SPECIFYING SUSTAINABLE CONCRETE

Minimising the environmental impact of concrete requires a detailed understanding of location factors and constituent materials. Jenny Burridge and Dr Chris Clear explain

Concrete, in its simplest form, is made by mixing a cementitious binder, aggregates and water. This is then poured into a mould, or formwork, where it sets to form the dense, durable substance we know as concrete. The proportions and types of binder, aggregate and water can be changed and admixtures or fibres added to give different properties to the concrete either in its liquid or hardened state. Choosing the correct concrete specification for the location and function of the concrete is the essence of specifying sustainable concrete. The relevant British standard is BS 8500-1, and this should be referred to when specifying concrete in the UK.

The biggest proportion of the embodied carbon dioxide (eCO_2) in concrete is from Portland cement, or CEM I. Aggregates, additions and water are naturally low in eCO_2. All constituent materials are also plentiful in supply locally and UK-sourced.

RIGHT Trafford Town Hall in Manchester, by 5plus Architects, where 50% cement replacement was specified. Watch a recent Concrete Elegance presentation by the architect here

Specification methods

There are five methods for specifying concretes in BS 8500. These are given in figure 1, below.

Exposure classes

Stronger concretes tend to be more durable, but also higher in embodied energy, so it is worth thinking about the location and specifying accordingly. Concrete that is to be exposed to rain, frost or chemicals will require a different specification to concrete in an internal dry environment, and a mix that will endure for 100 years inside a building may not last as long in the sea. BS 8500 gives six exposure classes for different types of environment (figure 2). These are then subdivided depending on the

FIGURE 1: SPECIFICATION METHODS

Specification method	When should it be used?	Key considerations
Designated concrete	Mass or reinforced concrete where strength is important and there are no chlorides present. Foundations where there are no chlorides present.	Cannot be used if chlorides are present. This method allows the concrete producer flexibility to select the most appropriate materials to give the required performance.
Designed concrete	Reinforced concretes, particularly where there are chlorides present. Visual (fair-faced) concrete. Where lower-carbon concretes are particularly important.	This method allows the specifier to define the concrete required. The concrete producer has some flexibility in the mix design to ensure that the performance requirements are met.
Standardised prescribed concretes	Site batching where ready-mixed concrete cannot be used. (At maximum cement content, the highest strength class that may be assumed for structural design is C20/25.)	The strength of the concrete cannot be specified and the cement content tends to be significantly higher than that for a designed or designated concrete. Do not use this method if a lower-carbon concrete is required.
Prescribed concrete	Specialised concretes where the specifier takes full responsibility for the performance of the concrete.	The strength of the concrete cannot be specified. Suitable if a concrete technologist is specifying the concrete. There is no flexibility for the producer to account for any inherent variation in the materials used in the concrete.
Proprietary concrete	Can be used for a number of high-performance concretes such as self-compacting concretes, low-shrinkage concretes, coloured concretes or high-strength concretes.	The concrete composition is designed by the concrete producer to provide a certain performance. The composition of proprietary concretes is confidential to the producer.

FIGURE 2: EXPOSURE CLASSES

Exposure class	Form of attack	Subclass	Example of location type
X0	No risk of corrosion or attack		Mass concrete not exposed to freezing or sulphates in the ground
XC	Carbonation	XC1	Internal
		XC2	Wet
		XC3	Damp, or cyclic wet/dry
XS	Chlorides in sea water	XS1	External concrete near the sea
		XS2	In the sea
		XS3	In the tidal zone
XD	Chlorides not from sea water	XD1	Possible spray from de-icing salts
		XD2	Permanently in salt water
		XD3	Areas where de-icing salts are used such as car park slabs
XF	Freeze-thaw	XF1	External vertical surfaces without de-icing salts
		XF2	External vertical surfaces with de-icing salts
		XF3	External horizontal surfaces without de-icing salts
		XF4	External horizontal surfaces with de-icing salts
ACEC	Aggressive ground conditions	AC-1s to AC-5m	Foundations in non-aggressive (AC-1s) to very aggressive (AC-5m) soils

CONCRETE QUARTERLY
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severity of the environment.

Note that carbonation and chlorides will affect the reinforcement within the concrete, and therefore do not apply to mass concrete. Freeze-thaw and aggressive ground affect the concrete matrix and therefore apply to both reinforced and mass concrete.

The durability required for these exposure classes is given in BS 8500 as concrete strengths and cover to the reinforcement. The stronger concretes tend to be more impermeable and therefore less vulnerable to penetration by water, chemicals, carbon dioxide (which leads to carbonation) or chlorides. The Concrete Centre's publication "How to Design Concrete Structures Using Eurocode 2: BS 8500 for Building Structures" provides a summary of the tables in BS 8500, giving concrete strengths, covers and allowable cement types.

