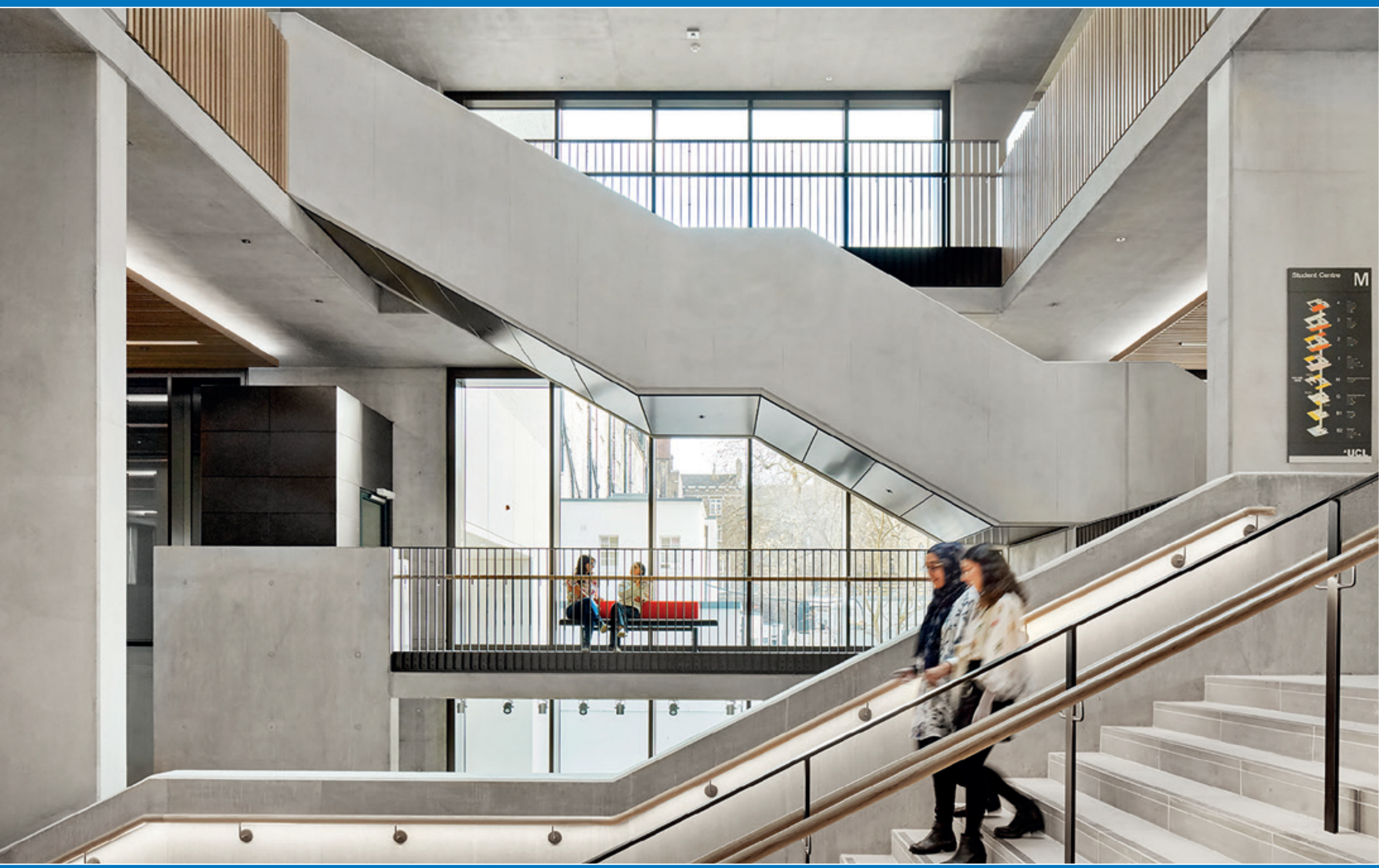
Specifying Sustainable Concrete



Understanding the role of constituent materials

Contents

About this publication

Concrete's flexibility offers many opportunities for designers to influence the environmental, economic and social credentials of their projects, including performance credentials such as fire, durability, acoustics and adaptability. This publication is intended to assist designers in optimising the sustainable credentials of concrete through specification.

This guide focuses on concrete, its constituent materials and how the variation of specification can influence the sustainability performance of concrete. Sustainable characteristics with the greatest scope for influence through specification include: the performance of fresh and hardened concrete (e.g. strength gain, durability); embodied CO_2; CO_2 associated with transportation; responsible sourcing and use of recycled or secondary materials.

Aspects of sustainability, outside the scope of this document, are addressed in other Concrete Centre guidance. Readers should refer to **www.concretecentre.com/publications** for titles including: *Concrete and BREEAM, Material Efficiency, Concrete and Fire Safety, Thermal Mass Explained* and *Whole-Life Carbon and Buildings*.

Cover image and left: The University College London's new student centre was awarded an 'Outstanding' BREEAM rating. It uses ground granulated blast-furnace slag (GGBS) and recycled aggregates within its concrete mix. The building fabric is also highly efficient, with exposed concrete used for thermal mass, helping to regulate temperature and minimise energy use. Image: Nicholas Hare Architects © Alan Williams Photography

Introduction

Whilst the purpose of this guide is to enable the specification of low carbon concrete that is appropriate to optimising a truly sustainable building solution, it is now recognised that concrete specification is but a part of the process. These considerations need to be balanced with other key criteria required by a life cycle analysis approached on a whole life basis, taking into account, sustainable engineering design solutions, construction methodologies, in use operational benefits (such as thermal mass and the potential for energy conservation), the potential for reuse or repurposing as well as end-of-life outcomes, all of which are key attributes of the material.

Thus, the focus on embodied carbon becomes an investment decision considering the whole life of the building, as well as using the material to its best advantage to save carbon now, whilst even lower carbon concrete solutions are in development to contribute to the Government's net zero commitment.

Concrete's role in delivering a sustainable built environment through the performance benefits of durability (long life), robustness (strength and low maintenance), fire resistance, thermal mass (energy efficiency), acoustic performance and climate change resilience (flood and extreme weather) – together with design excellence (potential for a reduced need for applied finishes) – is increasingly recognised and utilised by design teams in the delivery of the most sustainable projects and infrastructure.

Concrete is a versatile and natural material and designers can use it efficiently to deliver structure and other functions of integrated designs. Concrete and its constituents have other strong sustainability credentials; for example, they are local to the UK and most are certificated to the highest, most demanding responsible sourcing standards.

These are among the many sustainability factors that result in designers choosing concrete. Sustainability is about optimising economic, social and environmental issues. Many assessment tools and methodologies have been developed to provide measurement and comparison. The shortcoming of generalised tools is that – by definition - they are general, and specific geographical or project constraints may not be accounted for.

A challenge for all assessments is in weighting the different factors which often have different units of measurement; for example, how does one compare biodiversity, health and safety and transportation CO_2 emissions? Therefore, it is accepted good practice for designers to not simply follow a tick box mentality in their use of assessment tools but to understand the factors and take a holistic and whole-life view of sustainability when considering their project in a whole life context.

Whole-life thinking calls for a longer-term perspective. Specification decisions and carbon measurement must consider the operational performance of a building or structure, its flexibility to adapt to user needs and its recycling at the end of life, as well as the materials used to construct it.

While embedded carbon from manufacturing processes may be easier to calculate, it fails to address some critical factors that are of key importance when assessing the true environmental impact of buildings and infrastructure over their lifetime. Clients need to have a far greater appreciation of the fact that buildings must last longer and may have multiple uses over their lifecycle.

The European standard for concrete BS EN 206 [1] and its UK complementary Standard, BS 8500 [2] do not contain any provisions for specifying sustainability. This document aims to provide guidance over and above concrete codes and standards, to enable the project team to balance the desire to specify concrete with low environmental impacts whilst ensuring that its other performance parameters are optimised. These performance parameters can effect overall environmental impacts, client and construction programmes, in use benefits and long term sustainability issues.

Sustainability cannot be separated from performance. Concrete is a unique material in that the specifier has the ability to directly influence the constituent parts of the mix to ensure an optimum carbon footprint that meets the performance criteria and addresses the design imperatives of resource and energy efficiency within a whole life context, that also address the precepts of a circular economy.

Key guidance

- The balance between the reduction of embodied CO_2 of concrete and the design, specification, construction method and contract programme need to be considered at an early stage.
- Only specify responsibly sourced concrete and reinforcement.
- Consider specifying strength at 56 days rather than the conventional 28 days, where appropriate.
- Specify concrete with a wider range of cement types/combinations selected from Table 1 from BS 8500-2: 2015.
- Use of cementitious additions can both reduce the embodied CO_2 (ECO_2) of concrete and influence its visual appearance. When aesthetics are critical, specify the cement/combination to achieve colour consistency.
- Specify the strength required from producers with Product Conformity Certification.
- Permit the use of admixtures. Admixtures can be used to enhance sustainability credentials and reduce the ECO_2 of concrete, as well as modifying its physical properties.
- The specification of recycled and secondary aggregates may not be the most sustainable option.
- Permit the use of recycled or secondary aggregates but do not over specify.
- BS 8500 already allows producers to use up to 20% of recycled aggregates in many concretes.
- Recycled aggregates should generally only be specified when they are locally available, otherwise CO_2 transportation impacts are likely to exceed the intended benefits.
- Specify the largest maximum aggregate size conducive to achieving efficient placing and full compaction.

Specification of Concrete to BS 8500

In the UK concrete is specified in accordance with the European Standard for Concrete, EN 206[1], and the UK complementary Standard BS 8500[2]. BS 8500 is published in two parts: BS 8500-1, *Method of specifying and guidance for the specifier*, and BS 8500-2 *Specification for constituent materials and concrete*.

For particular applications, reference to alternate standards or specialist literature may be an option. For agricultural buildings, BS 5502-21 and BS 5502-22 could be appropriate and for maritime works then BS 6349-1-4 should be used. BS EN 13369 covers common rules for precast concrete products and there is further information in some individual concrete product standards. However, BS 8500 is appropriate for most building and civil engineering structures in the UK. The standard sets out five standard ways to specify concrete. These are: designed concretes, designated concretes, prescribed concretes, standardized prescribed concretes and proprietary concretes. The term 'concrete mix' is sometimes used to refer to a prescribed concrete but otherwise it is always a 'concrete' that is specified.

Designed concretes are for the informed specifier, where the designer considers all the requirements for the hardened concrete such as strength and durability to derive the necessary strength class and other properties such as cement type, minimum cement content and maximum water/cement ratio. Normally the designer will assess the exposure conditions and consider the recommendations set out in BS 8500: Part 1:2015+A2:2019 Annex A to determine the concrete properties and minimum cover to reinforcement required to achieve the structural performance and service life. Due to its inherent durability properties most reinforced concrete is designed for a minimum intended working life of at least 50 years, but often performance of 100 years can be achieved with zero or modest increases in cover or concrete quality. The longevity of concrete in use is an important sustainability consideration. The flexibility of designed concretes, makes them suitable for specifying the most sustainable concrete, that is with the minimum of embodied carbon using low carbon cements or combinations, together with the option of recycled or secondary aggregate where considered beneficial.

