

# Guidance on additional requirements for designed concrete

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The new standards for concrete, BS EN 206–1 and BS 8500 will co-exist and have equal status to the existing BS 5328 until its withdrawal in December 2003. However, BSI recommends that BS 5328 is used for specifications until the end of 2003 and BS EN 206–1/BS 8500 is used from 2004.

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Association of Concrete Industrial Flooring Contractors  
Association of Lightweight Aggregate Manufacturers  
British Cement Association  
British Standards Institution  
Building Research Establishment  
Cement Admixtures Association  
Cementitious Slag Makers Association  
Concrete Industry Alliance  
Concrete Society  
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Ove Arup & Partners  
Quarry Products Association  
Ready-mixed Concrete Bureau  
RMC Readymix  
L M Scofield Ltd.  
United Kingdom Quality Ash Association

A full list of the publications in this series is given on the back page.

## INTRODUCTION

Designed concrete gives maximum flexibility to the specifier to include additional requirements and provisions in the concrete specification in addition to those essential items given in BS 8500–1, clause 4.3.2. This publication recommends that two additional requirements for aggregates should be included in most specifications. In many cases, other additional requirements and provisions will not be needed, but there are situations where they are necessary to ease the construction process or to achieve the intended performance of the finished structure.

This publication focuses entirely on the options within concrete specification that are available for resolving a performance issue. In many cases there are potential options unrelated to the concrete specification such as the construction sequence, formwork/insulation type, accelerated curing etc. that are equal to, or better than, the concrete specification options. These options should also be considered when deciding the appropriate approach.

The additional requirements and provisions for designed concrete are listed in BS 8500–1, clause 4.3.3. General guidance is provided below for each of these items.

## SPECIAL TYPES OR CLASSES OF CEMENT OR COMBINATION (BS 8500–1, clause 4.3.3a)

Cement/combination type is a basic requirement of a designed concrete specification and is covered by clause 4.3.2d. However when a DC-class is specified under BS 8500–1, clause 4.3.2c, the cement type should not be specified under clause 4.3.2d, as the requirements for the DC-class given in BS 8500–2 already include cement/combination types.

BS 8500–1, Tables A.10 to A.16 give recommendations for cement and combination types that are suitable, within the context of the given concrete specification, for the exposure class and intended working life. Where there are combined exposure classes, the selected and specified cements and combinations should

**Table 1.** Selection of cement/combination types

Grouping with respect to sulfate resistance		Grouping with respect to chloride resistance		
		Group 4	Group 5	Group 6
Group 1		I, IIA, IIB-S	IIB-V, IIIA	–
Group 2	2a	–	IIB-V+SR	IVB+SR
	2b	–	–	IIIB+SR
Group 3		SRPC	–	–

satisfy the recommendations for all the exposure classes. In BS 8500, cements and combinations are grouped with respect to their sulfate-resisting properties (Groups 1 to 3) and their chloride-resisting properties (Groups 4 to 6). Where consideration of combined exposure leads to identifying cements/combinations in both of these groupings, Table 1 may be used to select cement/combination types

For chloride and aggressive chemical exposures, the choice of cement/combination type may affect the appropriate maximum w/c ratio, minimum cement/combination content, strength class and cover to reinforcement. Select the cover to reinforcement then include in the concrete specification as many cement/combination groups as possible together with their associated specifications. This will enable the concrete producer to offer the most economic concrete.

Clause 4.3.3a is provided to remind the specifier that there are situations where further restriction of the cement/combination type or class, special cements/combinations, e.g. composite cements/combinations, or extra special properties, e.g. low heat, may be appropriate. These situations include:

- a means of achieving high/low early strength, see guidance on clause 4.3.3g;
- a means of reducing the heat of hydration and early-age thermal cracking, see guidance on clause 4.3.3h.
- where composite cements/combinations are required.

A composite cement/combination is one with Portland cement clinker and two or more second main constituents, e.g. Portland cement plus ggbs plus silica fume; Portland cement plus pfa plus metakaolin.

