Specifying Sustainable Concrete

Understanding the role of constituent materials
Key guidance

Guidance that balances the desire to specify concrete with low environmental impact, whilst ensuring other performance parameters are optimised, can be summarised as follows:

- Do not over-specify strength.
- Consider the possibility of strength conformity at 56 days rather than the conventional 28 days.
- Specify responsibly-sourced concrete and reinforcement.
- Do not specify aggregate sizes below 10mm unless necessary.
- Permit the use of recycled or secondary aggregates but do not over specify.
- Specify that concrete should always contain CEM II/CEM III or an addition.
- Embodied CO₂ (ECO₂) of concrete should not be considered or specified in isolation of other factors such as strength gain.
- Permit the use of admixtures.
- Specify BES 6001 responsibly-sourced concrete and reinforcement to gain maximum credits under BREEAM and the Code for Sustainable Homes.
- The specification of recycled and secondary aggregates is often not the most sustainable option, although it may gain most points. BS 8500 allows producers to use up to 20% of recycled aggregates in concrete, they do this when it is available.
- The BRE Green Guide does not recognise the availability or otherwise of recycled product when incentivising the use of recycled content. Recycled aggregates should only be specified when they are locally available, otherwise transportation impacts exceed benefits. Within the current assessment method, this should be discussed with the client or project code assessor to prevent unfair penalisation.
- Use of cementitious additions can reduce the embodied CO₂ (ECO₂) of concrete and influence its visual appearance. When aesthetics are critical, specify the cement/combination to ensure colour consistency.
- Admixtures can be used to enhance sustainability credentials and reduce the ECO₂ of concrete, as well as modifying its physical properties.
Specifiers are offered five approaches for specifying concrete to BS 8500-1:2006. These are: designated, designed, prescribed, standardized prescribed and proprietary concretes. For structural applications, the most common approaches are designated or designed concretes.

**Designated concretes** were developed to make the specification of designed concretes simpler, complete and more reliable. They do not cover every application or permit use of every potential concreting material but are suitable for a wide range of housing, structural and other construction applications. Designated concretes allow the specifier to specify only the strength, maximum aggregate size and consistence. All other aspects are chosen by the producer. The specifier may specify various additional requirements such as the permitted range of cement and combination types, and any special requirements for aggregates. Recognised designated concretes carry coded appellations; examples include GEN1, RC28/35, PAV1 and FND2.

**Designed concretes** permit flexibility and are suitable for almost all applications. They may be used as an alternative to designated concretes and should be used when the requirements are outside of those covered by designated concretes. When specifying concretes with a focus on embodied carbon, the use of particular cements, combinations and/or recycled or secondary aggregate types is likely to require a designed concrete. For a designed concrete, the specifier must specify strength, allowable cement types and water/cement ratios. Additional requirements may also be specified, such as type and dosage of fibres, air-entrainment or restrictions on the use of certain aggregates.

**Prescribed concretes** allow the specification of the exact composition of the concrete, rather than using the expertise of the concrete producer. The specifier is responsible for initial testing of the concrete. It is not normally necessary to specify a prescribed concrete; except in particular circumstances such as, for example, where a visual concrete with an exposed aggregate finish is required.

**Standardized prescribed concretes** are used for small construction sites conducting small-scale site batching. They are unsuitable for situations in which strength is important.

**Proprietary concretes** are developed by the concrete producer and marketed as a proprietary product. The producer does not have to disclose the composition of the concrete but does have to confirm that any performance requirements are met by the concrete and provide relevant test data when requested.

For more information on specifying to BS 8500, refer to *How to Specify Concrete for Civil Engineering Structures using BS 8500* or, for buildings, an equivalent document *How to Design Concrete Structures to Eurocode 2*, both published by The Concrete Centre.

The information below relates to specification of concrete to BS 8500:2006 *Concrete, Complementary British Standard to BS EN 206-1, Specification for constituent materials and concrete*. When bespoke and proprietary concrete products are specified, the designer should work directly with the product manufacturer to agree a concrete mix specification.
Concrete and masonry are building materials that steadily absorb any heat that comes into contact with surfaces. The heat is conducted inwardly, and stored until the surface is exposed to cooler conditions and its temperature begins to drop. When this occurs, any heat begins to migrate back to the cooler surface and be released. In this way, heat moves in a wave-like motion, alternately being absorbed and released in response to the variation in day and night-time conditions. Exploiting thermal mass on a year-round basis is not difficult, but does require consideration at the outset of the design process when requirements for the building form, fabric and orientation are being established. This guide explains what thermal mass is, and how best to utilise it.

- **Publication date:** 2009
- **Ref:** TCC/05/11

**Concrete and Fire Safety**

Building owners, occupiers and insurance companies are increasingly asking for more than the minimum fire resistance as specified by the Building Regulations. Of particular concern is the need for a burning building to provide a level of structural integrity that goes beyond the means of escape times required by the Building Regulations. It is a concern that is also shared by fire fighters. This report 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.

- **Publication date:** 2008
- **Ref:** TCC/03/43

**Concrete and Flooding**

This publication aims to give designers an understanding of the issues of flooding, how to assess the risk, how to design appropriately and how to specify the correct materials to meet the challenge. It provides a background to the causes of flooding, the regulatory and government drivers that influence design and construction in flood risk areas and examines the concrete solutions to flood avoidance, resistance and resilience.

- **Publication date:** 2010
- **Ref:** TCC/05/19

**Material Efficiency**

Minimising the production of waste is an important factor in material resource efficiency. The concrete industry is a net user of waste, diverting significant amounts of waste from potential landfill and reducing depletion of natural resources. Designers can use concrete in ways that reduce waste during the construction and operation of buildings thereby achieving material efficiency.

- **Publication date:** 2010
- **Ref:** TCC/05/21

**Concrete Credentials: Sustainability**

Concrete is the robust construction material that provides a vital resource in the development of sustainable solutions. The UK is almost completely self-sufficient in concrete and the constituent materials needed for its manufacture, which makes it, both economically and environmentally, an option for any project. The tables within this document present the performance benefits of concrete that designers can utilise to create sustainable projects and sustainability credentials of concrete products and their constituent materials.

- **Publication date:** 2008
- **Ref:** TCC/03/43

**Concrete and the Green Guide**

The Green Guide is a tool for assessing some of the embodied impacts of construction elements as part of an overall environmental or sustainability assessment for a project or development. This publication is to assist designers to specify concrete in conjunction with the Green Guide to Specification. It highlights the guide’s relevance in the context of whole-life performance and sustainable design, SAP, the Code for Sustainable Homes and other sustainability assessment tools, including BREEAM for high-rise domestic and commercial buildings.