The designer's specification is then passed to the contractor where the concrete specification is completed with the addition of requirements for fresh concrete properties, such as consistence.

Designated concretes are types of designed concretes that allow scope to be achieved using a range of predetermined mixes, where for a range of applications the specifier only calls up the required designation, e.g. FND2 is a concrete suitable for use in ground assessed as 'DC-2', Design Chemical Class 2. Similarly, RC28/35 is a designated concrete of C28/35 strength class suitable for use in an internal suspended floor. Designated concretes are quality-assured designed concretes that conform to a specification detailed in BS 8500-2. These concretes have been selected to be fit for their intended use and they can only be supplied by ready-mixed concrete producers who have third-party product conformity certification. A QSRMC or BSI Kitemark logo on the delivery ticket provides this confirmation. Purchasers can be confident that the concrete will be delivered as specified and ordered, and as the concrete is optimised by the producer it will be the most cost effective, which can often also be the most sustainable.

Designated concrete is the preferred method of specifying concrete when working to the NHBC Standards. Guidance entitled *Concretes for Housing - Designated concrete* [3] is available from the British Ready-Mixed Concrete Association (BRMCA).

Designated concretes are not appropriate where concrete needs to resist the risk of corrosion by the ingress of chloride in such cases the specifier should specify a designed concrete.

Table 1: BS 8500-2: Guidance on the selection of designated concrete in housing and other applications

Typical application	Designated concrete	Recommended slump class
Foundation (fully buried)		
Unreinforced foundations in DC-1 soils	GEN1	S3 A)
Reinforced foundations in DC-1 soils	RC25/30	S3 A)
Unreinforced or reinforced foundations in DC-2 soils	FND2	S3 A)
Unreinforced or reinforced foundations in DC-xyz soils	FNDxyz	S3 A)
Floors B)		
Unreinforced floor with permanent finish to be added e.g. screed of floating floor	GEN1	S2
Unreinforced floor with no permanent finish to be added e.g. carpeted	GEN2	S2
Unreinforced garage floor	GEN3	S2
Reinforced house floor	RC20/25	S2
Reinforced garage floor with at least 40mm nominal cover to reinforcement	RC28/35	S2
Other applications		
Infill to insulated concrete formwork used above ground	RC20/25 C)	D)
Oversite	GEN1	S3
Kerb bedding and backing	GEN0	S1
Drainage works on DC-1 soils to give immediate support	GEN1	S1
Drainage works on DC-1 soils	GEN1	S3
House drives, domestic parking and external paving – no de-icing salt	PAV1	S2
Heavy-duty external paving for rubber-tyred vehicles	PAV2	S3

A) For trench fill, use S4
B) Floors with any embedded metal should be treated as being reinforced
C) Specify a 10mm maximum aggregate size
D) Follow the recommendation of the manufacturer of the insulated concrete formwork system being used
E) When to be placed by hand

Prescribed concretes allow the informed designer to specify concrete by prescribing the composition. This method is rarely used but is useful where a particular ratio of constituents is required for exposed aggregate concrete finishes.

Standardized prescribed concretes are intended for small building sites where concrete is either mixed by hand or in a small, less than 150 litre, concrete mixer. They are designated ST and are accepted by NHBC for some applications. There is no requirement to demonstrate the strength of ST concrete but BS 8500 Part 1:2015+A1:2019 Annex A provides some indicative values for the strength class that may be assumed for structural design, e.g. the highest grade of standardized prescribed concrete is ST5, where this may be assumed to be at strength class not greater than C20/25.

To ensure the ST designation recommendation is safe for the indeterminate range of materials and site supervision the prescribed cement content is very high, and the use of ST concretes should be avoided where a ready-mixed concrete in the form of a designated or designed concrete can be used. Standardized prescribed concretes have a much higher embodied carbon than the equivalent designated concrete. The GEN series of designated concretes are the more sustainable option because the cement content is optimised to that required for strength.

Table 2: Standardized prescribed and equivalent designated concretes

Standardized prescribed concrete	Designated concrete equivalent
ST1	GEN0
ST2	GEN1
ST3	GEN2
ST4	GEN3

Proprietary concretes are developed by the concrete producer and are marketed on the basis of their enhanced fresh or hardened properties. The producer will normally guarantee the performance of these products and provide test certificates. Proprietary concretes may be covered by third-party product conformity certification. Proprietary concretes are often used for high performance applications where the sustainability benefit is in the reduction in the total material volume used rather than the value per volume. For commercial reasons the producer may not disclose the exact composition and is not required to do so by the concrete Standards, EN 206 and BS 8500.

For more information on specifying to BS 8500, refer to *How to Design Concrete Structures to Eurocode 2* [4], published by The Concrete Centre.

Additional aids to specification of concrete include the *National Structural Concrete Specification (NSCS) Edition 4* [5] *and the National Building Specification (NBS)* [6]. More details of these resources can be found in Further Reading (see page 23).

Specification examples

Designated concrete example

For a building with external reinforced vertical elements exposed to rain (exposure class XC3/4 to BS 8500) with an intended working life of at least 50 years, a range of concretes are appropriate depending on the minimum cover to the reinforcement. These are shown in Table 3.

Table 3: Designated concretes for exposure class XC3/4 and minimum 50 years

Minimum cover (mm)	Strength class	Min cement content (kg/m^3)	Max w/c ratio	Designated concrete
20	C40/50	340	0.45	RC40/50
25	C30/37	300	0.55	RC30/37
30	C28/35	280	0.60	RC28/35
≥35	C25/30	260	0.65	RC25/30
An allowance for deviations (generally 10 mm for in situ work) is added to minimum cover to give nominal covers to reinforcement.				

In practice, for reasonable quality aggregate, RC30/37, RC28/35 and RC25/30 should be achievable at the minimum cement content with the use of water reducing or high range water reducing admixtures. This applies to all cements incorporating not more than 20% silica fume or limestone, 35% fly ash or 65% ggbs. At higher levels, an extra cementitious content above the minimum should be expected.

Even with reasonable quality aggregates and high performing admixtures, an extra cementitious content is likely to be required for RC40/50 concrete to achieve the required strength.

Since the water cement ratio has a large impact on the strength of the concrete, with higher water cement ratios producing lower strength concretes for the same cement content, the use of water reducing and high range water reducing admixtures can reduce the cement content and hence the ECO_2, while providing the same strength and improved durability characteristics.

Optimising strength class

A reduction in concrete strength class will typically offer immediate savings in terms of ECO_2 (reduced cement/combination content) for the same volume, unless limited by minimum cement content specifications. As an example, a reduction in strength class from C70/85 to C32/40 may reduce concrete's cement/combination content by around 150kg per m^3 of concrete, with corresponding ECO_2 reductions of around 185 kg of CO_2.

For a typical concrete column scenario (applied load of 24000kN and moment of 500kNm), however, the higher strength class would afford element size reductions of around 30% (from around 900 x 900mm to 750 x 750mm) and corresponding reinforcement content reductions of about a third. In addition, there may be potential reductions in foundation size.

The more slender, high strength structural solution may offer potential economic, environmental and social benefits to the design team, contractor and client alike that offset the higher ECO_2 per m^3 of concrete.

Table 4 illustrates an example case in which three options are considered compared with a base option. For this building, there is a small net reduction of ECO_2 by using higher strength concrete for columns (see option 3 compared with option 2 and option 1 compared with base option). The opposite is true for slabs (see option 2 compared with option 1).

Table 4: Comparison of ECO_2 for different construction options

	Base Option	Option 1	Option 2	Option 3
Concrete class for slab	C32/40	C32/40	C50/60	C50/60
Concrete class for vertical elements	C32/40	C50/60	C50/60	C60/75
Volume of slab concrete (m^3)	2,110	2,110	1,841	1,841
Volume of concrete in verticals (m^3)	1,112	956	956	885
Change in nett lettable area	0%	1.22%	1.22%	1.78%
Tonnes ECO_2	1,369	1,346	1,492	1,477
Variation from base option	100%	98%	109%	108%

Assessment Tools

A range of assessment tools exist. Product sustainability tends to focus on embodied impacts whereas the sustainability of construction systems have a much broader focus over the entire life cycle of the system. Existing mechanisms and tools to make such assessments are associated with project-level assessments or have a bias towards environmental issues, rather than incorporating social, environmental and economic aspects of sustainability. Existing assessment schemes such as the BRE Environmental Assessment Method (BREEAM), CEEQUAL and the BES 6001 Responsible Sourcing scheme have widespread credibility.

Responsible sourcing

If any construction product is to be regarded as sustainable it is vital to establish and provide credible evidence of responsible sourcing and production throughout its supply chain.

UK concrete producers, particularly those working within the Concrete Industry Sustainable Construction Strategy, [7], have chosen to provide this evidence by achieving independent certification to BRE's BES 6001 "Framework Standard for Responsible Sourcing" [8].

Based on 2018 data, 91% of all ready-mixed and precast concrete produced under the sustainable construction strategy [7] was certified to BES 6001. The full listing of products certified to BES 6001 is available at **www.greenbooklive.com**.

BES 6001– Framework Standard for Responsible Sourcing

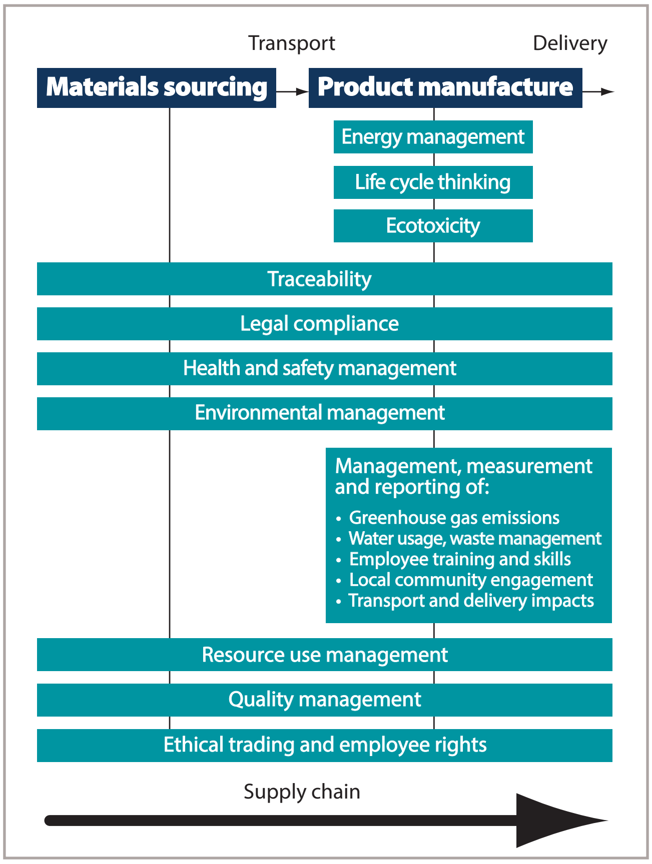
The BRE responsible sourcing standard, BES 6001 [8], first launched in October 2008, provides a benchmark to compare responsible sourcing performance for all construction products on an equal basis.