Reinforcement will be more prone to corrosion where exposed to chlorides than just by carbonation. Therefore, if chlorides are present, the tables covering XD or XS exposure classes should be followed.

Aggregates

The biggest proportion of concrete is normally aggregates, typically making up around 70% of the total volume. These can be primary aggregates, quarried to be made into concrete; secondary aggregates, which are by-products of another process; or recycled aggregates which tend to be crushed concrete from demolition or waste. Recycled aggregates are further sub-categorised as:

- RA (recycled aggregate), which is comprised of any inorganic material previously used in construction and can include a high proportion of masonry
- and RCA (recycled concrete aggregate) which is comprised of crushed concrete.

For the purposes of BREEAM assessments, secondary aggregates are considered as recycled aggregate.

Due to the crushing process, recycled aggregates contain a proportion of fine material that increases water demand and may increase drying shrinkage and creep of the hardened concrete. Coarse recycled aggregates can be used in concretes specified to BS 8500. For designated concretes, recycled aggregate can be used to the percentages shown in figure 3 without further specification. A greater percentage can be specified, but there should be rigorous testing to ensure that it does not contain anything deleterious to the reinforcement or concrete. The allowable limits for secondary

FIGURE 3: PERCENTAGE OF RECYCLED AGGREGATES ALLOWED IN DESIGNATED CONCRETES

Designated concrete	Allowable percentage of coarse RA or RCA
GEN 0 to GEN 3	100%
RC20/25 to RC40/50	20%*
FND1	20%*
RC40/50XF	0%
PAV1 and PAV2	0%
FND2 to FND4	0%

* Except where the specification allows higher proportions to be used

Photo: Jack Hobhouse

aggregates are far higher, with the exact percentage dependant on the type of aggregate and its use.

While recycled aggregate can be used in concrete, it may increase the eCO_2 because more cement is required due to the increased water demand. Recycled aggregate transported further than 15km by road is likely to have a higher eCO_2 than primary aggregate. Often the most sustainable use will be in other applications. All recycled aggregate that is available is fully used.

LEFT The concrete frame of Duggan Morris Architects' Ortus learning centre in south-east London contains 50% GGBS. Watch a Concrete Elegance presentation by the architect here

DESIGN ESSENTIALS

Tips for specifying sustainable concrete

- Do not over-specify strength
- Do not specify aggregate sizes below 10mm unless necessary
- Permit the use of recycled or secondary aggregates but do not over-specify. Recycled aggregates should only be specified when they are locally available
- Embodied CO_2 (eCO_2) of concrete should not be considered or specified in isolation of other factors such as strength gain
- Use of additions can reduce the eCO_2 of concrete and influence its appearance. When aesthetics are critical, specify the cement/combination to maintain colour consistency
- Permit the use of admixtures as these can be used to reduce the eCO2 and the environmental impact of concrete, as well as modifying its physical properties
- Specify BES 6001, responsibly sourced concrete and reinforcement

Cementitious material

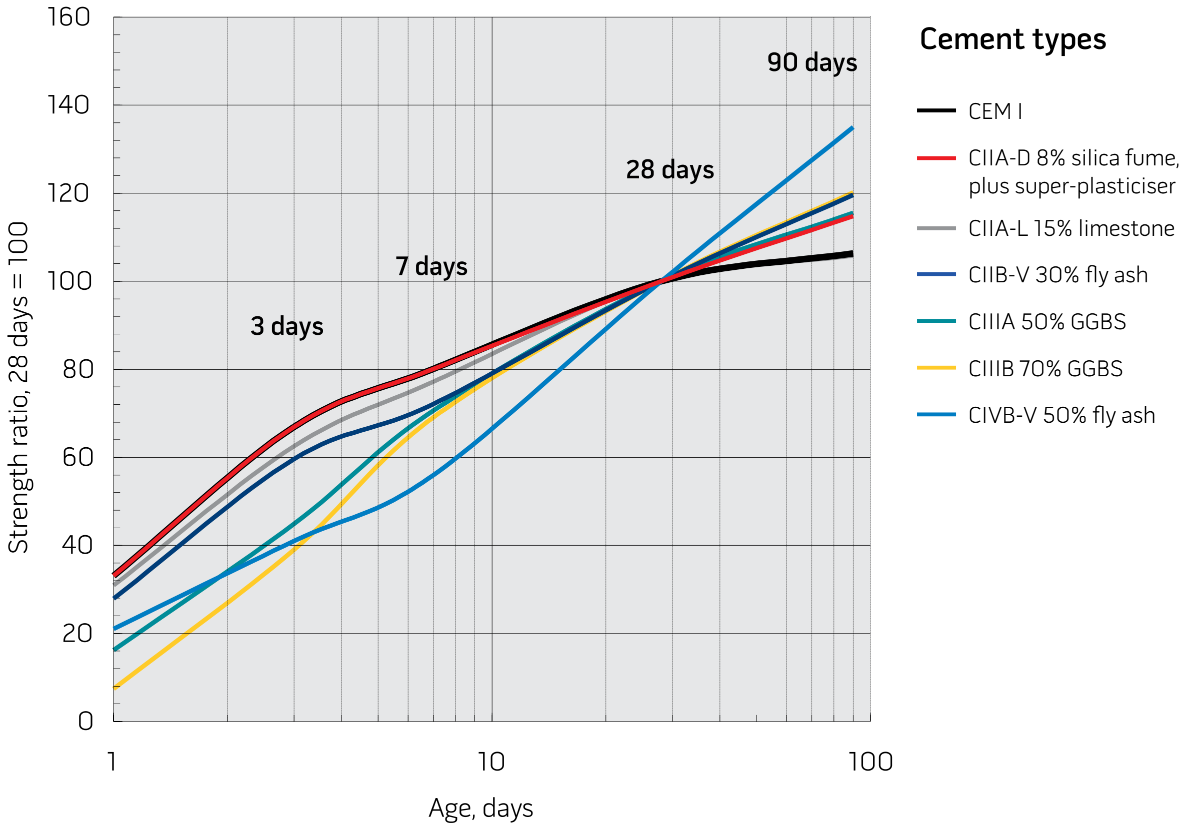
Cement is not only made of Portland cement (CEM I) but can also include additions such as fly ash and ground granulated blast furnace slag (GGBS). These additions provide some useful benefits, such as durability, workability and lower heats of hydration. They are also products recovered from other industries, and are therefore low in eCO_2, and their use can reduce waste to landfill. Most modern ready-mixed concretes in the UK include an addition.