- **Publication date:** 2009
- **Ref:** TCC/05/17

**How to achieve good acoustic performance in masonry homes**

This guide provides information relating to the acoustic design of attached masonry homes, and will assist home builders, developers, architects and specifiers in improving sound insulation and achieving good levels of acoustic performance in attached houses and apartments.

- **Publication date:** 2010
- **Ref:** TCC/04/10
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Introduction

Concrete's role in delivering a sustainable built environment through the performance benefits of durability, robustness, fire resistance, thermal mass, acoustic performance and flood resilience – together with a reduced need for finishes – is increasingly recognised and utilised by design teams in the delivery of the most sustainable projects.

Concrete is a versatile and natural material and designers can use it efficiently to deliver structure and other functions of integrated designs. In addition, concrete and its constituents have strong sustainability credentials; for example, they are local to the UK and many have been certificated to the highest responsible sourcing standards. These factors are resulting in designers choosing concrete on sustainability grounds alone.

Sustainability is now widely accepted as comprising economic, social and environmental issues. Many assessment tools and methodologies have been developed to provide measures and comparison tools. The shortcoming of generalised tools is that - by definition - they are general, and specific geographical or project constraints are not accounted for.

A challenge for all assessments is weighting the different factors which often have different units of measurement; for example, how does one compare biodiversity, health and safety and transportation CO₂ emissions? Therefore it is useful 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.

The increasing desire to specify 'sustainable' concrete adds a requirement that is not directly covered in the European standard for concrete, BS EN 206-1 or its UK Complementary Standard, BS 8500. Consequently this document aims to provide guidance over and above concrete codes, 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 affect overall environmental impacts, as well as other sustainability issues.

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 including admixtures and how the variation of the specification can influence the sustainability performance of the concrete. Sustainable credentials with greatest scope for influence through specification include: the performance of fresh and hardened concrete (e.g. strength gain, durability); embodied CO₂ (ECO₂); CO₂ associated with transportation; responsible sourcing or otherwise; and use of recycled or secondary materials.

Aspects of sustainability, outside the scope of this document, are addressed in other publications. Readers should refer to www.concretecentre.com/publications for titles including: Material Efficiency, Concrete and Fire Safety, Concrete and the Green Guide, Concrete Credentials: Sustainability and Thermal Mass Explained.
Responsible sourcing of materials

Responsible sourcing is an increasingly important factor for specifiers and clients in the construction industry. The UK government’s published strategy for sustainable construction [1] established a target that 25% of products used in construction projects should be sourced from schemes recognised for responsible sourcing by 2012. The concrete industry has responded to this challenge and, by 2010, had exceeded the Government target. For a list of products with responsible sourcing certification, see www.greenbooklive.com.

BES 6001 – Framework Standard for the Responsible Sourcing of Construction Products

The development of the BRE responsible sourcing standard, BES 6001[2] provides a benchmark to compare responsible sourcing performance for all construction products on an equal basis and should provide a single criterion for responsible sourcing performance within future updates to assessment schemes such as BREEAM.

BES 6001 was launched in October 2008 to integrate all of the activities associated with responsible sourcing, from the point at which a material is mined or harvested in its raw state through manufacture and processing; together with a delivery mechanism using certified management systems.

The responsible sourcing standard encompasses social, economic and environmental dimensions and addresses aspects such as stakeholder engagement, labour practices and the management of supply chains upstream of the manufacturer. Figure 1 shows activities in the supply chain which are addressed by this standard.

Accreditation to BES 6001 enables products to gain credits under BREEAM schemes, the Code for Sustainable Homes and CEEQUAL, (the assessment and awards scheme for improving sustainability in civil engineering and public realm projects).

The concrete industry has committed to leadership in the responsible sourcing of materials; 81% of concrete in the UK was responsibly sourced to BES 6001, based on 2009 production.
Concrete was the first construction industry to issue a guidance document [3] supporting compliance with the standard, resulting in the widespread accreditation of concrete products to BES 6001. This is, in part, because the concrete industry is able to 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 management and environmental management are also reflected.

The requirements of BES 6001 are consistent with commitments to the concrete industry’s sustainable construction strategy. The strategy (launched in 2008) sets the vision that, by 2012, the UK concrete industry will be recognised as the leader in sustainable construction; taking a dynamic role in delivering a sustainable built environment in a manner that is profitable, socially responsible and functions within environmental limits. As a key part of the strategy, the concrete industry published its first sustainability report [4] in March 2009. This annual report is a vehicle for demonstrating active sustainable management across concrete manufacture and its supply chain, and the latest report can be downloaded from www.sustainableconcrete.org.uk.

Many concrete and reinforcement products have achieved accreditation to BES 6001, and the specification of accredited product enables designers to easily source certified materials and help gain maximum credits in sustainability assessment tools such as the Code for Sustainable Homes and BREEAM.

The British Standards Institution has also published a framework standard for responsible sourcing, BS 8902:2009 [5], which supports the development of sector based schemes. While it provides a similar scope to BES 6001, it does not contain specific performance requirements. The concrete industry is supporting BES 6001 responsible sourcing standard as it is the most comprehensive standard available and measures the whole infrastructure of the supply chain.

Guidance for specification

**Responsible sourcing**

Recommendation: Specify BES 6001 responsibly sourced concrete and reinforcement.

Quick Facts:

Responsible sourcing

- Responsible sourcing is a holistic approach to the sustainable assessment of materials.
- Responsible sourcing of materials (RSM) 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.
- The concrete industry is the first to link its sustainable construction strategy to BES 6001.
- Eco-reinforcement is the certification scheme for responsibly sourced reinforcement steel to the standard BES 6001. www.eco-reinforcement.org.

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

- A responsible sourcing policy and comply with all relevant legislation.
- A quality management system that must follow the principles of ISO 9001.
- Have a greenhouse gas reduction policy and measures that comply with ISO 16064-1.
- Have policies that cover the efficient use of resources.
- Demonstrate that at least 60% of its constituent raw materials are fully traceable through its quality management system. This increases to 90% in order to achieve the highest performance in this area.
- Demonstrate that the supply chain has document environmental management systems that comply with ISO 14001.
- Demonstrate that the supply chain has documented Health and Safety system that are compliant with local legislation and record incidents.

For more information download the Concrete Industry Guidance to Support BES 6001 from www.sustainableconcrete.org.uk.
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 CO₂ emissions.

The standard BS EN 12620:2002 – Aggregates for concrete [6] 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.

In addition to natural aggregates, suitable materials for use in concrete include recycled aggregate (RA), recycled concrete aggregate (RCA), blast furnace and zinc slag, foundry sand, slate aggregate and china clay sand or 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.

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 ECO₂. 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.

Recycled aggregates

BS 8500 permits the use of coarse RA and RCA 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 RCA principally comprises crushed concrete.

Provisions for the use of fine RCA 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, significant quantities of deleterious materials are not present and their use has been agreed.