The aim of BES 6001 is to verify that companies manufacture to sustainable development principles using materials sourced from suppliers that operate to ethical, social and environmentally responsible principles. This is achieved largely by manufacturers providing evidence of policies and embedded management systems for supply chain, quality, environmental and health and safety management both for their own production and their suppliers' materials throughout the supply chain. Verification that these management systems are embedded tends to be through certification to recognised management standards such as ISO 9001 Quality, ISO 14001 Environmental, ISO 50001 Energy and ISO 45001 Health and Safety.

This tends to give BES 6001 a more comprehensive scope than similar responsible sourcing schemes that typically focus on evidence of traceability/chain of custody. Figure 1 shows activities in the supply chain which are covered within BES 6001.

Certification to BES 6001 is accompanied by a performance rating of 'Pass', 'Good', Very Good' and 'Excellent' depending on the extent of verified evidence of the supply chain activities achieved.

Figure 1: The activities of the supply chain covered by the responsible sourcing standard BES 6001



Guidance for specification

Responsible sourcing

Recommendation: Specify BES 6001 certified responsibly sourced concrete.

IN 2018 91% OF PRECAST AND READY-MIXED CONCRETE PRODUCTION WAS CERTIFIED RESPONSIBLY SOURCED TO BES 6001 WITH >90% OF THIS AT "VERY GOOD" OR "EXCELLENT" LEVEL.

Benefits of specifying responsibly sourced concrete

Specifying concrete products that are certified to BES 6001 provides confidence that they are sourced to sound ethical, social and environmentally responsible principles without resorting to potentially costly and time-consuming methods of establishing credentials directly with the manufacturer.

For example, with the current vital importance of reducing carbon and greenhouse gases, it is compulsory under BES 6001 certification that: *"The organisation shall establish a policy, supported by a documented management system, for the monitoring and reduction of the GHG intensity of its operations."* This is not necessarily the case with other responsible sourcing schemes.

A key benefit from this specification is that accreditation to BES 6001 enables products to gain credits within construction project assessment schemes, including BREEAM, Homes Quality Mark and CEEQUAL – the assessment and awards scheme for improving sustainability in civil engineering and public realm projects.

For example, within BREEAM assessments, it is possible to achieve a range of credits for materials that are certified as responsibly sourced using a Responsible Sourcing Certification Scheme (RSCS) score on a scale of 1-10, provided by BRE, that is then input to a materials calculator. The baseline default level for BES 6001 to Pass level is 5 but higher levels of BES 6001 performance can move this up to 7, which is currently the highest score available to any responsible sourcing scheme for new materials. Each concrete producer's certificate will be accompanied by its own RSCS score which can be obtained from the manufacturer or viewed at the BRE website **www.greenbooklive.com**

It is important to obtain this score for the products actually used to maximise credits for concrete products within BREEAM.

Support from the concrete industry

Concrete can demonstrate the highest level of responsible sourcing, based on the local availability of materials, short supply chains and regulated management systems. The industry's high standards, achieved in areas such as employment rights, waste and environmental management and health and safety are also highlighted.

BES 6001 was viewed by the UK concrete industry as the most comprehensive responsible sourcing standard available, measuring the whole infrastructure of the supply chain. The industry quickly adopted independent certification to BES 6001 as a measure within its Sustainable Construction Strategy, launched in 2008 and overseen by the Sustainable Concrete Forum.

The Sustainable Concrete Forum has published a guidance document, approved by BRE, which provides interpretations of the requirements in BES 6001 specific to the concrete industry. It gives details of suitable metrics, benchmarks and improvement targets which the industry has established and typical examples of policies and management approaches. This document can be used by concrete producers, as an aid to assessment. The latest version [9] can be viewed at **www.sustainableconcrete.org.uk**.

Precast concrete certification will include the embedded reinforcing steel. For ready-mixed concrete, the reinforcing steel used on site can also be certified as responsibly sourced either directly to BES 6001, through the ECO Reinforcement scheme based on BES 6001 [10] but with additional requirements or the CARES Sustainable Reinforcing Steel Scheme [11].

Other schemes linked to concrete and responsible sourcing also exist, including BES 6002, an Ethical Labour Sourcing Standard, which was established following the Modern Slavery Act of 2015, and PAS 2080 which was designed to specifically address the management of carbon in infrastructure, including a product's supply chain and delivery.

Quick Facts

BES 6001 Responsible sourcing

- Responsible sourcing is a holistic approach to the sustainable assessment of materials.
- Responsible sourcing of materials to BES 6001 is demonstrated through an ethos of supply chain management and product stewardship and encompasses social, economic and environmental dimensions and is broader than the scope of many stewardship schemes.
- The latest listing of responsibly sourced materials to BES 6001 can be found at **www.greenbooklive.com**.
- Eco-reinforcement is the certification scheme for responsibly sourced reinforcement steel to the standard BES 6001. **www.eco-reinforcement.org**.
- An alternative is the UKCARES sustainable reinforcement scheme **www.ukcares.com**.

To gain accreditation to BES 6001 the organisation must have as a minimum:

- A responsible sourcing policy and compliance with all relevant legislation.
- A greenhouse gas reduction policy and measures using the principles of ISO 16064-1.
- Policies supported by management systems that cover the efficient use of resources, water, waste management, life cycle thinking, transport, training and development and the local community engagement.
- Demonstrate that at least 60% of its constituent raw materials are fully traceable, covered by documented environmental management systems that comply with ISO 14001 and documented Health and Safety systems that is compliant with local legislation and recorded incidents.

In practice the concrete supply chain generally operates at above 90% regarding these aspects.

For more information download the *Concrete Industry Guidance to Support BES 6001* [9] from **www.sustainableconcrete.org.uk.**

Environmental Product Declarations

An Environmental Product Declaration (EPD) is a document that uses life-cycle assessment (LCA) and other information to report on the environmental data of products. Standards such as ISO 14025 and BS EN 15804 exist to ensure consistency of format and comparability of data. EPDs can be verified by accredited third parties so that users have assurance that the EPD complies with the specific requirements of the standard that has been applied. The concrete industry has produced generic EPDs to BS EN 15804 for a range of commonly used precast concrete products and ready-mixed specifications and these can be used in BREEAM assessments and for inclusion with BIM software. Manufacturers are also producing product specific EPDs.

EPDs produced before 2019 may cover all stages in the life-cycle of a construction material or have a narrower scope covering just the cradle-to-gate impacts arising from the manufacturing process. It is important therefore to be aware of this when using them, particularly when working with multiple EPDs from a variety of sources. This issue is avoided with newer EPDs produced in accordance with the 2019 version of BS EN 15804, which requires all stages in the lifecycle of construction materials to be included.

The UK concrete industry's generic EPDs are a good starting point for early stage design, for example, the generic ready-mixed concrete EPD is a C30/37 suitable for all foundations, floors and the majority of building structures. It covers the complete life-cycle of the product from manufacturing through to end-of-life and contains a level of cementitious additions (ggbs and fa) that reflect average UK concrete production by member companies of the British Ready-Mixed Concrete Association. Later in the design process when the concrete performance requirements are known, the use of suitable product specific EPDs from manufacturers may offer opportunities to further optimise the ECO_2 through a greater use of cementitious additions and other construction efficiencies. Generic and product specific concrete EPDs are freely available to download at:

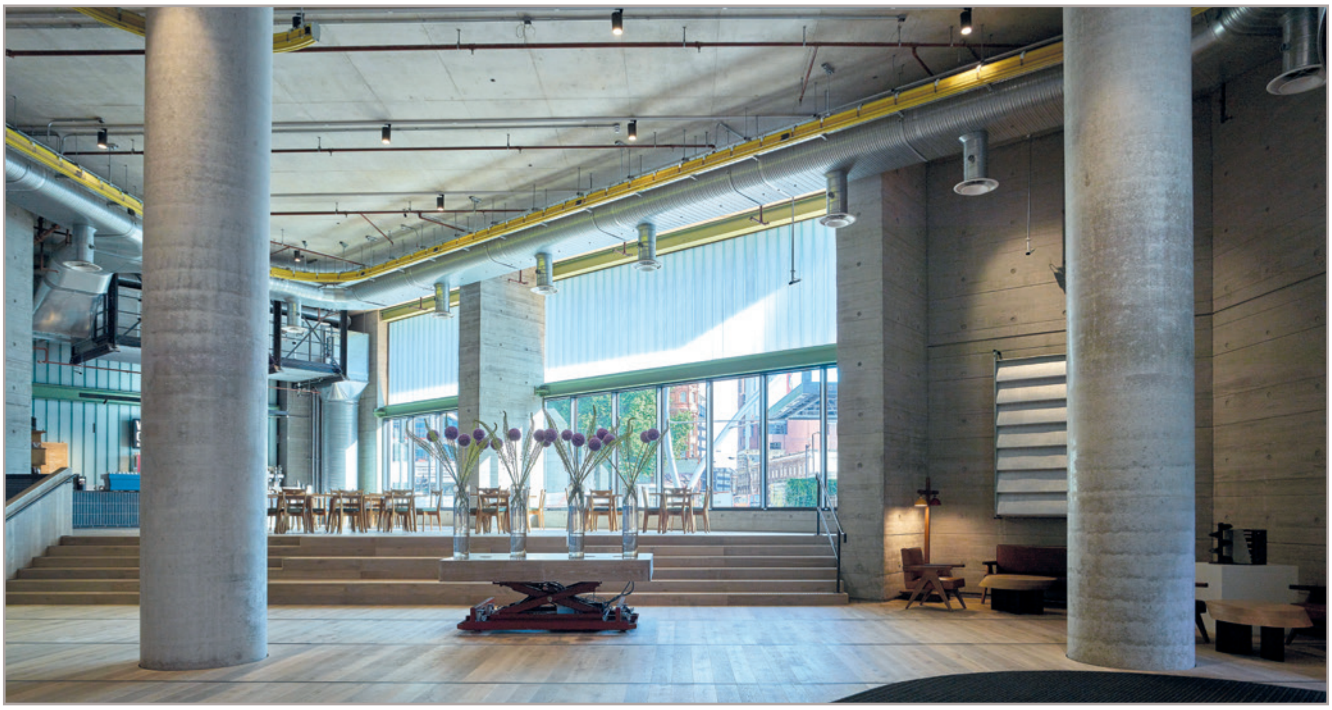
https://ibu-epd.com/en/published-epds/
http://www.greenbooklive.com/

See **www.concretecentre.com/EPD** for more information on EPD.

BRE Environmental Assessment Method (BREEAM)

BREEAM is a recognised global benchmark for sustainability performance. It measures performance, against established benchmarks, to evaluate a development's specification, design, construction and use. The measures cover a broad range of factors related to energy and water use, the internal environment (health and wellbeing), pollution, transport, materials, waste, ecology and management. The scheme is essentially voluntary, but has often been referred to in local authority planning guidance as a prerequisite for publicly funded developments. There are country-specific standards and international standards for a range of development and assessments types. In the UK, assessment schemes include BREEAM New Construction, BREEAM Communities, BREEAM In-use and BREEAM Refurbishment. BREEAM UK New Construction is used to assess non-domestic buildings, during design and on completion. BREEAM is updated periodically with the aim of continuously challenging industry to drive beyond standard practice.