The use of composite cements/combinations is relatively new in the UK and BSI was unable to provide guidance on their use.

There is a trend to use these types of cements/combinations in extremely aggressive environments.

- Visual and coloured concrete.  
See *Visual concrete* and *Coloured concrete* in this series.

Where further restrictions on the cement/combination types, special cements/combinations or extra special properties are required, these should always be specified under BS 8500–1, clause 4.3.2d and not under 4.3.3a, i.e. do not split the requirements for cements/combinations between two clauses.

## SPECIAL TYPES AND CLASSES OF AGGREGATE (BS 8500-1, clause 4.3.3b)

### Drying shrinkage

Aggregates with high drying shrinkage have to date led only to localised problems, but with the recent trend to ship aggregates longer distances, it would be a sensible precaution to include a limit on the drying shrinkage of aggregates in all concrete specifications except where the concrete will never dry or where the structure has been designed with these high shrinkage aggregates in mind. Except for these situations, the following is recommended as a standard requirement for all designed concrete specifications:

“When tested in accordance with BS EN 1367–4, the aggregate drying shrinkage shall be not more than 0.075%.”

It should be noted that the BS EN 1367–4 test actually measures the drying shrinkage of a standard concrete containing the aggregate

under test, not the specific drying shrinkage of the aggregate.

### Resistance to fragmentation of coarse aggregate

To ensure adequate resistance to fragmentation, the UK guidance to EN 12620 recommends that the Los Angeles coefficient of the coarse aggregate is  $\leq 40$  when tested in accordance with BS EN 1097-2. Using the categories given in EN 12620, this transposes to a LA<sub>40</sub> category. The lower the number, the greater is the resistance of the aggregate to fragmentation.

All designed and designated concrete specifications should contain the following requirement:

“The BS EN 12620 Los Angeles category of the coarse aggregate shall be not be greater than LA<sub>40</sub>”

### Carbonate content

The recommendations to resist aggressive chemical environments vary depending on the aggregate carbonate range. If a DC-class is specified, the producers will select the limiting values that are appropriate for their aggregate carbonate range and consequently the aggregate carbonate range should not be specified under clause 4.3.3b. In the case where a ‘starred’ or ‘double-starred’ DC-class is specified, this will automatically invoke special requirements on the aggregate carbonate range and consequently there is no need to specify this as an additional requirement.

However, there are a few situations where it is not feasible to specify the DC-class (this occurs in complex combined exposure conditions). In these cases, the specifier should specify the aggregate carbonate range under clause 4.3.3b, the maximum w/c ratio and minimum cement/combination content under clause 4.3.2c and the selected cement/combination type under clause 4.3.2d. Where possible provide alternative specifications.

### Density

Where lightweight or heavyweight concrete is specified, the producer is likely to use a lightweight or heavyweight aggregate. These aggregates are permitted in the general

requirements of BS EN 206-1/BS 8500-2 and consequently need not be specified under clause 4.3.3.

### Other properties

Other situations where special types and classes of aggregates may be required include:

- Where the relevant exposure classes include XF3 or XF4.

In this case, the specification should contain the requirement: “The aggregates shall be freeze/thaw resisting as defined in BS 8500-2: 2002, clause 4.3.” This requires a defined performance in a magnesium sulfate soundness test for all natural aggregates except porous flints. Acceptability of porous flints is based on track record.

BS 8500-2, clause 4.3 does not cite BS EN 136-1 on freeze/thaw testing, as this very severe test would wrongly classify some UK aggregates that have a long and successful track record in the UK.

- Where enhanced wear or polishing resistance is required.

Most industrial floors do not require the specification of special wear classes of aggregate because the floor is regarded to have failed if the coarse aggregate is showing. For the few exceptions, BS 882 recommends that when tested in accordance with BS 812-111, the oven-dry 10% fines value shall be not less than 150 kN. The 10% fines test is not part of the European suite of tests and its future is uncertain. At present there are no data that enable an equivalent Los Angeles category to be cited.

