.1.1 activator

source of one or more elements in the alkali metals group, and/or magnesium, and/or calcium and/or other, which when incorporated in aqueous or solid form, induces a reaction, setting and hardening of an ABS

3.1.2 admixture

constituent added during the mixing process in small quantities related to the mass of binder to modify the properties of fresh or hardened concrete

3.1.3 alkali-activated material (AAM)

type of ABS consisting of one or more powders containing both oxides of aluminium and silicon which can be induced to react and harden through the addition of an alkali activator

NOTE Typically high calcium AAM is used in ambient cure applications and low calcium AAM is used in heat cured precast applications. Some low calcium AAM can be used in ambient conditions, dependent on activator types/combinations and initial concrete temperatures.

3.1.4 alternative binder system (ABS)

substance formed by a combination of one or more constituent materials together with chemicals or activators which react to form a hardened monolithic material

3.1.5 alternative binder system (ABS) concrete

substance formed by combining ABS with fine and coarse aggregates and water, with or without the incorporation of admixtures

3.1.6 design 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 service life.

3.1.7 embodied carbon dioxide equivalent (kgCO_2e)

total mass of greenhouse gases (GHG) emitted during the product stage (Cradle to gate – A1-A3) converted to a carbon dioxide equivalent by multiplying the mass of each GHG by its corresponding global warming potential (GWP)

3.1.8 equivalent performance

criteria that an ABS concrete needs to achieve to demonstrate equal performance compared with a reference concrete in conformity with specified requirements, especially the requirements for the relevant exposure class with respect to its reaction to environmental actions

3.1.9 exposure class

category of environmental or mechanical actions that pose a risk of damage to concrete or its reinforcement