Concrete has been used effectively in many award-winning buildings that have achieved the very highest BREEAM ratings. Concrete's versatility offers construction solutions that provide opportunities to score credits, either directly or indirectly, in nearly all of the categories of BREEAM New Construction. Direct credits include those based on the material specification and selection itself, such as responsibly sourced concrete with low embodied impacts or high levels of recycled content, but also the performance of the material in use. Credits scored through the performance characteristics of concrete include durability, acoustic and fire insulation and flood resilience. Significant credits are available by adopting a low-energy and/or passive ventilation strategy - a technique often made more effective when designed to work with the thermal mass of concrete. Concrete also offers the potential to score credits for low-waste construction, ease of recycling, local availability, offsite construction and cost-effectiveness. For more information, see *Concrete and BREEAM* [12], published by The Concrete Centre.



White Collar Factory, London is a BREEAM 'Outstanding' 17-storey office building that has extensive exposed concrete throughout. This provides the thermal mass that's intrinsic to its passive cooling strategy. Image © Timothy Soar

Aggregates

Aggregates are the major component of concrete by volume and are inherently a low carbon product. Most are naturally occurring materials requiring little processing and are usually locally sourced, with the associated benefit of low transport CO_2 emissions. Contact your local concrete supplier to find out about your local aggregates.

The standard BS EN 12620:2002 – Aggregates for concrete [13] does not discriminate between different sources of material and permits aggregates from natural, recycled and manufactured sources. The focus is on fitness for purpose, rather than origin of the resource. EN 12620 does not discriminate between aggregates, giving a wide selection of potential local aggregates available for use. Specifying a precise aggregate can be more carbon intensive, less economic, and is likely to cause more logistical issues for the supplier.

In addition to primary aggregates, suitable materials for use in concrete include air cooled blast-furnace slag, crushed concrete aggregate (CCA), manufactured and lightweight aggregates, as well as some by-products from the china clay industry, sometimes referred to as stent.

The UK leads Europe in recycling rates for hard demolition waste, and sources of secondary aggregates are utilised by the industry. Primary aggregates are needed and as a resource are abundant. Their extraction is tightly regulated, and sites of mineral extraction are restored, often to an enhanced state, delivering significant biodiversity benefits.

Total aggregate use in Great Britain is relatively low in comparison with other countries. Annual per capita use of aggregates in GB is approximately 20% below the European average [14].

Depending on the type of recycled or secondary aggregates used, there may be increased water demand and a need to increase the cement content of the concrete to achieve the specified characteristic strength, with a consequential increase in ECO_2. When assessing the broader sustainability aspects it will, in many cases, prove to be better if recycled aggregates are used in other applications (in lieu of primary aggregate) in preference to their use in concrete. Within the UK economy there is little evidence that aggregates which could be recycled are sent to landfill or wasted.

If exposed aggregates are a requirement for a visual concrete finish, the architect and concrete contractor should agree the specification; a test panel of the required finish is recommended.

Recycled aggregates (RA)

BS 8500 permits the use of coarse RA and CCA in concrete, providing certain quality and performance criteria are met. RA is aggregate resulting from the reprocessing of inorganic material previously used in construction, while CCA principally comprises crushed concrete.

Clauses 4.3.3 and 4.3.6 of BS 8500-2:2015 [2] and clause A.7.10 of BS 8500-1: 2015 provide guidance on RA and CCA use in designated concrete, as shown in Table 5.

Table 5: Designated concrete - allowable percentage of coarse CCA

Designated concrete	Allowable CCA as a percentage of coarse aggregate
GEN 0 to GEN 3	100%
RC20/25 to RC40/50	20%*
RC40/50XF	0%
PAV1 & PAV2	0%
FND2 to FND4	0%

* Except where the specification allows higher proportions to be used.

Note: On larger contracts an increased % CCA can achieve the concrete specification, this is usually demonstrated based on proving trials or the experience of the specifier.

Since the amount of recycled content permissible in a mix varies between different designations it follows that the opportunities for including recycled aggregates varies between concrete uses. For example 100% is allowable in GEN1, used for many reinforced foundations. Cross reference Table 5 with Table 1 for more information.

CCA is also permitted in designed concrete, although no direct guidance is given on limiting proportions. BS 8500-2 does, however, provide guidance on limiting concrete strength and exposure classes for CCA use, as shown in Table 6.

Table 6: Permitted use of CCA in designed concretes

Exposure	Use of CCA permitted
XO	Yes
XC1, XC2 & XC3/4	Yes
XD1, XD2 & XD3	Possibly**
XS1, XS2 & XS3	Possibly**
XF1	Yes
XF2, XF3 & XF4	Possibly**
DC1	Yes
DC-2, DC-3 & DC-4	Possibly**

**CCA may be used if it can be demonstrated that it is suitable for the exposure condition.

Note: The maximum strength class should be C40/50, unless the CCA comes from previously unused concrete of known composition, for example from a precast factory.

This is carried out via testing to prove the resistance to freezing and thawing (and possibly to chloride ingress) or a proven history of use (10years+) with no issues.

Provisions for the use of fine CCA and fine RA are not given in BS 8500 but this does not preclude their use when it is demonstrated that, due to the source of material, or verified via testing, significant quantities of deleterious materials are not present and their use has been agreed.

Constraining factors for the use of CCA include consistency of supply and the original source. Due to their inherent variability, testing regimes for quality control of the RA or CCA aggregates may need to be more rigorous than for natural/primary aggregates.

Secondary aggregates

Secondary or manufactured aggregates may also be specified for use in structural concrete. These materials are typically industrial by-products not previously used in construction. These aggregate types are derived from a very wide range of materials; many having a strong regional character.

Examples include china clay waste in South West England and air cooled blast-furnace slag in South Wales, Yorkshire and Humberside.

Materials such as china clay sand and stent have similar properties to primary aggregates. As such they conform to BS EN 12620:2002 [13] and their use is well established for fine and coarse aggregate substitution in concrete. However, it is important to ensure that the aggregates conform with all requirements of the specification and an appropriate mix design is used, while an enhanced level of testing may be required.

Guidance for specification

Specification of aggregates

Recommendation: Specification of natural aggregates for concrete, which may contain up to 20% of recycled content, as permitted under BS 8500, is a practical alternative to more overly prescriptive specifications.

Any recycled content used in this approach will be at the discretion of the concrete producer based on availability and cost (with aggregates levy and landfill tax in-built to any cost comparison).

Recycled and secondary aggregates

Recommendation: Permit the use of recycled or secondary aggregates but do not over-specify. When specifying recycled and secondary aggregates, the factors to balance are resource depletion, transportation CO_2 impacts and implications on concrete mix design. These are all impacted by availability, and concrete producers are well placed to ensure the most sustainable aggregates for each project are used.

Aggregate size

Aggregate size can have a significant impact on the cement content of concrete; larger aggregate sizes generally requiring lower cement content for the same or similar strength class.

As an example, the limiting mix design requirements for designated concretes are given in BS 8500-2: 2015 (Table 6). It should be noted that each designation class is assigned minimum cement contents (kg/m^3) for different maximum aggregate sizes. For an RC32/40 designation, for example, the minimum cement content for concrete with maximum aggregate sizes of 10mm and 20mm is 340 and 300kg/m^3 respectively.

Where possible, therefore, reduced ECO_2 levels will be achievable by specifying increased maximum aggregate sizes. It should be noted that most plants and factories do not stock aggregate sizes greater than 20mm.

Transportation impact from the use of recycled/secondary aggregates

The UK construction industry is very efficient at recycling hard construction and demolition waste in non-concrete applications, and there is very little evidence that any material is being land-filled as waste [15]. Approximately a third of all UK aggregates used in concrete and other applications are either recycled or secondary aggregates. Urban regions provide the principal share of recycled materials and construction and demolition waste.

Given that recycling is already efficiently undertaken, most available recyclable materials are already in the market and future growth is likely to be incremental and linked to the future amounts of construction and demolition activity. As such, primary aggregate extraction is unlikely to be reduced by further encouragement of use of recycled aggregates on concrete projects. Overly prescriptive specifications will result in recycled aggregates being transported longer distances to meet specific project requirements rather than being used more efficiently in the locations where the materials are generated. Such a distortion of markets could be less environmentally friendly than using locally available primary aggregates due to the related increase in CO_2 due to the delivery distances. There will be no net reduction in primary aggregate use; just increased transportation of material. As a bulk material road transport is a significant element of delivered aggregates carbon emissions relative to the typically low per tonne emissions associated with the extraction and processing of aggregates.

The impact of this is illustrated in Table 7, which provides indicative ECO_2 for the extraction and production of virgin and recycled aggregates, as well as their delivery to site. Table 7 demonstrates that ECO_2 values for recycled aggregates may be higher than for virgin materials if delivery distances are longer than around 15km (10 miles). As recycling rates are so high, no tangible benefits in terms of resource depletion will be achieved.

This approach to sustainable aggregate specification is reflected in a BREEAM New Construction 2018 which has revised its method of assessment relating to the use of recycled aggregates. The credit now recognises that local aggregates may be the most sustainable source for a given location using a new metric linking abundance with the method and distance of transportation has been introduced.

Guidance for specification

Aggregate size

Recommendation: Do not specify maximum aggregate sizes below 10mm unless necessary.

Table 7: Indicative CO_2 for virgin and recycled aggregates

Material and delivery distance	Cradle to gate kg CO_2/tonne	Transport kg CO_2/tonne	Total kg CO_2/tonne	+/– % CO_2
Virgin aggregates				
+58.5km (delivery and return distance by road)	6.6	2.7	9.3	–
Recycled C&D aggregates compared to the use of virgin aggregates				
Used on-site, 0 km transport	7.9	0.0	7.9	–15%
+5km (delivery distance by road)	7.9	0.5	8.4	–10%
+10km (delivery distance by road)	7.9	0.9	8.8	–5%
+15km (delivery distance by road)	7.9	1.4	9.3	0%
+20km (delivery distance by road)	7.9	1.8	9.7	5%
+58.5km (delivery and return distance by road)	7.9	2.7	10.6	14%
*C&D - Construction and Demolition				

Guidance for specification

Use of recycled and secondary aggregate

Recommendation: Recycled and secondary aggregates should only be specified when they are locally available or delivered using low-carbon transportation. Availability of resource and technical implications should be discussed with the client and contractor. Within the current assessment method, discussion with the client or project code assessor is recommended to prevent unnecessary penalisation.