Constraining factors for the use of RCA include consistency of supply and original source. Due to their inherent variability, testing regimes for quality control of the aggregates may need to be more rigorous than for natural/primary aggregates.
Secondary and manufactured 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 metallurgical 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 12620:2004 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

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 CO₂ impacts and implications on 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 contents.

As an example, the limiting mix design requirements for designated concretes are given in BS 8500-2: 2006 (Table 5, p14). It should be noted that each designation class is assigned minimum cement contents (kg/m³) 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/m³ respectively. Where possible, therefore, reduced ECO₂ levels will be achievable by specifying increasing maximum aggregate sizes. It should be noted that most plants and factories do not stock aggregate sizes greater than 20mm.

Guidance for specification

Aggregate size
Recommendation: Do not specify aggregate sizes below 10mm unless necessary.
Transportation impact from the utilisation 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 [7]. In 2009, the Mineral Products Association reported the use of 56.5 million tonnes of recycled and secondary aggregates, representing 28% of the aggregate market. This level of performance is a real success story; the UK leads mainland Europe by a factor of three.

Given that recycling is already efficiently undertaken, primary aggregate extraction is unlikely to be reduced by further encouragement of use of recycled aggregates on particular concrete projects. Instead, overly prescriptive specifications will result in recycled aggregates being moved from one place to another, which is likely to be less environmentally-friendly than using primary aggregates. There will be no net reduction in primary aggregate use; just increased transportation of material.

The impact of this is illustrated in Table 3, which provides indicative ECO₂ values for the extraction and production of virgin and recycled aggregates, as well as their delivery to site. Table 3 demonstrates that ECO₂ values for recycled aggregates may be higher than for virgin materials if delivery distances are longer than around 15km (10 miles). Furthermore, as recycling rates are so high, no benefits in terms of resource depletion will have been achieved.

Table 3: Indicative CO₂ for virgin and recycled aggregates

<table>
<thead>
<tr>
<th>Material and delivery distance</th>
<th>Cradle to gate kg CO₂/tonne</th>
<th>Transport kg CO₂/tonne</th>
<th>Total kg CO₂/tonne</th>
<th>+/- % CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin aggregates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+58.5km (delivery and return distance by road)</td>
<td>6.6</td>
<td>2.7</td>
<td>9.3</td>
<td>–</td>
</tr>
<tr>
<td>Recycled C&amp;D aggregates compared to the use of virgin aggregates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Used on-site, 0 km transport</td>
<td>7.9</td>
<td>0.0</td>
<td>7.9</td>
<td>–15%</td>
</tr>
<tr>
<td>+5km (delivery distance by road)</td>
<td>7.9</td>
<td>0.5</td>
<td>8.4</td>
<td>–10%</td>
</tr>
<tr>
<td>+10km (delivery distance by road)</td>
<td>7.9</td>
<td>0.9</td>
<td>8.8</td>
<td>–5%</td>
</tr>
<tr>
<td>+15km (delivery distance by road)</td>
<td>7.9</td>
<td>1.4</td>
<td>9.3</td>
<td>0%</td>
</tr>
<tr>
<td>+20km (delivery distance by road)</td>
<td>7.9</td>
<td>1.8</td>
<td>9.7</td>
<td>5%</td>
</tr>
<tr>
<td>+58.5km (delivery and return distance by road)</td>
<td>7.9</td>
<td>2.7</td>
<td>10.6</td>
<td>14%</td>
</tr>
</tbody>
</table>

* C&D - Construction and Demolition

Guidance for specification

Specification of natural aggregates
Recommendation: Specification of natural aggregates, which may be delivered to site with up to 20% of recycled content, as allowed under BS 8500, is a practical alternative to 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).

Green Guide to Specification and Specification of Aggregates for Concrete

The Green Guide to Specification is a component of the Code for Sustainable Homes and BREEAM, within the materials section. It gives a large reward for the use of recycled aggregates but the methodology doesn’t acknowledge that aggregates are plentiful in the UK and available recycled aggregate stocks are being used in other non-concrete applications. It is based on the principle that extraction of a certain tonnage of material has the same impact whether it is abundant or scarce [8].

This contradicts standards being developed at European and international level to provide common approaches to quantifying material environmental credentials. For instance, there is a strong view that mineral depletion should take account of the rate of depletion (i.e. volumes used in relation to the size of reserves).


Guidance for specification

Use of recycled aggregate
Recommendation: The current Green Guide does not recognise the volumes of unused and available recycled product when incentivising the use of recycled content. Therefore, recycled aggregates should only be specified when they are locally available, and can be demonstrated to reduce ECO₂. Within the current assessment method, discussion with the client or project code assessor is recommended to prevent unfair penalisation.
CASE STUDY

**White River Place, St Austell**

‘Excellent’ BREEAM rating

This £75 million scheme, which involved the renovation of a brownfield site into a stimulating town centre for St Austell, features a mix of uses including retail, catering, cinema and a 550 space car park.

The cement addition, ggbs (see page 10) was used to reduce the ECO₂ of the concrete. Local materials, including bricks from neighbouring Devon and concrete blocks sourced from St Austell were used. Slightly damaged blocks were used for areas of the building where finishes allowed, saving some 60 skips worth of construction waste.

Responsible sourcing was also important – sub-contractors and suppliers were required to provide the environmental credentials of materials used.

For more information on BREEAM visit [www.concretecentre.com](http://www.concretecentre.com).

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CASE STUDY

**Tarmac House, Nottingham**

Code for Sustainable Homes – level 6

The Tarmac Homes project, a test-bed initiative led by Tarmac, affordable housing developer Lovell and The University of Nottingham’s Department of the Built Environment, has built two landmark homes – one to level 4 and the other to level 6 of the Code for Sustainable Homes.

Both properties are traditional, semi-detached homes built using concrete and masonry to maximise their thermal efficiency. The project, which also tested the commercial viability of building low and zero-carbon homes, provides the housing industry with an indication of the current costs to meet the Government’s residential carbon reduction targets.

For more information on the Code for Sustainable Homes, visit [www.concretecentre.com](http://www.concretecentre.com).

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CASE STUDY

**Underhill House, Cotswolds**

First UK PassivHaus

Underhill House, in the heart of the Cotswolds, is the first in England to be certified to PassivHaus standards. One of the key sustainability elements which led to successful PassivHaus certification was the entirely concrete structure. Concrete brings many benefits to the passive eco design in the exploitation of its thermal mass and the formation of a monolithic structure which is naturally airtight. The use of precast concrete delivers the benefits of off-site construction including reduced wastage but also achieves an excellent finish, which is exposed throughout.