BS EN 12620 provides a means of selecting and specifying categories of aggregate with defined physical properties.

A general requirement for resistance to fragmentation of coarse aggregate has been given above using one of the Los Angeles coefficient categories; lower values are not normally necessary. The BS 812 aggregate impact value test results correlate well with the Los Angeles test results and consequently the use of Los Angeles

categories is the recommended way to specify resistance to fragmentation. The impact value category, given as an alternative in EN 12620, is not the same as the BS 812: Part 112 test and it requires a large testing machine not available in UK test laboratories. There is no established correlation between this test and traditional UK tests and consequently the alternative impact value category is not appropriate for UK conditions.

Resistance to wear, as measured by the micro-Deval test, is not an appropriate requirement for normal concrete as it measures the resistance to wear between interlocking particles. It may be an appropriate requirement for cement bound pavement bases.

- Pavements

The *Specification for Highway Works* gives specific requirements for this application

Resistance to abrasion from studded tyres (a Nordic abrasion value category) is not an appropriate requirement for UK conditions.

- A means of reducing the risk of early-age thermal cracking (see also guidance on clause 4.3.3h).

As aggregates provide the bulk of concrete, the specification of aggregates with low coefficients of thermal expansion will reduce the expansion or contraction of concrete and the risk of early-age thermal cracking.

Limestone and lightweight aggregates have lower coefficients of thermal expansion than flint gravels.

Consequently, where limestone coarse aggregate is specified, the thermal crack control reinforcement may be reduced by up to one third and/or limits on the temperature differential in a concrete element can be relaxed.

Further guidance on reducing the risk of early-age thermal cracking can be found in:

Concrete Society Digest 2: *Mass concrete* (1984).

Harrison, T A, *Early-age thermal crack control in concrete*, CIRIA Report 91 (1992).

- Visual and coloured concrete  
See *Visual concrete* and *Coloured concrete* in this series.

### Restrictions on the use of certain aggregates (BS 8500–1, clause 4.3.3c)

To contribute towards sustainability, BS 8500 permits the use of coarse recycled concrete aggregate (RCA) and coarse recycled aggregate (RA) in certain exposure conditions. Whilst the relevant exposure classes do not form part of the specification or the exchange of information, these will be obvious from most specifications. The exchange of information will declare the producer's intention to use these aggregates.

The producer is free to use these aggregates in these exposure classes provided they are not excluded by the specification. Specifiers should contribute to sustainability by not excluding these aggregates unless there is a clear need. Examples where they may not be appropriate are surfaces subject to wear and visual concrete.

### GENERIC TYPE AND DOSAGE OF FIBRES (BS 8500–1, clause 4.3.3d)

The use of fibres in concrete is increasing. If the specifier wishes to have fibres in the concrete, they have to specify the generic type (steel or polymer) and dosage of fibres. The producer of concrete does not underwrite the claims of the fibre suppliers. Their contractual obligations are only to add the specified fibres at the dosage specified and to distribute these within the cement paste within the concrete.

### CHARACTERISTICS REQUIRED TO RESIST FREEZE/THAW ATTACK (BS 8500–1, clause 4.3.3e)

Where air-entrained concrete is required, the minimum air content should be specified. The appropriate value will depend on the specified maximum aggregate size; see BS 8500–1, Table A.14. It should be noted that the approach in BS EN 206–1/BS 8500 is different from the mean value approach used in

BS 5328. Whilst the approach to specification has changed, the actual amounts of air in the concrete are generally unchanged. For example, to achieve a minimum air content of 3.5%, the recommended value of air content for 20 mm maximum aggregate size in BS 8500, the target air content would be about 5.5%, which is the recommended target air content for 20mm maximum aggregate size in BS 5328.

There is no need to specify a spacing factor for air-entrained concrete. The possibility of adverse interactions between admixtures affecting the spacing factor has been adequately addressed in BS 8500–2, clause 4.5.