Quick Facts

The aggregates sector

- Primary aggregates are predominantly UK-sourced, their extraction is tightly regulated and adverse environmental impacts – such as noise and dust – are minimised.
- Regulators such as the Environment Agency work closely with industry to ensure the life cycle of a quarry is environmentally positive.
- Over 700 sites of special scientific interest are current and former mineral extraction sites. The significant contribution to UK biodiversity from the minerals sector is being increasingly recognised.
- Approximately a third of all UK aggregates used in concrete and other applications are either recycled or secondary aggregates. Urban regions provide the principal share of recycled materials and construction and demolition waste.
- The concrete industry makes a significant contribution to biodiversity and nature conservation through the management and restoration of sites of mineral extraction. The industry strategy prioritises its actions within quarries and the indicator reports on the proportion of relevant production sites that have an action plan relating to site restoration, biodiversity or geodiversity. The value reported for 2018 is 99.7% against our 2020 target of 100%.
- The aggregates sector is a key part of a partnership programme Nature after Minerals (NAM). NAM has stated that the restoration of sites of mineral extraction represents the largest expansion of habit in the UK. The industry's investment in restoration is uniquely placed to enable the UK to achieve biodiversity targets that will directly safeguard the future of 960 priority species. Case studies, advice and further information can be found at **www.afterminerals.com** and **www.mineralproducts.org**

For more information visit **www.mineralproducts.org**

Cements

'Cement' generally refers to the powder component of concrete which, when mixed with water, becomes the glue-like material, or binder, that allows concrete to set, harden and strengthen. The cement content of concrete is normally in the range from 10-15% by volume.

Clinker and CEM I

Portland cement, or CEM I, is made by grinding clinker, which comes from the cement kiln, together with gypsum to produce a fine powder. Most cements in the UK contain a portion of clinker, and these are the cements on which BS 8500 is based. Cements containing clinker as the key binding ingredient are produced either at the cement factory or at the concrete mixing plant.

Secondary cementitious materials or additions

Secondary cementitious materials (SCMs) are materials that may be used as part of cements. When added at the concrete mixing plant such SCMs are referred to as 'cementitious additions' as they are added to high-clinker CEM I or CEM II/A cements. SCMs may be naturally occurring with minimal processing or may arise from wastes or by-products from other industries. The UK average for cementitious additions across all concretes is approximately 33%.

The following are cementitious materials or additions permitted in BS 8500.

Ground granulated blast-furnace slag (ggbs)

Ggbs (BS EN 15167-1:2006) is a by-product from the manufacture of iron. Molten slag is tapped off from the blast furnace during the production of molten iron. If it is cooled rapidly, the granulated material has latent cementitious properties; i.e. when water is added, it reacts. However, the reaction is very slow but when placed in the alkaline environment created by the clinker component, the reactions are accelerated. The most commonly used proportion of ggbs in UK-produced cements is 50% by mass of total cementitious content.

Fly ash

The majority of fly ash used in the UK is a by-product from the burning of pulverised coal to generate electricity at power stations. When coal is burnt, the resulting fine ash is captured and classified. Fly ash for concrete (BS EN 450-1:2012) has pozzolanic properties and therefore does not react when water is added but does so in the alkaline environment created by the clinker component, where the pozzalanic reactions are initiated. The most commonly used proportion of fly ash in UK cements is 25% by mass of total cementitious content.

Natural pozzolana and natural calcined pozzolana

Some naturally occurring clay materials have pozzolanic properties and react with the clinker component in a similar way to fly ash. An example is natural pozzolana which is a naturally occurring siliceous (or silico-aluminous) material found in volcanic deposits. Furthermore, if these materials are calcined (heated) their reactivity with clinker may be increased, thus reducing setting times and improving early strengths (compared with the non-calcined material). However, unlike fly ash and natural pozzolana, natural calcined pozzolanas are usually limited to 25% of the total cementitious content, as recommended in BS8500-1:2019, due to the pozzolanic inactivity that results at higher addition levels. Specification for the production of these materials as additions for concrete are given in BS 8615-1:2019.

High reactivity natural calcined pozzolana

High reactivity natural calcined pozzolanas (BS 8615-2:2019) such as metakaolin may be used to improve durability while potentially accelerating early setting and strength. For similar reasons to natural calcined pozzolanas, addition levels are restricted to 15-20 % of the total cementitious content.

Silica fume

Silica fume (BS EN 13263-1:2005+A1:2009) is a by-product from the manufacture of silicon. It is an extremely fine powder (as fine as smoke) and therefore it is used in concrete production in either a densified or slurry form. Due to economic considerations, the use of silica fume is generally limited to high strength concretes or concretes in aggressive environmental conditions. Concretes containing silica fume are more liable to spalling in fire and therefore care should be taken with the specification if fire may be an issue. The most commonly used proportion of silica fume in UK cements is 10% by mass of total cementitious content.

Limestone

Limestone is abundantly available and in powdered form it serves as a very effective SCM. Powdered limestone (BS 7979:2016) works particularly well in combination with other SCMs in "multi-component" cements i.e. cements incorporating more than one SCM type. BS 8500 was recently amended to make provisions for limestone-containing multi-component cements in non-aggressive exposure conditions. Wider implementation of limestone containing multi-component cements will be achieved following the completion of a UK validation programme in 2021. In BS 8500, limestone is limited to 20% of the total cementitious content in Portland-limestone cements (i.e. CEM II/A and C II/A cements) and 15% in limestone-containing multi-component cements (CEM II/A-M, CII A-M, CEM II/B-M and CIIB-M cements).

Table 8: Designations of cements and combinations permitted in BS 8500

Broad designation[a,b]	Composition	Cement types (BS 8500)
CEM I	Portland cement	CEM I
SRPC	Sulfate-resisting Portland cement	CEM I, SR0 or SR3
IIA	Portland cement with 6–20% fly ash, ground granulated blastfurnace slag, limestone, or 6–10% silica fume[c]	CEM II/A-L, CEM II/A-LL, CIIA-L, CIIA-LL, CEM II/A-S, CIIA-S, CEM II/A-V, CIIA-V, CEM II/A–D
IIB-S	Portland cement with 21–35% ground granulated blastfurnace slag	CEM II/B-S, CIIB-S
IIB-V	Portland cement with 21–35% fly ash	CEM II/B-V, CIIB-V
IIB-P	Portland cement with 21–35% natural pozzolana	CEM II/B-P, CIIB-P
IIB-Q	Portland cement with 21–35% natural calcined pozzolana or high reactivity natural calcined pozzolana	CEM II/B-Q, CIIB-Q
IIB+SR	Portland cement with 25–35% of either fly ash, natural pozzolana, natural calcined pozzolana or high reactivity natural calcined pozzolana	CEM II/B-V+SR, CIIB-V+SR, CEM II/B-P+SR, CIIB-P+SR, CEM II/B-Q+SR, CIIB-Q+SR
IIA-M	Portland cement with 12–20% limestone in combination with 12–20% of either: ground granulated blastfurnace slag, fly ash, natural pozzolana, natural calcined pozzolana or high reactivity natural calcined pozzolana (and where the mass fraction of Portland cement clinker is not less than 80%)	CEM II/A-M (S-L or LL), CEM II/A-M (L or LL-S), CEM II/A-M (V-L or LL), CEM II/A-M (L or LL-V), CEM II/A-M (P-L or LL), CEM II/A-M (L or LL-P), CEM II/A-M (Q-L or LL), CEM II/A-M (L or LL-Q)
IIB-M	CEM II/A-L or LL in combination with 6–29% of either: ground granulated blastfurnace slag or fly ash (and where the mass fraction of Portland cement clinker is not less than 65%)	CEM II/B-M (S-L or LL), CIIB-M (S-L or LL), CEM II/B-M (L or LL-S), CIIB-M (L or LL-S), CEM II/B-M (V-L or LL), CIIB-M (V-L or LL), CEM II/B-M (L or LL-V), CIIB-M (L or LL-V)
IIIA[d, e]	Portland cement with 36–65% ground granulated blastfurnace slag	CEM III/A, CIIIA
IIIA+SR[e]	Portland cement with 66–80% ground granulated blastfurnace slag with additional requirements that enhance sulfate resistance	CEM III/B+SR[f], CIIIB+SR[f]
IIIB[e, g]	Portland cement with 66–80% ground granulated blastfurnace slag	CEM III/B, CIIIB
IIIB+SR[e]	Portland cement with 66–80% ground granulated blastfurnace slag with additional requirements that enhance sulfate resistance	CEM III/B+SR[f], CIIIB+SR[f]
IVB-V	Portland cement with 36–55% fly ash	CEM IV/B(V), CIVB
IVB-P	Portland cement with 36–55% natural pozzolana	CEM IV/B(P), CIVB-P
IVB-Q	Portland cement with 36–55% of either natural calcined pozzolana or high reactivity natural calcined pozzolana	CEM IV/B(Q), CIVB-Q

Key
- **a** There are a number of cements and combinations not listed in this table that may be specified for certain specialist applications. See BRE Special Digest 1 for the sulfate-resisting characteristics of other cements and combinations.
- **b** The use of these broad designations is sufficient for most applications. Where a more limited range of cement or combinations types is required, select from the notations given in BS 8500–2:2015+A2:2019, Table 1.
- **c** When IIA or IIA–D is specified, CEM I and silica fume may be combined in the concrete mixer using the k-value concept; see BS EN 206:2013, Cl. 5.2.5.2.3.
- **d** Where IIIA is specified, IIIA+SR may be used.
- **e** Inclusive of low early strength option (see BS EN 197–1 and the "L" classes in BS 8500–2:2015+A2:2019, Table A.1).
- **f** "+SR" indicates additional restrictions related to sulfate resistance. See BS 8500–2: 2006, Table 1, footnote D.
- **g** Where IIIB is specified, IIIB+SR may be used.

Designation of cements

Table 1 in BS8500-1:2015+A2:2019 [2] provides details of the cement types recommended for UK structures. For most applications and construction scenarios, BS 8500-1:2015+A2:2019 [2] allows considerable specification flexibility in terms of cement type used. However, BS 8500 does not provide specific guidance on the relative merits of cements in terms of their associated performance and environmental impacts, apart from exposure classes.

In BS 8500, factory-produced cements carry the 'CEM' designation (mirroring the cement types from EN 197-1:2011) whereas cements produced at the concrete plant carry the 'C' designation, replicating the proportions of powder constituents in their corresponding CEM designations. It is well established that CEM and C cements have equivalent performance; however, C cements (those produced at the concrete plant) are required to follow special conformity protocols (described in Annex A of BS 8500-2:2015+A2:2019). C cements use high-clinker CEM I or CEM II/A as base cements in combination with low carbon cementitious additions.

At many ready-mixed concrete plants, producers typically stock CEM I or CEM II/A and one or two cementitious addition types to formulate C cements. When possible and appropriate, specifications should allow flexibility and choice to enable the most appropriate, sustainable and economic additions to be used.

Embodied CO_2 of cements

Cement plays a significant role in the properties of the concrete but, at present, also represents the majority of the embodied CO_2 (ECO_2). The UK cement industry has taken early action on carbon reduction by gradually using fewer fossil fuels. For over 20 years the cement industry has been replacing coal with waste derived fuels including bio-based waste. This fuel switching and the use of mineral by-product and waste has made significant progress in reducing the ECO_2 of cement and means that the UK cement industry hasn't sent any process waste to landfill since 2012. UK cement's production emissions have reduced faster since 1990 than the UK as a whole [14].