Concretes that contain high levels of additions have longer setting times than pure CEM I concretes, and are therefore more suitable for foundations or ground-bearing slabs. Lower levels of additions, up to approximately 35% GGBS or fly ash, should not significantly extend the striking times for suspended concrete slabs in reasonable weather. In cold weather the strength gain of concrete is reduced and therefore the percentage of additions that will still allow a striking time of about three days is also reduced.

Figure 4 shows the relative strength gain of concretes with different proportions and types of additions. All reach the required strength at 28 days, as that is the specified time, but the concretes with higher proportions of additions take longer to gain early strength and continue to gain significant strength after 28 days.

Cement types tend to be blended at the concrete batching plant and normally the addition is either fly ash or GGBS, not both. Fly ash tends to make the concrete darker in colour and improves its workability; GGBS tends to lighten the colour and improve its reflectance.

FIGURE 4: THE EARLY AGE STRENGTH GAIN OF DIFFERENT CONCRETE MIXES



Embodied carbon

The eCO_2 of concrete is highly dependent on the level of Portland cement in the concrete. Figure 5 gives the embodied carbon of the different constituents of concrete. From this, it can be seen that a higher percentage of additions will reduce the embodied carbon significantly.

Admixtures are chemicals added to concretes in small quantities to improve some aspects of its performance. These include water-reducing admixtures, also known as super-plasticisers. Super-plasticisers can reduce the embodied carbon of concrete by reducing the water/cement ratio, which increases the strength for a given cement content. Figure 6 gives an example of how a super-plasticiser may be used to reduce cement content.

FIGURE 5: EMBODIED CARBON IN CONCRETE CONSTITUENTS

Material	Embodied CO_2 (kg/tonne)
CEM I	913
GGBS	67
Fly ash	4
Limestone	75
Aggregate	5
Reinforcement	427

FIGURE 6: REDUCTION IN CEMENT CONTENT WHEN USING WATER-REDUCING ADMIXTURES

Cement content (kg/m^3) required for a C32/40 concrete with an S3 slump using marine sand and gravel aggregate

Cement type	No admixture	Water-reducing admixture	High-range water-reducing admixture
CEM I	315	285	250
CIIA-LL (15% limestone)	325	295	260
CIIB-V (30% fly ash)	335	300	270
CIIIA (50% GGBS)	325	295	260

Responsible sourcing

The relevant standard for the responsible sourcing of construction materials is BES 6001, which can apply to all building materials and covers a range of environmental and social factors. The concrete industry has worked to BES 6001 since it was published in 2008. In 2012, when the most recent data was published, some 89% of all concrete produced in the UK was responsibly sourced.

The concrete industry is also a net user of waste, consuming 63 times more than it produces. Much of this is used as fuel in cement kilns, but it also includes recovered materials such as fly ash and GGBS, which are used instead of a manufactured product such as CEM I.

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Key references

BS 8500-1: 2006, **Concrete – Complementary British Standard to BS EN 206-1, Part 1: Method of specifying and guidance for the specifier, BSI**

How to Design Concrete Structures Using Eurocode 2, **chapter 11: BS 8500 for Building Structures, The Concrete Centre, 2008**

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