For more information on PassivHaus and other sustainability schemes, visit [www.concretecentre.com](http://www.concretecentre.com).
The cementitious component of concrete represents the majority of the embodied CO₂ (ECO₂) of concrete. ECO₂ is the carbon emissions associated with the production and manufacture of a product (cradle to gate). The UK cement industry, through the implementation of a range of measures – including using waste-derived fuel and incorporating mineral additions - has made significant progress in reducing the ECO₂ of cement.

Cementitious additions

A number of by-products from other industries can be blended with Portland Cement (CEM I) which can improve performance but also increase the recycled content and reduce the ECO₂ content of the concrete. The use of these secondary materials utilises material which might otherwise be disposed in landfill.

There is a long track record of using the following cementitious additions with CEM I. The UK average across all concretes is approximately 18% with the permitted percentage use of each given in Table 4.

Ground granulated blastfurnace slag (ggbs)

Ggb 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 hydraulic properties; i.e. when water is added, it reacts very slowly but when placed in the alkaline environment created by CEM I, the reactions are accelerated. The most commonly used proportion of ggb in UK-produced combinations 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. It has pozzolanic properties and therefore does not react when water is added but when placed in the alkaline environment created by CEM I, the pozzalanic reactions are initiated. The most commonly used proportion of fly ash in UK-produced combinations is 25% by mass of total cementitious content.

Silica fume

Silica fume 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. The most commonly used proportion of silica fume in UK-produced combinations is 10% by mass of total cementitious content.

Limestone fines

Limestone fines can be used as a constituent of cement to produce Portland limestone cement. BS 7979 provides additional information on the specification of limestone fines for use with Portland cement. The most commonly used proportions of limestone fines in UK-produced combinations is 6-10% by mass of total cementitious content.

Designation of cements

Table A.6 in BS 8500–1:2006 provides details of the cement and combination types recommended for UK structures. For most applications and construction scenarios, BS 8500–1:2006 allows considerable specification flexibility in terms of cement or combination type used. However BS 8500 does not provide specific guidance on the relative merits of cements/combinations in terms of their associated performance and environmental impacts, apart from exposure classes.

Table 4: Cement and combination types from BS 8500

<table>
<thead>
<tr>
<th>Broad designationa,b</th>
<th>Composition</th>
<th>Cement/combination types (BS 8500)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I</td>
<td>Portland cement</td>
<td>CEM I</td>
</tr>
<tr>
<td>SRPC*</td>
<td>Sulfate-resisting Portland cement</td>
<td>SRPC</td>
</tr>
<tr>
<td>II A</td>
<td>Portland cement with 6–20% fly ash, ground granulated blastfurnace slag, limestone, or 6–10% silica fume</td>
<td>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</td>
</tr>
<tr>
<td>II B–S</td>
<td>Portland cement with 21–35% ground granulated blastfurnace slag</td>
<td>CEM II/B-S, CIIB-S</td>
</tr>
<tr>
<td>II B-V</td>
<td>Portland cement with 21–35% fly ash</td>
<td>CEM II/B-V, CIIB-V</td>
</tr>
<tr>
<td>II B+SR</td>
<td>Portland cement with 25–35% fly ash</td>
<td>CEM II/B+SR, CIIB-V+SR</td>
</tr>
<tr>
<td>II A+C</td>
<td>Portland cement with 36–65% ground granulated blastfurnace slag</td>
<td>CEM III/A, CIIA</td>
</tr>
<tr>
<td>II A+SR*</td>
<td>Portland cement with 36–65% ground granulated blastfurnace slag with additional requirements that enhance sulfate resistance</td>
<td>CEM III/A+SR, CIIA+SR</td>
</tr>
<tr>
<td>II B+C</td>
<td>Portland cement with 66–80% ground granulated blastfurnace slag</td>
<td>CEM III/B, CIIB</td>
</tr>
<tr>
<td>II B+SR*</td>
<td>Portland cement with 66–80% ground granulated blastfurnace slag with additional requirements that enhance sulfate resistance</td>
<td>CEM III/B+SR, CIIB+SR</td>
</tr>
<tr>
<td>IV B–V</td>
<td>Portland cement with 36–55% fly ash</td>
<td>CEM IV/B(V), CIVB</td>
</tr>
</tbody>
</table>

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 12 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: 2006, Table A.1.

c When II A or II A–D is specified, CEM I and silica fume may be combined in the concrete mixer using the k-value concept; see BS EN 206–1:2000, Cl. 5.2.5.2.3.

d Where IIA is specified, IIA+SR may be used.

e Inclusive of low early strength option (see BS EN 197–4 and the "L" classes in BS 8500–2: 2006, Table A.1).

f "+SR" indicates additional restrictions related to sulfate resistance. See BS 8500–2: 2006, Table 1, footnote D.

g Where III B is specified, III B+SR may be used.

* SRPC is no longer manufactured in the UK.
The designation CEM refers to materials produced at a cement factory as a single powder (e.g., CEM III/A, a composite of ggbs and CEM I). Within the UK, it is common practice for the concrete producer to purchase separate powders and blend them at the mixer to produce the required cement. These are called combinations (designated ‘C’) and are recognised to have equivalent performance to factory-made composite cements.

Fly ash and ggbs are widely available in the UK, and transport distances from the point of production to the point of use are similar to that for Portland cement. At ready-mixed concrete plants, producers typically stock Portland cement and either ggbs or fly ash. Limestone fines and silica fume may be available in some ready-mixed concrete plants, or be made available given sufficient notice but may not be available at all locations.

When possible and appropriate, prepare specifications that allow flexibility and choice to enable the most appropriate and economic additions to be used.

### Values of embodied CO₂

Indicative ECO₂ values for the main cementitious constituents of reinforced concrete are provided in Table 5. Published by MPA – Cement, UK Quality Ash Association and Cementitious Slag Makers Association, these figures are derived using data for the calendar year 2007 and represent ‘cradle-to-factory-gate’ values as they do not consider transport from place of manufacture to concrete plants.

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied CO₂ (kg / tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland cement, CEM I</td>
<td>930</td>
</tr>
<tr>
<td>Addition or cement constituent</td>
<td></td>
</tr>
<tr>
<td>Ground granulated blastfurnace slag (ggbs)</td>
<td>52</td>
</tr>
<tr>
<td>Fly ash</td>
<td>4</td>
</tr>
<tr>
<td>Limestone</td>
<td>32</td>
</tr>
<tr>
<td>Minor additional constituent</td>
<td>32</td>
</tr>
<tr>
<td>Aggregate</td>
<td>4</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>427</td>
</tr>
</tbody>
</table>

Table 5: Embodied CO₂ for main constituents of reinforced concrete

Corresponding ECO₂ values for factory-made composite cements and combination types are presented in Table 6. The ranges presented are clearly a function of both the ECO₂ value of the individual materials and their permitted levels of use. The values range from 930kg per tonne (CEM I) to as low as 230kg per tonne (CEM III/B; 80% ggbs content).