In XF4 exposures, there may be a need to restrict the types of cement/combination, see BS 8500–1, Table A.14 footnote e.

In XF3 and XF4 exposures, there is a need to specify freeze/thaw resisting aggregates, see guidance on clause 4.3.3b above.

#### **REQUIREMENTS FOR THE TEMPERATURE OF FRESH CONCRETE WHERE DIFFERENT FROM THE LOWER LIMIT IN BS EN 206–1, 5.2.8 OR THE UPPER LIMIT IN BS 8500–2, 5.4 (BS 8500–1, clause 4.3.3f)**

BS EN 206–1, clause 5.2.8, states that the temperature at delivery shall not be less than 5°C and in BS 8500–2, clause 5.4 states that the temperature at delivery shall not exceed 35°C. Situations where different limits may be appropriate include:

- **Cold weather working**  
A higher minimum temperature may be appropriate. This may require the aggregates to be heated and/or steam injected into the concrete. This has cost implications and therefore this requirement should be included at the tender stage.
- **Hot weather working**  
A lower maximum temperature may be appropriate. This may require the constituent materials and/or the concrete to be cooled. This has cost implications and therefore this requirement should be included at the tender stage.

Some reinforcement designs for the control of early-age thermal cracking are based on the assumption that the maximum temperature of the concrete at placing is not greater than 25°C. In these cases the maximum temperature at delivery should be reduced to 25°C.

- **Large sections**

A technique for reducing the peak temperature in a large section is to reduce the placing temperature. This technique is likely to require the constituent materials and/or the concrete to be cooled. This has cost implications and therefore this requirement should be included at the tender stage.

#### **STRENGTH DEVELOPMENT (BS 8500–1, clause 4.3.3g)**

In most cases, the normal rate of strength gain is adequate for construction purposes. Information on this can, on request to the concrete producer, be supplied under BS EN 206–1: 2000, clause 7.2e. The construction process is scheduled around the achieved rate of strength gain. Increasing the rate of strength gain tends to increase the risk of early-age thermal cracking and consequently both aspects need to be considered. Situations where specification requirements to change the rate of strength development may be appropriate include:

- **Cold weather**  
Cold conditions reduce the rate of strength development with consequential effects on construction operations such as formwork striking.
- **To speed up the construction process**  
Formwork striking times will be reduced, particularly soffit formwork to suspended slabs.  
The time to prestressing will be reduced.  
Optimises the use of expensive formwork systems such as apartment forms.  
The time to subsequent operations will be reduced where these depend on the strength achieved in the structure, e.g. the anchorage strength when using jump-forms.

- **Special construction techniques**

Secant piling requires the strength gain of the female piles to be sufficiently slow that the piling rig can cut the male piles.

Concrete that is to be exposed to traffic or wear a few hours after placing.

The strength development of concrete is a function of the section geometry, the insulation provided by the formwork and the ambient conditions, in addition to the properties of the concrete. The following options apply to the last item in this list of influencing factors and they often have to be used in conjunction with requirements that are outside the scope of this publication.

- **Specify a higher/lower concrete compressive strength class.**

There is rarely a problem with specifying a higher compressive strength class, but specifying a lower strength class to reduce the rate of strength development requires careful consideration of all the factors. However it may still be possible in some circumstances to justify a lower compressive strength class. For example, the recommendations for resistance to aggressive chemical environments do not include a requirement for compressive strength except in one particular set of circumstances. The requirements for strength then relate to structural requirements and if it can be shown that the concrete in situ will continue to develop in strength, a lower compressive strength class may be appropriate.

An estimate of the reduction in formwork striking times that can be achieved by specifying a higher strength class can be made using the tables of formwork striking times in CIRIA Report 136: *Formwork striking times – criteria, prediction and methods of assessment* (1995)

- **Specify cements/combinations types, classes and sub-classes that gain strength more/less rapidly.**

Cement type CEM I gains strength most rapidly at 20°C followed by cement/combination types IIA and IIB.