The use of waste derived fuels not only diverts waste from landfill and saves on the need for fossil fuels, but can reduce the need for raw materials; for example, the use of waste tyres provides a fuel and minimises the need to add iron-oxide to cement due to the steel wire content of the tyres. The use of the combustion ash from fuels and the other waste material means that on average a tonne of cement contains around 10% recycled content.

Indicative ECO_2 values for the main cementitious constituents of reinforced concrete are provided in Table 10. Published by MPA Cement, UK Quality Ash Association and Cementitious Slag Makers Association [16], and from the British Association of Reinforcement [14], these figures are derived using data from 2017/18 and represent 'cradle to- factory-gate' values as they do not consider transport from place of manufacture to concrete plants.

Table 9: Embodied CO_2 of typical UK Cements

Cement types in BS 8500*		Secondary Main Constituent (smc) or Addition Low – High Content %	Embodied CO_2[c] smc content Low – High, kg CO_2/tonne
Produced at the cement factory	Produced at the concrete mixing plant		
CEM I Portland cement			860
CEM II/A-LL or L Portland limestone cement	**CIIA-LL or L**	6 - 20 limestone	842 - 721
CEM II/A-V Portland fly ash cement	**CIIA-V**	6 - 20 fly ash	825 - 686
CEM II/B-V Portland fly ash cement	**CIIB-V**	21 - 35 fly ash	694 - 555
CEM II/B-S Portland slag cement	**CIIB-S**	21 - 35 ggbs	712 - 585
CEM III/A Blastfurnace cement	**CIIIA**	36 - 65 ggbs	594 - 350
CEM III/B Blastfurnace cement	**CIIIB**	66 - 80 ggbs	359 - 232
CEM IV/B-V Siliceous fly ash cement	**CIVB-V**	36 - 55 fly ash	564 - 381

Notes

a For CEM I 1% minor additional constituent (mac) and 5% gypsum is assumed. For CEM II, CEM III and CEM IV at the highest proportion of the smc it is assumed that no mac is incorporated and at the lowest proportion of smc it is assumed that mac is added at 1% with the appropriate proportions of limestone, fly ash and ggbs.

b For Combinations the CO_2e figure for CEM I is used together with the figures for limestone, fly ash and ggbs in the appropriate proportions.

c CO_2e figures for CEM II, CEM III and CEM IV and their equivalent combinations are based on the range of smc proportion, where the range is from the minimum to maximum proportion of smc or addition. CO_2e can be interpolated for proportions of smc or addition between the minimum and maximum, noting that the minimum CO_2e is associated with the highest proportion of smc or addition.

Table 10: Embodied CO_2 for main constituents of reinforced concrete

Material		Embodied CO_2 (kg / tonne)
Portland cement, CEM I		860
Secondary cementitious materials (SCMs)	Ground granulated blastfurnace slag (ggbs)	79.6
	Fly ash	0.1
	Limestone	8
Aggregate		2.6
Reinforcement		412

The use of cement additions does affect the total amount of cementitious binder; yet any increases are typically small. ECO_2 reductions for a range of typical concrete designation types are shown in Table 11.

Guidance for the specification of cements

Portland Cement clinker is the controlling constituent material in terms of the embodied CO_2 content of concrete. As such, if ECO_2 content is critical for a given structure, close consideration should be given to the concrete's clinker content but within the context of functional design requirements, construction practice and ultimate fitness for purpose.

When specifying concrete to BS 8500-1:2015+A2:2019 [2], there are several strength classes and cement types permitted for selected minimum working lives, exposure classes and nominal covers to normal reinforcement. All of these strength classes and cement types should be considered by the designer.

Giving preference to options with low recommended minimum cement content, and permitted cement types with the highest levels of clinker replacement, will directly reduce ECO_2 values of concrete.

However, consideration also needs to be given to savings in concrete and reinforcement through structural design solutions, the specification of higher strength concrete as well as potential savings in construction timelines. While meeting specified durability requirements, cement contents and types may have a significant impact on associated structural and/or other concrete construction criteria and finishing processes.

As well as giving preference to specific cement types at the specification stage, consideration may be given to attaching preferred minimum levels of SCMs or additions. For cement IIIA, for example, a preferred minimum replacement of cement with ggbs of 50% could be stipulated, but should be discussed with the supplier.

Admixture use should be considered as an effective way of reducing cement content (see page 18). High range water-reducing admixtures (super plasticizers) typically give water reductions of 16% to 30% without loss of consistency or final properties; allowing corresponding reductions in cement content or improved strength for similar cement content.

It is important to note that ECO_2 values for concrete should not be considered or specified in isolation. Adopting holistic approaches to sustainability-related decision-making is always advisable; given the significant impact of cement type and content on a range of key concrete properties and benefits.

Table 11: Effect of cement type on ECO_2 content of designated concretes (cradle to gate).

Concrete	Concrete type (slump class)	ECO_2 ($kgCO_2/m^3$)		
		CEM I concrete	30% fly ash concrete	50% GGBS concrete
Blinding, mass fill, strip footings, mass foundations	GEN1 (S2)	165	120	95
Reinforced foundations	RC25/30 (S2) **	295	245	190
Ground floors	RC28/35 (S2) *	295	245	175
Structural: in-situ, superstructure, walls, basements	RC32/40 (S2) **	345	295	220
Higher strength concrete	RC 40/50 (S2) **	405	330	255
* includes 30 kg/m^3 steel reinforcement ** includes 100 kg/m^3 steel reinforcement				

Guidance for specification

Minimising ECO_2

Recommendation: Specify that concrete should permit a wide range of cements from BS 8500-2: 2019, Table 1

Visual concrete

The surface colour of concrete is dominated by its finest particles, which typically includes cement/combination and sand particles smaller than around 0.06mm. The colour of cement varies according to the materials from which it is manufactured. The incorporation of additions such as fly ash, ggbs and silica fume also has a major influence.

Ggbs is off -white in colour and substantially lighter than Portland Cement. Concretes containing CEM III/B cements are often specified as a more sustainable and economic alternative to white Portland Cement. Fly ash is dark grey in colour, resulting from a combination of iron compounds present and carbon residues left after the coal is burned as part of its manufacturing process; the shade depending on the source of coal and the process plant used.

Where aesthetics are critical, the impact of cement/combination type on concrete colour may dominate considerations of local availability and ECO_2 content.

There are many other sustainability benefits gained by using concrete as a finish. Although visual concrete may have a small cost premium compared to a standard concrete, considerable savings are made when comparing the cost including other materials that only provide the finish. Visual concrete also encourages the exposure of the concrete surface; increasing operational energy savings in buildings from the utilisation of thermal mass.

Precast visual concrete can be specified in collaboration with your precast concrete manufacturer. Coloured concrete can also be produced by adding coloured pigments to the concrete (see *Admixtures*, page 18).

Guidance for specification

Colour

Recommendation: When aesthetics are critical, specify the cement/combination to ensure colour consistency.

The Angel Building, London used a concrete mix containing 40 per cent fly ash replacement, which helped to achieve its dark grey finish. Image courtesy of AHMM Architects.

The Simon Sainsbury Centre, Cambridge used 50% GGBS in the mix for the project's extensive exposed concrete. The building achieved a BREEAM rating of Excellent. Image © Hufton and Crow.

Quick Facts

The cement sector

- Over 75% of the cement used in the UK is produced in the UK.
- In 2018, carbon dioxide emissions per tonne of production from all UK cement manufacturing sites were 29% lower than 1990.
- The UK cement industry is a net consumer of waste. It sends zero waste to landfill and uses 1.4Mt of waste and by-products recycled from other industries [14].
- In 2018, 43% of the UK cement industry's fuel requirement was from waste derived fuels [14]. The sector is also leading a project looking at innovative fuel switching technologies as part of the journey to net zero.

For more information:

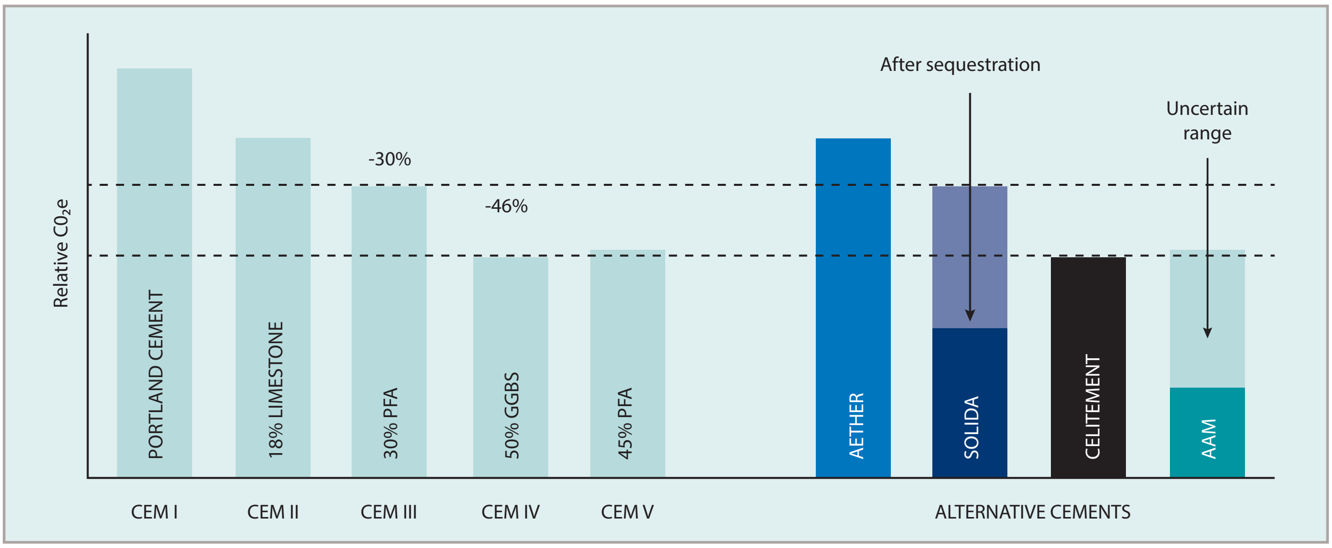
- MPA Cement (**cement.mineralproducts.org**)
- MPA Cement Sustainable Development Report - download at **www.mineralproducts.org/sustainability**
- UK Quality Ash Association (**www.ukqaa.org.uk**)
- Cementitious Slag Makers Association (**www.ukcsma.co.uk**)
- Silica Fume Association (**www.silicafume.org**)

Next-generation cements

The British Standard PAS 8820 has been introduced for alkali-activated materials (AAMs) suitable for use in UK concrete products. Successful trial concrete pours have also provided confidence that existing plant can be used to batch, transport and place novel mixes. Calcium sulfoaluminate cements are now well-established in Europe for specialist applications, although the carbon savings are similar to existing composite cements already widely used in the UK. In the US, Solidia has completed manufacturing trials of concrete pavers formulated with carbon-cured (calcium metasilicate) cement. Celitement (calcium hydrosilicate) in Germany is at the pilot plant production stage with laboratory testing underway.