<table>
<thead>
<tr>
<th>Cementa Factory made cement</th>
<th>Combinationb CEM I and addition combined at concrete plant</th>
<th>Secondary Main Constituent (smc) or Addition</th>
<th>Low – High Content %</th>
<th>Embodied CO₂ c smc content Low – High, kg CO₂/tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I</td>
<td>Portland cement</td>
<td>CIIA-LL or L</td>
<td>6 - 20 limestone</td>
<td>880 - 750</td>
</tr>
<tr>
<td>CEM II/A-LL or L</td>
<td>Portland limestone cement</td>
<td>CIIA-V</td>
<td>6 - 20 fly ash</td>
<td>870 - 750</td>
</tr>
<tr>
<td>CEM II/A-V</td>
<td>Portland fly ash cement</td>
<td>CIIB-V</td>
<td>21 - 35 fly ash</td>
<td>730 - 610</td>
</tr>
<tr>
<td>CEM II/B-V</td>
<td>Portland fly ash cement</td>
<td>CIIB-S</td>
<td>21 - 35 ggbs</td>
<td>740 - 620</td>
</tr>
<tr>
<td>CEM III/A</td>
<td>Blast furnace cement</td>
<td>CIIA</td>
<td>36 - 65 ggbs</td>
<td>610 - 360</td>
</tr>
<tr>
<td>CEM III/B</td>
<td>Blast furnace cement</td>
<td>CIIIB</td>
<td>66 - 80 ggbs</td>
<td>340 - 230</td>
</tr>
<tr>
<td>CEM IV/B-V</td>
<td>Siliceous fly ash cement</td>
<td>CIVB-V</td>
<td>36 - 55 fly ash</td>
<td>590 - 420</td>
</tr>
</tbody>
</table>

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 ECO₂ figure for CEM I is used together with the figures for limestone, fly ash and ggbs in the appropriate proportions.

c ECO₂ 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. ECO₂ can be interpolated for proportions of smc or addition between the minimum and maximum, noting that the minimum ECO₂ is associated with the highest proportion of smc or addition.
The use of cement additions does affect the total amount of cementitious binder; yet any increases are typically small. ECO2 reductions for a range of typical concrete designation types are shown in Table 7.

### Table 7: Effect of cement type on ECO2 content of designated concretes

<table>
<thead>
<tr>
<th>Concrete type</th>
<th>Concrete type</th>
<th>ECO2 (kgCO2/m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CEM I concrete</td>
<td>30% fly ash concrete</td>
</tr>
<tr>
<td>Blinding, mass fill, strip footings, mass foundations</td>
<td>GEN1 70 mm</td>
<td>173 124 98</td>
</tr>
<tr>
<td>Trench foundations</td>
<td>GEN1 120 mm*</td>
<td>184 142 109</td>
</tr>
<tr>
<td>Reinforced foundations</td>
<td>RC30 70 mm**</td>
<td>318 266 201</td>
</tr>
<tr>
<td>Ground floors</td>
<td>RC35 70 mm***</td>
<td>315 261 187</td>
</tr>
<tr>
<td>Structural: in-situ, superstructure, walls, basements</td>
<td>RC40 70 mm***</td>
<td>372 317 236</td>
</tr>
<tr>
<td>High strength concrete</td>
<td>RC50 70 mm***</td>
<td>436 356 275</td>
</tr>
</tbody>
</table>

* includes 25 kg/m3 steel reinforcement  
** includes 30 kg/m3 steel reinforcement  
*** includes 100 kg/m3 steel reinforcement

Guidance for the specification of cements

Portland cement or CEM I is the controlling constituent material in terms of the embodied carbon dioxide content of concrete. As such, if ECO2 content is critical for a given structure, close consideration should be given to the concrete's CEM I content but within the context of functional design requirements, construction practice and ultimate fitness for purpose.

When specifying concrete to BS 8500-1:2006, there are several strength classes and cement/combination 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/combination types with the highest levels of Portland cement replacement, will directly reduce ECO2 values of concrete. However, consideration also needs to be given to savings in concrete and reinforcement through the specification of higher strength concrete.

While meeting required durability requirements, cement/combination 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/combination types at the specification stage, consideration may be given to attaching preferred minimum levels of addition. For cement/combination type 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/combination content. 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/combination content.

It is important to note that ECO2 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/combination type and content on a range of key concrete properties and benefits.

### Total cementitious content and the use of additions

The use of cement additions affects the total amount of cementitious binder. Although any increases are typically small, designers should be aware of these differences when assessing relative ECO2 values for concrete.

Generally speaking, mass for mass replacement of cement with fly ash or ggbs may result in reduced 28-day strengths, particularly at higher replacement levels. As such, in order to achieve the specified characteristic strength, the total cement/combination type may often be higher for concrete containing additions.

For concrete containing 40% fly ash, the total cement/combination content may be around 15% higher than a reference concrete containing CEM I only. Ggbs concretes typically require cement/combination content increases up to replacement levels of 50% of 5-10kg/m3; at higher percentages the cementitious content may need to be increased further to achieve equivalent 28-day strength. Where practical, the characteristic strength can be specified to be achieved at a later age. Concrete producers can provide details for specific concrete specifications.

### Concrete surface colour and the use of additions

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 Portland 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 ECO₂ 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 effect of thermal mass.

Precast visual concrete can be specified in collaboration with your precast concrete manufacturer. For more information on specifying visual concrete, see page 21.

Coloured concrete can also be produced by adding a colouring agent to the mix (see Admixtures).

Guidance for specification

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

Quick Facts:

**The cement sector**

- The UK produces 95% of its Portland cement and cementitious additions requirement.
- The cement industry is a net consumer of waste, using waste as a fuel source and by-products from other industries as cementitious additions.
- Waste-derived fuels used by the cement industry include solvents, meat and bone meal, sewage sludge, paper and plastics. Overall, 35.1% of the UK cement industry’s fuel requirement in 2009 was met by alternative fuels [4].
- In 2009, absolute emissions of CO₂ from the UK cement industry were 58% lower than in 1990 [4].

For more information visit
MPA – Cement (www.mineralproducts.org)
UK Quality Ash Association (www.ukqaa.org.uk)
Cementitious Slag Makers Association (www.ukcsma.co.uk)
Silica Fume Association (www.silicafume.org)
Specifying Sustainable Concrete

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 8: Strength gain of different concretes

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Strength* at 7 days</th>
<th>Strength* gain from 28 to 90 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I concrete</td>
<td>80%</td>
<td>5-10%</td>
</tr>
<tr>
<td>30% fly ash concrete</td>
<td>50-60%</td>
<td>10-20%</td>
</tr>
<tr>
<td>50% ggbs concrete</td>
<td>50-60%</td>
<td>10-20%</td>
</tr>
<tr>
<td>50% fly ash concrete</td>
<td>40-50%</td>
<td>15-30%</td>
</tr>
<tr>
<td>70% ggbs concrete</td>
<td>40-50%</td>
<td>15-30%</td>
</tr>
</tbody>
</table>

* Strength as a percentage of 28-day strength

Clearly, this relationship introduces a potential conflict between demands for achieving low concrete ECO₂ 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.

