CONCRETE PRACTICE

BCA
British Cement Association

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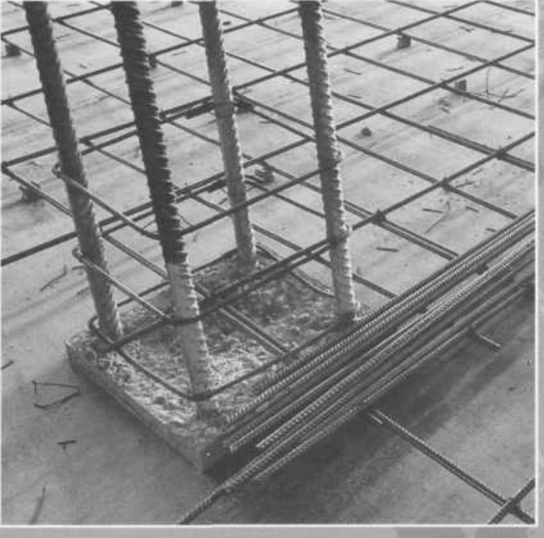

This publication

This publication is for the guidance of those concerned with the construction and day-to-day supervision of concrete work in the UK. It gives useful advice, which will also provide students with an insight into the many and varied practical aspects relating to concrete and its uses. It is not intended to take the place of regulations, codes of practice or specifications. Where it is inappropriate to deal in detail with specialist topics, sources of further information are referred to.

The scope is generally related to British Standard BS 5328 *Concrete,* current at the time of publishing this handbook. European Standard BS EN 206-1, *Concrete - specification, performance, production and conformity,* dated 2000, was followed in 2002 by its complementary British Standard BS 8500 for additional UK provisions. Reference is made to BS EN 206-1 /BS 8500 where appropriate to the specification, production and general use of concrete.

Much of the technology and site practice described in this handbook also applies to the production of ready-mixed and precast concrete. Contractors have a choice in their procurement of concrete and expert advice is available in technical literature describing the benefits and production methods for specialised applications such as ready-mixed, precast or sprayed concrete that are not included in this handbook.

Safety on site

Many construction activities are potentially dangerous so care is needed at all times. Current legislation requires all persons to consider the effects of their actions or lack of action on the health and safety of themselves and others. Advice on safety legislation can be obtained from any of the area offices of the Health & Safety Executive.

Cement burns: health hazard

Dry cement powders in normal use have no harmful effect on dry skin. As with any dusty material there may be ill effects from the inhalation or ingestion of cement dust and suitable precautions should be taken.

When cement is mixed with water, alkali is released.

Precautions should therefore be taken to prevent dry cement entering the eyes, mouth or nose and to avoid skin contact with wet concrete and mortar.

Repeated skin contact with wet cement over a period of time may cause irritant contact dermatitis. The abrasiveness of the concrete or mortar constituents can aggravate the effect.

Some skins are sensitive to the small amount of chromate that may be present in cements and can develop allergic contact dermatitis, but this is rare.

Continued contact with the skin can result in cement burns with ulceration.

Handling precautions

Protection for the eyes, mouth and nose should be worn in circumstances when dry cement may become airborne.

When working with wet concrete or mortar, suitable protective clothing should be worn such as long-sleeved shirts, full-length trousers, waterproof gloves with cotton liners and Wellington boots.

Clothing contaminated with wet cement, mortar or concrete should be removed and washed before further use. Should concrete or mortar get into boots, remove them IMMEDIATELY and thoroughly wash the skin and the inside of the boots before proceeding with the job.

If cement enters the eye it should be washed immediately and thoroughly with clean water and medical advice sought.

Concrete or mortar elsewhere on the skin should also be washed off immediately.

Whenever there is persistent or severe irritation or pain a doctor should be consulted.

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CONCRETE PRACTICE

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INTRODUCTION

Concrete is a construction material composed of crushed rock or gravel and sand, bound together with a hardened paste of cement and water. A range of different cements and aggregates, chemical admixtures and additions can be used to make an array of concretes that have the required properties in both the fresh and hardened states for a wide range of applications.