An available alternative to innovative cements is to save carbon through the more efficient use of cement replacement materials. Recent research has shown that materials such as GGBS, fly ash, calcined clay and powdered limestone can work better in a multi-component cement. Combinations such as cement-GGBS-limestone, cement-fly ash-limestone and cement-calcined clay-limestone potentially enable higher rates of cement replacement. In 2018 MPA initiated a project to develop new low-carbon multi-component cements for UK concrete applications, forming a consortium with Hanson, BRE and Bison Precast. The research and demonstration are part-funded by the government under the £9.2m Industrial Energy Efficiency Accelerator programme. Good progress is being made, with BRE carrying out validation testing of new concretes in which 65% cement replacement has been achieved. On completion of the technical programme, recommendations will be presented to BSI to support standardisation of low-carbon multi-component cements in BS 8500.

Figure 2: Relative carbon dioxide equivalent of common cements vs alternative cements



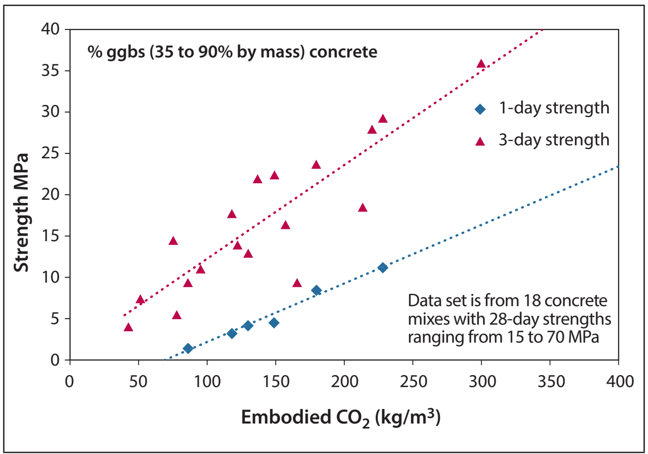
Early strength development

For a given value of 28-day strength, concrete containing additions such as fly ash and ggbs will exhibit lower relative early age strengths than those containing Portland Cement only. This is because concrete's early strength is dependent, primarily, on its Portland Cement content. The table below provides information on strength gain of different concretes.

Table 12: Strength gain of different concretes

Concrete	Strength* at 7 days	Strength* gain from 28 to 90 days
CEM I concrete	80%	5-10%
30% fly ash concrete 50% ggbs concrete	50-60%	10-20%
50% fly ash concrete 70% ggbs concrete	40-50%	15-30%
* Strength as a percentage of 28-day strength These figures are based on standard cure at 20ºC.		

Figure 3: Influence of embodied CO_2 on early strength



Clearly, this relationship could introduce a potential conflict between demands for achieving low concrete ECO_2 values (driven, most likely, by architects, consulting engineers or clients) and the achievement of adequate early strengths to satisfy programming requirements, such as timely formwork removal (driven, most likely, by contractors). Specifications should, therefore, be written to allow flexibility and compromise between conflicting concrete attributes. It may be beneficial to involve the contractor at the earliest stage of specification production to assist in optimising concrete specifications.

It is possible to specify 56 day strength provided this has been considered in the structural design and the construction programme. The use of 56 day strength specification may have an effect on the striking times for suspended slabs and vertical elements. Early discussion with the contractor and concrete producer is advisable.

When early strength is important, some compromise on the level of cement replacement may be needed. In precast factories, rate of production and turnaround of mould may be important. For in-situ concrete, under normal circumstances, the striking times for concretes containing up to 50% ggbs do not increase sufficiently to significantly affect the construction programme. However, concretes with higher levels of ggbs will not always achieve sufficient strength after one day to allow removal of vertical formwork, particularly at lower temperatures, lower cementitious contents and in thinner sections. Generally, high (> 50%) ggbs levels may be less appropriate for soffit applications and thin sections; particularly during winter months unless the slower strength gain and prolonged striking times have been built into the programme .

Water reducing and accelerating admixtures can be added to enhance early strength (see *Admixtures*).

To limit any impact on programming, established methods for more accurately determining in-situ early age concrete strengths and/or formwork striking times are available [17, 18, 19]. These include the use of maturity methods using site-specific or predicted input data; testing of site-cured or temperature-matched test cubes; and penetration, pull-out or break-off tests.

Using maturity methods, it is understood that concrete strength is a function of time between casting and testing and the temperature at which concrete specimens are stored. For a particular concrete, therefore, it is possible to develop a time-temperature relationship to predict maturity and strength. On-site temperature history can be measured using thermocouples or predicted using established models which account for variables such as cement/combination type and content, section size, ambient conditions and formwork materials. Test cubes, match cured at the same temperature as the element poured, can add relevant data to decisions about striking and load transfer times.

Specialist contractors are able to erect in-situ concrete structures, such as framed buildings, conventionally (to programme and budget) using low ECO_2 concrete mixes. Indeed, using the established assessment techniques described above, innovative UK construction teams are presently erecting high rise structures year-round using average to high Portland Cement replacement levels. Further details may be sourced from CONSTRUCT and British Ready Mixed Concrete Association members.

Guidance for specification

Strength

Recommendation: Do not over-specify strength.

Recommendation: Consider the possibility of strength conformity at 56 days rather than the conventional 28 days.

Admixtures

Admixtures are defined in EN 934-2 [20] as 'material added during the mixing process of concrete in a quantity not more than 5% by mass of the cement content of the concrete, to modify the properties of the mix in the fresh and /or hardened state'. In both cases there are potential benefits for the sustainability of concrete.

Admixtures are now an essential component of modern concrete, facilitating environmentally optimised mix design, innovative building design, improved job site placing and enhanced long term durability of the concrete.

Modifications to the fresh concrete can significantly improve the handling and compaction of both site placed and precast concrete production, allowing more efficient and lower energy processes.

In the hardened state admixtures can significantly improve the durability of the concrete to a range of aggressive environments, extending the maintenance free service life. The dosage rates of admixtures are so small that their own ECO_2 is insignificant, but the improvements that admixtures can bring can contribute specifically to a reduction in the ECO_2 of concrete and more widely enhance the sustainability credentials of concrete.

Admixture types

BS EN 934-2 [20] defines admixture types and their associated performance requirements depending on the role the admixture is intended to play in modifying the concrete properties.

Typical dosage rates for and approximate UK usage of admixtures based on 2018 CAA data, are shown in Table 13. Despite the relatively small dosage, the modifications to concrete properties achievable by admixtures can reduce the ECO_2 of concrete, mainly through the more effective use of the cementitious component, while maintaining and even enhancing the properties of the concrete.

In terms of current usage two main types are dominant: water-reducing admixtures (WRA) and high range water-reducing admixtures (HRWRA) also referred to as super-plasticising admixtures, however, other types can make a key contribution to the sustainability of concrete in specific situations such as freeze-thaw and complex exposure conditions.

Table 13: Typical UK use and dosage rates for admixtures [21]

Admixture Type to EN 934-2	Proportion of sales by weight	Average Dosage % by weight of cement
Superplasticisers	48	0.81*
Normal Plasticisers	29	0.50
Accelerating	2	1.36
Retarding	2	0.33
Air Entraining (AEA)	2	0.21
Other concrete admixtures	13	–

Notes:
*Dosage based on 40% solution; some super-plasticizers will be sold at greater dilution with a correspondingly higher dose.

Construction site benefits

Correct placing, compaction and finishing of concrete during construction is vital for quality and long term performance. Admixtures can make a key contribution towards this. For example:

- Plasticisers enable a wide range of concrete consistency right up to self-compacting at different water and cement contents to achieve optimal workability for the placing situation and reduce onsite labour and energy required for compaction.
- Pumping aids reduce the energy for hydraulic pumps where site procedures are enhanced by concrete pumping.
- Admixtures can be used to achieve viable, good quality concrete where there may be less than optimal local materials.
- Accelerating admixtures can reduce curing times and allow for earlier removal of formwork and faster strength development.
- Anti-washout admixtures prevent potential environmental hazards.

Reduced embodied carbon

Water reducing admixtures can contribute significantly to lowering the embodied carbon of concrete by enabling lower cement content and optimisation of alternative cementitious material content.

The Cement Admixtures Association (CAA), **www.admixtures.org.uk**, estimates that, based on normal water reducing admixture use alone in 2018, current admixture use already saves around 420,000 tonnes of ECO_2 per annum and this could be significantly increased by further mix optimisation.

The enhanced control of concrete placing efficiency on site allows reduction in energy use and associated carbon emissions.

Whole life performance and reduced maintenance

Long term durability and low maintenance/replacement are key factors in in concrete being a sustainable material. Structures with concrete using BS 8500 are generally specified to have a 50- or 100-year life, although are often in service longer. Admixtures help optimise performance through:

- Enabling high quality, low permeability concrete
- Ensuring good compaction around and bond with steel reinforcement preserving steel cover and reducing potential for corrosion
- Meeting the requirements for concrete performance in difficult exposure conditions
- Enhancing resistance to freeze-thaw conditions using air entrainers.

Guidance for specification

Admixtures

Recommendation: The use of admixtures by the concrete producer should be permitted in the specification.

Admixtures and improved durability performance

When specifying concrete to BS EN 206 [1] and BS 8500 Parts 1 and 2: 2015, consideration needs to be given to the environmental conditions the concrete will be exposed to. The five main exposure classes defined in BS 8500 are listed below. Each class has several sub-categories depending upon the severity of exposure.

- XC Exposure class for risk of corrosion induced by carbonation
- XD Exposure class for risk of corrosion induced by chlorides other than from sea water
- XS Exposure class for risk of corrosion induced by chlorides from sea water
- XF Exposure classes for freeze/thaw attack
- DC Exposure classes for chemical attack

Depending upon the exposure condition and the cover, BS 8500 gives recommendations for a minimum cement content, maximum water: cement ratio and possible required strength to give the desired design life.

The use of water-reducing or super-plasticizing admixtures enables a given strength and/or water cement ratio to be achieved with lower cement content (subject to achieving the minimum cement content). Thus, the correct use of admixtures can allow concrete to meet the requirements for an exposure class at a lower cement content, reducing the ECO_2 while enhancing long-term performance.

Table 14: Designated concrete for freeze-thaw exposure XF3

Exposure class	Min. Strength class	Max. w/c ratio	Min cement content, kg/m^3	Min. air content	Alternative designated concrete
XF3	C25/30	0.60	280	4.5	PAV1
	C40/50	0.45	340	–	RC40/50XF

The table above indicates how it is possible to meet the requirements for freeze thaw resistance at lower cement contents by the use air entraining agents to provide a controlled and stable air content.