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 are not appropriate for soffit applications and thin sections; particularly during winter months unless the slower strength gain and prolonged striking times can be accommodated in the programme.

Water reducing and accelerating admixtures can be added to accelerate early strength gain (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 [9, 10, 11]. 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.

In terms of maturity methods, for example, 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 ECO₂ 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.
CASE STUDY
The Angel Building

Throughout the building the exposed concrete is of a very high quality finish. A self-compacting concrete containing 36 per cent fly ash was specified in order to eliminate the need for traditional methods of compaction such as vibrating poker units. This reduced the potential for blemishes and honeycombing and improved the workability around difficult interfaces and cast-in elements. Fair faced concrete was used for the new core lobby areas, the entrance hall and atrium and the consistent quality finish is of an even light grey that features the tie-bolt holes and pour lines as aesthetic points of interest.

The retained concrete frame is wrapped with a highly-efficient glazed skin. The bespoke curtain walling works together with the exposed thermal mass of the concrete to passively control the internal environment and has contributed to the building’s ‘Excellent’ BREEAM rating. Sunlight glare and solar heat gain are reduced by fritting on the glass above eye level. The curtain wall includes opening windows that allow occupants direct control of natural ventilation.

CASE STUDY
The Shard

The Shard in London will be the UK’s tallest building. An innovative approach was used on this project to allow construction above and below ground to start simultaneously. The core had already reached 21 storeys high by the time that 700 truckloads of concrete were poured into the basement to form the 3m deep raft foundation upon which the tower will sit. Carried out over 36 hours, the 5,500m³ single concrete pour is one of the largest ever undertaken in the UK.

The C35/45 concrete contains a cement blend using 70 per cent ground granulated blastfurnace slag (ggbfs) to limit early heat gain. This high level of cement replacement has the potential disadvantage of low early strength gain. This was overcome by developing the concrete so that it would achieve sufficient strength gain to meet initial structural requirements within 14 days with the full strength being achieved at 56 days.

Levels 40 to 72 are to be constructed with post-tensioned concrete slabs on high strength (C65/80) concrete columns. Concrete will be pumped to a height of 250m.
Admixtures are defined in EN 934-2 [12] 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 the hardened state admixtures can significantly improve the durability of the concrete to a range of aggressive environments, extending the maintenance free service life. However, as well as modifying the physical properties of the concrete, admixtures can be used to enhance sustainability credentials and reduce the ECO₂ content of concrete.

Admixtures can reduce ECO₂ of concrete, despite having relatively high ECO₂ themselves. This is because the dosages are so small, they contribute less than 1% to the total ECO₂ of concrete while allowing other high ECO₂ constituents to be reduced. (Under BS EN ISO 14001 components, constituents contributing less than 1% of the impacts can be ignored, and this would apply to most cases of admixture usage.) Admixtures can reduce the ECO₂ of concrete while maintaining and even enhancing the properties of the concrete.

The Cement Admixtures Association (CAA), www.admixtures.org.uk, estimates that current admixture use already saves about 600,000 tonnes of ECO₂ per annum and this could be significantly increased by further mix optimisation. Typical dosage rates for admixtures are shown in Table 9. In certain specialist applications such as very high strength concrete, these dosages may be exceeded.

Table 9: Typical UK use and dosage rates for admixtures (CAA, 2009)

<table>
<thead>
<tr>
<th>Admixture Type to EN 934-2</th>
<th>Proportion of total admixture sales %</th>
<th>Average dosage % by weight of cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superplasticizers</td>
<td>40</td>
<td>0.80*</td>
</tr>
<tr>
<td>Normal Plasticizers</td>
<td>34</td>
<td>0.45</td>
</tr>
<tr>
<td>Accelerating</td>
<td>2</td>
<td>1.00</td>
</tr>
<tr>
<td>Retarding</td>
<td>2</td>
<td>0.26</td>
</tr>
<tr>
<td>Air Entraining (AEA)</td>
<td>4</td>
<td>0.20</td>
</tr>
<tr>
<td>All other concrete admixtures</td>
<td>18</td>
<td>–</td>
</tr>
</tbody>
</table>

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

Concrete for different exposure conditions

When specifying concrete to BS EN 206-1 and BS 8500 parts 1 and 2, 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 a number of 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
- XA Exposure classes for chemical attack

Depending upon the exposure condition and the cover, BS 8500 will define a minimum cement content, maximum water-cement ratio and possibly 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). The correct use of admixtures can reduce the ECO₂ of the concrete, while maintaining or enhancing the long-term durability performance of the concrete.

Resistance to freeze-thaw

When concrete is exposed to significant freeze-thaw cycles, it should be specified in accordance with the guidance set out in BS 8500-1 Table A.8 to resist XF exposures. To achieve this, either a minimum quantity of air is entrained using an air-entraining admixture or a minimum strength class is specified.

The most severe form of freeze-thaw exposure is when there is also the possibility of high water saturation; typically horizontal surfaces. Under these conditions, freeze-thaw resisting aggregates are required and there are limitations on the type of cement which should be used. Cement with more than 35% fly ash should not be used and, when de-icing agent is used, no more than 55% ggbs should be added to minimise surface scaling.

XF3 exposure is when concrete is exposed to significant freeze-thaw cycles and high water saturation but where de-icing agents are unlikely to be used. For a maximum aggregate size of 20 mm, the requirements are shown in Table 10.
Table 10: Designated concrete for freeze-thaw exposure XF3

<table>
<thead>
<tr>
<th>Exposure class</th>
<th>Min. Strength class</th>
<th>Max. w/c ratio</th>
<th>Min cement content, kg/m³</th>
<th>Min. air content</th>
<th>Alternative designated concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>XF3</td>
<td>C25/30</td>
<td>0.60</td>
<td>280</td>
<td>3.5</td>
<td>PAV1</td>
</tr>
<tr>
<td></td>
<td>C40/50</td>
<td>0.45</td>
<td>340</td>
<td>–</td>
<td>RC40/50XF</td>
</tr>
</tbody>
</table>

From Table 10, it is evidently easier to call up PAV1 or RC40/50XF than set out the limiting values of a designed concrete.

A freeze-thaw resistant aggregate will be a reasonably strong aggregate and coupled with a minimum cement content of 280 kg/m³, plus addition of a water-reducing agent, could give a concrete that achieves around 45 N/mm² at 28 days, in the absence of an air-entraining admixture. However, introduction of entrained air affects strength and each 1% entrained air reduces 28-day strength by about 5% and to ensure a minimum air content of 3.5%, as required for a PAV1 concrete, the average value will be about 5%. At 5% air, 280 kg/m³ may only achieve 35 N/mm²; to safely achieve the required C25/30 strength class, the cement content may need to be 300 - 320 kg/m³.