Cement/combination type IIIA has a moderate rate of strength development at 20°C.

Cement/combination types IIIB, IIIC and IVB gain strength slowly at 20°C.

The early strength development of a cement/combination is given by the letter ‘R’ for rapid, ‘N’ for normal and ‘L’ for low. For a given concrete strength, high strength class cements/combinations, e.g. 52,5, may enable the concrete to gain strength a little more rapidly than low strength class cements/combinations, e.g. 32,5.

The rate of strength development of cement/combination types III and IV is affected more by temperature than cement type CEM I, i.e. at low temperatures (0 to 10°C) they gain strength very slowly but at high temperatures ( $\geq 35^\circ\text{C}$ ) they are comparable in the rate of strength development to that achieved with CEM I cement. Further guidance on the strength development of different cement/combination types can be found in:

Concrete Society Technical Report 40: *The use of ggbs and pfa in concrete* (1991.)

Harrison, T A and Spooner, D C, *The properties and use of concretes made with composite cements*, C&CA, Ref: ITN 10 (1986).

NOTE. The scope of the publication above is restricted to cements/combinations with ggbs or pfa, not triple (ternary) blends. Since its publication the term ‘composite cement’ has been reserved for triple blends, see guidance on clause 4.3.3.

- **Specify different minimum/maximum concrete temperatures at delivery, see clause 4.3.3f.**

- **Specify the use of an admixture that accelerates/retards the gain of strength.**

- **Specify an early strength requirement for the concrete under standard laboratory conditions, e.g. strength development of 20°C water cured specimens.**

Maturity calculations can relate the strength development under standard conditions to those expected in the structure; see CIRIA

Report 136. *Formwork striking times – criteria, prediction and methods of assessment* (1995).

For strength requirements at 3 days or less, the temperature of the constituent materials at mixing can have a significant influence on the measured early strength. If reliable results are to be achieved, the materials should be stored at  $20^{\circ}\text{C} \pm 2^{\circ}\text{C}$  for several days prior to making the concrete, but few, if any, concrete producer have such facilities.

### HEAT DEVELOPMENT DURING HYDRATION (BS 8500–1, clause 4.3.3h)

This may need to be limited for one or both of the following reasons:

- a) to prevent or reduce early-age thermal cracking, see also guidance on clause **4.3.3b**;
- b) to minimise the risk of delayed ettringite formation (known by the acronym DEF).  
Further guidance on reducing the risk of early-age thermal cracking can be found in:  
Concrete Society Digest 2: *Mass concrete* (1984).  
Harrison, T A, *Early-age thermal crack control in concrete*, CIRIA Report 91 (1992).  
Further guidance on delayed ettringite formation can be found in:  
Quillin, K. *Delayed ettringite formation – In-situ concrete*, BRE Information Paper IP11/01 (2001).

In cold weather, it may be appropriate to increase the heat of hydration to increase the in-situ strength gain. Techniques that increase the rate of strength gain, see guidance on clause **4.3.3g**, will, in effect, increase the heat of hydration.

Specifying one or more of the following will reduce the heat of hydration of concrete:

- Specify cements/combinations that produce less heat, see guidance on clause **4.3.3g**.  
In the future there will be European standards that define low and very-low heat cements and the same criteria is likely to be applied to the UK system for combinations. The characteristic heat of

low heat cements is expected to be 270 J/g and the characteristic heat of very-low heat cements is expected to be 220 J/g.

Until these standards are available, specify cements/combinations that have generally agreed low heat characteristics such as IIIB, IIIC and IVB.