Quick Facts

Admixtures

- The durability, sustainability and environmental profile of concrete can all be enhanced by admixture use.
- Admixtures provide enhanced concrete quality and deliver cost benefits to both the producer and the user.
- A range of technical guidance for admixture types is available including:
  - Normal water reducing/plasticizing admixtures
  - High range water reducing/super-plasticizing admixtures
  - Retardation
  - Acceleration
  - Air-entrainment
  - Water resisting (waterproofing)
  - Corrosion inhibition
  - Polymer dispersion admixtures
  - Pumping aids
  - Self-compacting concrete
  - Precast, semi-dry concrete
  - Anti-washout / underwater admixtures
  - Shrinkage reducing admixtures
  - Truck washwater admixtures

Admixture environmental impacts

All admixtures from UK manufacturers are produced under third party certified ISO 14001 compliant Environmental Management Systems.

The admixture industry has for many years provided detailed information relating to environmental aspects of the production and use of admixtures. More recently, the UK Cement Admixture Association (CAA) has worked in conjunction with the European Federation of Concrete Admixtures (EFCA) to produce generic model Environmental Product Declarations (EPD) independently verified to EN 15804 for a range of admixtures:

- Plasticisers and superplasticisers
- Retarders
- Hardening accelerators
- Set accelerators
- Air entrainers
- Water resisting

These EPDs can be downloaded from the CAA website and in the UK are only applicable to members of the CAA. Further guidance and information on admixtures is available from the Cement Admixtures Association (CAA),
www.admixtures.org.uk

Water

Water is essential to the hydration of cement, which enables it to act as the main binder for concrete. Water management is also an essential part of responsible concrete manufacture, with industry guidance in place for best practice.

It is recognised by specifiers and the concrete industry alike that water needs to be treated as a valuable resource. The concrete industry and its constituent material sectors committed to the MPA Water Strategy in 2017. It is based around three main principles:

- Minimising water consumption
- Prioritising use of the most sustainable water sources available
- Protecting the environment through good water stewardship.

Water extraction and responsible sourcing

Water extraction is an important aspect of responsible sourcing certification to BES 6001[8] (see page 6). To achieve a primary level of performance the organisation must establish a policy and metrics for water extraction in terms of reducing mains water use and the efficient and effective use of 'controlled groundwater'. Controlled groundwater is defined as all water abstracted from boreholes and other surface water features which need an abstraction license known as a 'Full License' in the Water Act 2003. To achieve a higher performance rating in BES 6001 the organisation must demonstrate external verification of the reported data on water extraction.

Embedded water

Concrete's cradle-to-gate water consumption can be found using the 'net freshwater' category as defined in Environmental Product Declarations (EPDs), this is often less than comparative building materials, however any comprehensive comparison should be done at a building level.

For making concrete general suitability is established for water conforming to BS EN 1008: 2002 [22]. This standard gives guidance on mixing water for concrete and the use of water recovered from processes in the concrete industry.

Limitations on use of recovered water include additional mass of solid material (which must be less than 1.0% by mass of the total mass of aggregates present in the concrete) and any impacts on the chemical and physical concrete properties such as setting time and strength.

Wash-water admixtures

Specialist admixtures are available that reduce the waste produced at a ready-mixed concrete plant. At the end of a working day, concrete trucks need to be cleaned to prevent the build-up of hardened concrete in the mixer drum. Traditionally, large quantities of water have been added to the mixer, which has then been spun and the detritus dumped in a settlement pit. An alternative treatment involves incorporating a wash-water stabilising admixture into the drum overnight. The admixture stops the hydration of the main phase of the Portland cement even after initial hydration has started. The following day, the wash-water residue is incorporated into the first delivery of the day. The addition of significant volumes of cementitious material activates the hydration reactions. Alternatively, a special activator can be added to the wash-water. Further guidance is available in the BRMCA guide *Best Practice Managing Concrete Plant Water and Wash Water* [23].

Guidance for specification

Recovered or combined (mixture of recovered and from other sources) water may be used for both un-reinforced and reinforced (including pre-stressed) concrete, and its use should be allowed for at the specification stage.

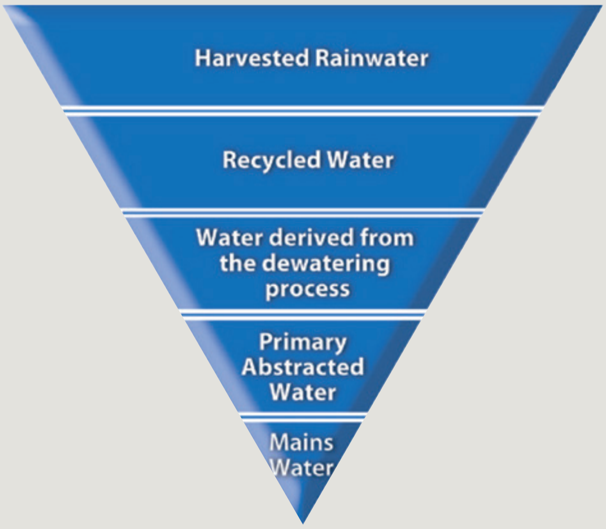
If its use is proposed, its influence should always be considered as there may be special requirements for the production of concrete; for example, air-entrained concrete or concrete exposed to aggressive environments. As recovered water generally contains varying concentrations of very fine particles (typically less than 0.25mm), its use in visual or architectural concrete should also be assessed in detail.

Concrete Industry Sustainable Construction Strategy

Water is important at many stages of concrete production. It is used for washing during the extraction of aggregates, as quenching for GGBS, during the mixing and placing of concrete, for cleaning plant and in dust suppression measures.

The concrete industry strategy is a commitment to meet the aims and objectives of the MPA Water Strategy and reports on mains water consumption and progress and measures to reduce mains water consumption. In 2008, the base year of data collection, the value was 86 litres/tonne (including water used in the supply of raw materials). In 2017, mains water consumption had reduced by 18% to 70 litres/tonne.

Sustainable Water Hierarchy



This has been achieved by using alternative sources such as licensed water abstraction, recycled production water and harvested rainwater. Water reducing admixtures are now used in most types of concrete. Recent developments in high performance water reducers and such innovations as "wash-water admixtures", which allow residues in mixer trucks to be treated and reused, have also contributed. More information and detailed action plans as part of sector Resource Efficiency Action Plans can be found at www.sustainableconcrete.org.uk or directly from British Precast or BRMCA.

Reinforcement

Concrete on its own performs well in compression but not in tension. Steel reinforcement is used to deliver tensile capacity where it is needed. Hence reinforced concrete uses different materials very efficiently. This minimisation of material use is often taken for granted but is a major contributor to sustainability.

About half of all concrete cast in Britain is reinforced. Steel reinforcement should comply with BS 4449: 2005 [24] or BS 4483: 2005 [25] and be cut and bent in accordance with BS 8666: 2005 [26]. Efficient use of reinforcing steel is dependent on good structural design and on the material's chemical composition, mechanical properties and rib geometry, as well as accurate cutting, bending and fixing.

The embodied energy values of reinforcing steel are based on the energy used to melt scrap metal and reform it. Although all steel manufacture is an energy-intensive process, the energy needed to produce one tonne of steel from scrap steel is as low as one third of that needed to make one tonne of steel from iron ore. All the reinforcement made in the UK is made from recycled scrap steel. Equally, reinforcing steel itself can be recovered, recycled and re-used at the end of a building or structure's service life.

Manufacturing of reinforcement steel

There are two common steelmaking processes used for steel in the UK market. These are Basic Oxygen Steelmaking (BOS) and Electric Arc Furnace (EAF) steelmaking. The BOS route is the most widely used steelmaking process worldwide and involves the smelting of iron ore, coal and other raw materials in a two-stage process. The EAF production process involves passing an electric charge through scrap metal, melting it; thus enabling it to be recycled into new products.

The EAF process normally uses approximately 98% scrap metal as the raw material. An EAF furnace generally produces 0.5 to 1.0 million tonnes per annum, making it ideally suited to smaller-scale steel making operations typically used for the manufacture of reinforcing steel. EAF production sites typically include specialised rolling mills producing long products such as reinforcing bar.

All UK produced rebar is sourced from UK recycled scrap metal. This makes up around 65% of rebar used in the UK market. Almost all of the balance is also produced via the Recycled scrap metal (EAF) route.

Guidance for specification

Reinforcement steel

There are two accreditation schemes in the UK for verifying the sustainability credentials of reinforcement. CARES, the certification body for ensuring quality in reinforcement also has the CARES sustainability certification scheme which quantifies the environmental impact of the reinforcement. This scheme complies with BS 8902. Another scheme is the Eco-reinforcement scheme from BAR. This complies with BES 6001. Both schemes provide reassurance that the reinforcement specified will be made using the EAF process from recycled steel and will be responsibly sourced. For more information on the two schemes, visit **https://www.ukcares.com/certification/sustainable-reinforcing-steel** or **http://www.eco-reinforcement.org/**.

It is recommended that all steel reinforcement should be obtained from companies holding a valid CARES certificate of product approval, as well as certification from one of these two sustainability accreditation schemes.

Quick Facts

Reinforcement

- The combination of reinforcement and concrete utilises tensile and compressive qualities respectively: an efficient sustainable solution.
- UK-produced reinforcement uses UK scrap steel.
- UK-produced reinforcement and most of the imported reinforcement uses the low-energy EAF process.

For more information visit: UK CARES (**www.ukcares.com**) and British Association of Reinforcement (**www.uk-bar.org**).

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Everyman Theatre, Liverpool, utilised ground-granulated blast-furnace slag (GGBS) as a cement replacement and was winner of 2014 RIBA Stirling Prize. Image courtesy of Philip Vile.

Further reading

To download or access many of these publications, visit
www.concretecentre.com/publications

Case studies of exemplar, sustainable, concrete projects are listed at
www.concretecentre.com/casestudies

Specific titles from The Concrete Centre that accompany this guide, include:

Concrete and BREEAM

Guidance on how concrete can be used to achieve credits under the latest version of BRE Environmental Assessment Method (BREEAM) UK New Buildings.

Material Efficiency

Provides information on the material and resource efficiency of concrete and masonry at each stage of their manufacture, design, construction and demolition.

Thermal Mass Explained

Introduction to thermal mass and its advantages which will provide a basic working knowledge of its function and how best to use it.

Offsite Concrete Construction

Guidance on the benefits of using offsite concrete construction and delves into details of some of the more common techniques.

Concrete Floor Solutions for Passive and Active Cooling

Details all the various cooling systems currently available, from the simple passive approach to the more sophisticated active systems.

Whole-Life Carbon and Buildings

Focus on how the unique attributes of a concrete building, including its durable structure, which is a fundamental aspect of whole-life performance, can be used to minimise CO_2 emissions.

Concrete and Fire Safety

Explains how concrete construction, which is well suited to the new performance-based fire safety approach, can minimise the impact of fire upon a building.

Additional aids to specification (in more detail)

National Structural Concrete Specification (NSCS) – Edition 4: 2010

Covering three sections – Standard Specification, Project Specification and Guidance – this document assists the project team in the specification of structural concrete and concrete finishes. The fourth edition recognises the latest standard for responsible sourcing, BES 6001, and, in the final section, provides guidance on materials for sustainable construction.

National Building Specification (NBS)

NBS encompasses a range of services provided by RIBA, many via subscription, to assist in the creation of accurate and up-to-date specifications for building projects.

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