Even with a reasonable quality aggregate and a water reducing admixture or high range water reducing admixture, it is likely that the cement content required to achieve C40/50 concrete will be in excess of 340 kg/m³ and may be as much as 380 kg/m³.

Thus, air-entrained concrete will normally have lower cement content than a non-entrained concrete to meet the recommendations for freeze-thaw resistance, and therefore a lower ECO₂ content. However, if C40/50 is required anyway to meet structural requirements, then all the cement is usefully employed.

Table 11: Design life of structures

<table>
<thead>
<tr>
<th>Design working life category</th>
<th>Indicative design working life (years)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>Temporary structures *</td>
</tr>
<tr>
<td>2</td>
<td>10 to 25</td>
<td>Replaceable structural parts, e.g. gantry girders, bearings</td>
</tr>
<tr>
<td>3</td>
<td>15 to 30</td>
<td>Agricultural and similar structures</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>Building structures and other common structures</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>Monumental building structures, bridges, and other civil engineering structures</td>
</tr>
</tbody>
</table>

* Structures or parts of structures that can be dismantled with a view to being re-used should not be considered as temporary.

Extending design life through use of admixtures

Concrete structures designed to BS 8500 are generally specified to have a 50- or 100-year life, although EN 1990 defines five working life categories ranging from 10 to 100 years.

The Design Manual for Roads and Bridges (published by the Department for Transport) calls for 60- or 120-year design life. This is achieved through a combination of specifying cover (where corrosion of steel reinforcement is a risk) and concrete quality (specified through maximum water cement ratio and minimum cement content and possibly strength). Admixtures can be used to achieve these durability requirements in a more sustainable way (section 2.1). However, when the concrete is exposed to a particularly aggressive environment or guaranteed long-term performance is critical, specialist admixtures can be utilised. Admixtures falling within this category include corrosion inhibitors, waterproofers and shrinkage reducers. The small increase in ECO₂ using these products will easily be offset if significant repairs to a structure are prevented.

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 is available including:
  - Normal water reducing/plasticizing admixtures
  - High range water reducing/super-plasticizing admixtures
  - Retarding
  - Accelerating
  - Air-entraining
  - Water resisting (waterproofing)
  - Corrosion inhibiting
  - Polymer dispersion admixtures
  - Pumping aids
  - Self-compacting concrete
  - Precast, semi-dry concrete
  - Shrinkage reducing admixtures
  - Anti-washout / underwater admixtures
  - Truck washwater admixtures

Further guidance on the use of admixtures is available from the Cement Admixtures Association (www.admixtures.org.uk)
Water

BS EN 1008: 2002 [13] gives guidance on the use of water recovered from processes in the concrete industry. This includes water which was part of surplus concrete, used to clean the inside of stationary mixers, mixing drums of truck mixers or agitators and concrete pumps; process water from sawing, grinding and water blasting of hardened concrete; and water extracted from fresh concrete during concrete production.

Limitations on use 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 chemical and physical concrete properties such as setting time and strength.

Specification guidance

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

If used, however, its influence should always be taken into account if there are 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.

Water extraction and BES 6001

Water extraction is an important aspect of responsible sourcing certification to BES 6001 (see page 4). 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 needs 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.

Wash-water admixtures

Specialist admixtures are available that reduce the waste produced at a ready-mix concrete plant. At the end of a working day, ready-mix 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.
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 [14] or BS 4483: 2005 [15] and be cut and bent in accordance with BS 8666: 2005 [16]. 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 reinforcing steel is as low as one third of that needed to make one tonne of structural steel from iron ore. 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 recycling 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.

The majority of reinforcing steel used in the UK is produced by the EAF process.

### Guidance for specification of reinforcement steel

The ECO₂ of reinforcing steel is shown in Table 5 (page 11). Steel contents of reinforced concrete will vary and this will influence the ECO₂. At a value of 110 kg of reinforcement per cubic metre of concrete (considered typical for the UK), the reinforcement will add 15 kg of ECO₂ per tonne of concrete as illustrated in Table 12 [17].

The ECO₂ for the cementitious content in this example is based on the UK weighted average value of 720 kg CO₂ T plus an allowance for transport. If a cement/combination utilising fly ash or ggbs at a normal UK addition rate of 30% or 50% respectively was used, a lower ECO₂ would be achieved for both examples, but the differential due to reinforcement would stay the same.

In order to guarantee material is produced in conformance with British Standards, it is recommended that all steel reinforcement should be obtained from companies holding a valid CARES (Certification Authority for Reinforcing Steels) certificate of product approval.

### Table 12: Indicative ECO₂ for C28/35 concrete; unreinforced and reinforced

<table>
<thead>
<tr>
<th>UK concrete products</th>
<th>Constituents of product</th>
<th>Embodied CO₂ for the product</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cementitious Content (kg/m³)</td>
<td>Water (kg/m³)</td>
</tr>
<tr>
<td>C28/35 unreinforced</td>
<td>300</td>
<td>165</td>
</tr>
<tr>
<td>C28/35 reinforced</td>
<td>300</td>
<td>165</td>
</tr>
</tbody>
</table>
Specifying Sustainable Concrete

Sustainability accreditation of reinforcement steel

Sustainability credentials can be demonstrated by specifying reinforcement accredited to the Eco-Reinforcement or CARES sustainability certification scheme.

**Eco-Reinforcement** is a third-party certification scheme developed by the reinforcing steel industry to comply with BRE BES 6001:2008 – *Framework Standard for the Responsible Sourcing of Construction Products*.

Eco-Reinforcement provides a means for construction clients, specifiers and contractors to purchase reinforcing steel from a supply chain which is pro-actively addressing issues of sustainability. The Eco-Reinforcement scheme assesses against a number of different organisational, supply chain, environmental and social criteria; with some defined as compulsory and others voluntary or ‘tradeable’. Certificates are awarded on a ‘Pass’, ‘Good’, ‘Very Good’ and ‘Excellent’ scale, based on the number of points awarded for different performance levels. All Eco-Reinforcement companies are required to print information such as transport-related CO₂ emissions from scrap-yard to site on their delivery notes.

The scheme intends to develop further and provide more extensive environmental impact information. All companies supplying Eco-Reinforcement will be certified to BS EN ISO 14001 and will operate an auditable H&S management system. All Eco-Reinforcement is manufactured through the EAF process, from recycled scrap metal. For more information see [www.eco-reinforcement.org](http://www.eco-reinforcement.org).