- Specifying a maximum limit on cement/combination content.  
A maximum cement/combination content, in  $\text{kg}/\text{m}^3$ , determined as 170 divided by the maximum w/c ratio should be relatively easy to obtain provided the required compressive strength class is driven by durability and not by structural performance.  
In some circumstances, a maximum cement/combination content, in  $\text{kg}/\text{m}^3$ , determined as 140 divided by the maximum w/c ratio is achievable. Consult with local concrete producers.
- Specify a lower compressive strength class, see guidance on clause **4.3.3g**
- Specify a maximum adiabatic temperature rise for the concrete at a given age, typically 3 to 5 days.  
This is the temperature rise that occurs when all the heat of hydration is retained. As only a few (research) laboratories have adiabatic calorimeters, an approximation to the adiabatic temperature rise is often accepted based on the temperature rise of a 300 mm cube of concrete in a low mass container with high levels of insulation on all sides, e.g. 200 mm of expanded polystyrene.
- Specify a lower maximum concrete temperature at delivery, see guidance on clause **4.3.3f**.

### RETARDED STIFFENING (BS 850–1, clause 4.3.3i)

Situations where retarded stiffening may be required include:

- To avoid cold joints in large volume pours

Where needed, specify either the use of a set-retarding admixture or specify the number of hours by which the set should be retarded.

- To avoid premature stiffening in very hot conditions

Test data obtained at standard laboratory temperatures will be of little value.

It may be prudent to specify a site trial in similar conditions to those anticipated for the main operation.

Specify a higher consistence than that needed for placing and accept the loss of consistence between delivery and placing. Admixtures will not stop premature stiffening if this is due to the loss of mixing water.

Instruct the producer to take measures to reduce the loss of mixing water during transportation.

### **RESISTANCE TO WATER PENETRATION (BS 8500–1, clause 4.3.3j)**

The water penetration test is described in BS EN 12390–8. It has been, and is being, used in parts of Europe where they have had problems with insufficient fine material in the concrete. It has not been a specification requirement in the UK because of the quality of the UK fine aggregates and the high minimum cement/combination contents recommended in BS 8500–1.

### **RESISTANCE TO ABRASION (BS 8500–1, clause 4.3.3k)**

The following additional requirements should be considered:

- Requirements on the coarse aggregate if it will be exposed, see guidance on clause 4.3.3b.
- Tighter limits on the content of unstable and weak material in the aggregate, e.g. pyrite and lignite.

It is impractical to specify that the aggregate contain no unstable or weak material.

Consult local concrete producers on what is achievable in the particular location.

### **TENSILE SPLITTING STRENGTH (BS 8500–1, clause 4.3.3l)**

Some methods of designing concrete pavements use the tensile splitting strength of concrete. In this special situation, some specifiers prefer to specify their requirements directly in terms of tensile splitting strength whilst others will accept the concrete based on an equivalent compressive strength class verified on the basis of initial testing.

### **OTHER TECHNICAL REQUIREMENTS (BS 8500–1, clause 4.3.3m)**

This is a catch-all clause to allow the specifier to introduce any other requirement. Examples of the use of this clause include specific durability requirements (permeability, chloride diffusion, carbonation resistance, freeze/thaw testing etc.), self-compaction and flexural strength.

### **ANY ‘CONCERNING EFFECTS’ (BS 8500–1, clause 4.3.3n)**

This is provided to cover the situation where the conditions of the initial tests on the concrete are significantly different to those occurring in practice. If the concrete is to be placed in very hot or very cold conditions, it may be appropriate to gather data on the performance of the concrete under these conditions as well as under laboratory conditions. Whilst it is the specifier’s responsibility to anticipate the possible problems subsequent to delivery, the concrete producer may be able to provide solutions.

### **FURTHER READING**

The other publications from this series will be helpful. Visit [www.cementindustry.co.uk](http://www.cementindustry.co.uk) and click ‘information’/‘library’/‘BCA publications’ to check availability and for free download.

*Standards for fresh concrete – a composite of BS EN 206-1 and BS 8500*

*Specifying concrete to BS EN 206–1/BS 8500:  
Concrete for normal uses  
Concrete resistant to chemical attack  
Guide to the selection of concrete quality and cover for reinforcement for normal concrete structures*

*Examples of the specification of designated concrete*

*Examples of the specification of designed concrete*

*Guidance on additional requirements for designed concrete*

*Lightweight concrete*

*Visual concrete*

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