**UK CARES sustainability certification** requires steel products, as well as manufacturers’ quality and environmental management systems, to be assessed and approved. The main aim of this approach is to establish a framework to improve the energy and environmental performance of products and provide a robust and transparent mechanism for communicating the environmental performance of steel products to designers, specifiers and clients.

For more information visit UK CARES – [www.ukcares.co.uk/sustainable_reinforcing_steel.html](http://www.ukcares.co.uk/sustainable_reinforcing_steel.html).

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Quick Facts:

Reinforcement

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

For more information visit:
UK CARES - ([www.ukcares.com](http://www.ukcares.com)) and British Association of Reinforcement ([www.uk-bar.org](http://www.uk-bar.org)).
Visual concrete

Visual concrete, whether it be in-situ or precast, is once again being appreciated and used expressively by architects. Partly this is due to the wish to use the thermal mass of concrete to reduce heating and cooling loads.

The latest version of the National Structural Concrete Specification (NSCS) from Construct, the concrete frame contractors’ trade association, now makes the specification of visual in-situ concrete much easier. The previous specifications found in BS 8110 have now been replaced by four different classes of formed finish: basic, ordinary, plain and special. Normally either ‘plain’ finish or ‘special’ finish should be used for concrete which is to be visible during the lifetime of the building.

A plain finish is for use where visual quality is of some importance such as areas occasionally seen or to be directly painted. Joints between formwork panels will show and the step may be up to 3mm. Tie-bolt holes should ideally be recessed and panels and bolt holes should be in a regular pattern. The colour might change with the concrete delivered and the re-use of the forming material. A project example should be produced as one of the first areas of concrete poured on the project and used as the benchmark for the rest of the concrete.

A special finish should be specified where the visual quality is of great importance. Sample panels should be specified using the formwork system, the concrete and the typical reinforcement to be used on the project for producing the particular finish. The size and complexity of the sample should be agreed to test the project detail and confirm that the execution can produce the finish on a repetitive basis.

The concrete should be specified using BS 8500-1. It is recommended that the concrete be specified as a designed concrete, which allows the designer to specify minimum cement content and maximum water/cement ratios. Prescribed concrete, where the exact composition and constituent materials are specified, may also be used, although the strength of the concrete cannot be specified using this method. Some concrete producers have their own proprietary concretes, some of which are suitable for visual concrete (e.g. self-compacting concrete). In this case the specification should give the name of the proprietary concrete and the options required if offered by the producer.

The colour of the concrete is determined by the colour of the smallest particles in the concrete, as this is what forms the surface. These are normally the cement; therefore the type of cement will affect the colour. White cement can be used, but is imported into the UK and therefore is more expensive. The blended cements containing either ground granulated blastfurnace slag (ggbs) or fly ash can be used to modify the colour of the concrete: ggbs will produce a lighter concrete and fly ash a darker concrete. As the colour of concrete varies around the country, it is necessary to view examples of visual concrete in the locality of your project. To produce a good finish on concrete a reasonably high cementitious content is required, most experts suggesting that a minimum of 325 - 350kg/m³ is specified.

Aesthetically pleasing and durable concrete finishes are achieved through team work (collaboration, co-operation and understanding), with each member of the team committed to making their contribution and to understanding how their role has an influence in achieving the required finish. The key players for the execution of the works are the concrete producer, the formwork supplier, the precast supplier and the specialist concrete contractor.

It is important to appreciate that an acceptable appearance for visual concrete cannot be achieved through a written specification alone. It should be established as early as possible that the required finishes are achievable within the cost constraints and then a written specification can be discussed and adapted if necessary so that it is achievable and affordable. Clear communication is required between members of the team so that the results do not fall short of expectations.
Specifying Sustainable Concrete

Specification examples

Designed 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 designed concretes are appropriate depending on the minimum cover to the reinforcement. These are shown in Table 13.

<table>
<thead>
<tr>
<th>Minimum cover (mm)</th>
<th>Strength class</th>
<th>Min cement content (kg/m³)</th>
<th>Max w/c ratio</th>
<th>Designed concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>C40/50</td>
<td>340</td>
<td>0.45</td>
<td>RC40/50</td>
</tr>
<tr>
<td>25</td>
<td>C30/37</td>
<td>300</td>
<td>0.55</td>
<td>RC30/37</td>
</tr>
<tr>
<td>30</td>
<td>C28/35</td>
<td>280</td>
<td>0.60</td>
<td>RC28/35</td>
</tr>
<tr>
<td>≥35</td>
<td>C25/30</td>
<td>260</td>
<td>0.65</td>
<td>RC25/30</td>
</tr>
</tbody>
</table>

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. This grade is generally restricted to precast concrete elements when the minimum cover can be consistently achieved at minimum tolerance, and extra cement content is useful to minimise formwork striking and reinforcement stressing times.

Optimising strength class

A reduction in concrete strength class will typically offer immediate savings in terms of ECO₂ (reduced cement/composite content) 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/composite content by around 150kg per m³ of concrete, with corresponding ECO₂ reductions of around 185 kg of CO₂.

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. Clearly, in this simple example, any increases in ECO₂ for the higher strength class would have to be offset against a more slender, high strength structural solution offering potential economic, environmental and social benefits to the design team, contractor and client alike.

However the example in Table 14 illustrates that the opposite is true. The effect of increasing concrete strength and reducing section size on the floor area available to let and the total ECO₂ of a structure is considered in more detail in Concrete Structures 9 [18].

<table>
<thead>
<tr>
<th>Base Option</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete class for slab</td>
<td>C32/40</td>
<td>C32/40</td>
<td>C50/60</td>
</tr>
<tr>
<td>Concrete class for vertical elements</td>
<td>C32/40</td>
<td>C50/60</td>
<td>C50/60</td>
</tr>
<tr>
<td>Volume of slab concrete (m³)</td>
<td>2,110</td>
<td>2,110</td>
<td>1,841</td>
</tr>
<tr>
<td>Volume of concrete in verticals (m³)</td>
<td>1,112</td>
<td>956</td>
<td>956</td>
</tr>
<tr>
<td>Change in nett lettable area</td>
<td>0%</td>
<td>1.22%</td>
<td>1.22%</td>
</tr>
<tr>
<td>Tonnes ECO₂</td>
<td>1,369</td>
<td>1,346</td>
<td>1,492</td>
</tr>
<tr>
<td>Variation from base option</td>
<td>100%</td>
<td>98%</td>
<td>109%</td>
</tr>
</tbody>
</table>
References

4. The Concrete Industry Sustainability Report – 1st Report, MPA on behalf of the Sustainable Concrete Forum, 2009. All reports can be downloaded from www.sustainableconcrete.org.uk.
12. BS EN 934-2, Admixtures for Concrete Mortar and Grout - Part 2: Concrete admixtures — Definitions, requirements, conformity, marking and labelling, BSI, 2009.