History

Concrete was known to the Romans, Egyptians and to even earlier Neolithic civilisations. After the collapse of the Roman Empire its secrets were almost lost, to be rediscovered in more recent times. Its modern development spans less than 200 years - 1824 is the date on the patent for the manufacture of the first Portland cement, one of the important milestones in concrete's history.

Since the middle of the 19th century, open sea has been spanned, huge buildings erected, mighty rivers dammed and extensive networks of roads constructed. In these and a thousand other ways the face of the world has been changed as a result of the discovery of concrete. Concrete has also been instrumental in improving the health of the world's inhabitants, through its use for sewage disposal and treatment, and for dams and pipes providing clean water for drinking and washing.

Uses of concrete

Concrete plays a major role, often unseen, in every aspect of our daily lives. Its strength and durability are exploited to the full by North Sea oil platforms and sea defences, while its thermal and acoustic insulation properties help make houses and flats more comfortable places to live.

Concrete bases to motorways and runways provide a solid transport infrastructure, and the material's ability to span large rivers makes a useful and often striking addition to our landscapes. Dams, ring mains and water towers use concrete's ability to contain water, and its resistance to chemicals make it an ideal choice for sewerage works, slurry pits and even wine vats.

Not surprisingly, artists make full use of concrete, as its potential to take any shape, colour or texture is limited only by their imaginations.

The future

The way forward for concrete construction will be largely influenced by the need to conserve the earth's resources, be they materials, land or energy. Concrete has a major role to play in sustainable construction, as it can be recycled after use, requires relatively little energy in its manufacture and provides thermal mass in buildings, thus reducing the need for air conditioning.

Skilled site labour is another resource that is likely to become scarce in the future. Innovative construction techniques can help overcome this. Self-compacting concrete is easier to place and unmanned equipment could be used to finish concrete floors. Transferring the construction process to a controlled operation in a factory is another way of coping with a skills shortage. For example, whole bathroom pods can be assembled off-site, even down to the installation of the plumbing, and then slotted into place at the site.

Accompanying all these advances will be the development of concrete as a material. Continued improvements in cement and concrete production, alternative reinforcing materials and the use of computer-aided design will all have parts to play.

These developments will be complemented by the adoption of construction techniques that will cut out waste and reduce time taken on site, so shortening the period before a building or structure can be brought into use and begin to earn its keep.

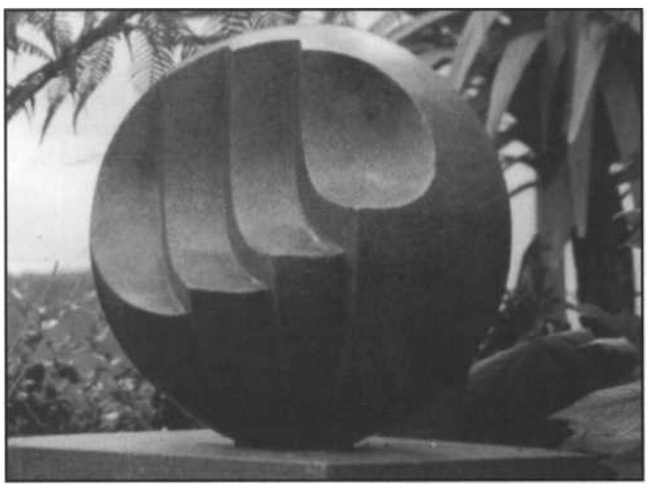
The success of all these endeavours, both now and in the future, will depend very much on sound concrete practice on site. This publication combines the authors' many years of practical experience gained on site with information about the latest techniques and developments in standards. It is aimed both at those starting out on a career in construction as well as those who may wish to refresh their knowledge on a particular aspect of site practice.

References/further reading

BCA. *Concrete through the ages - from 7000 BC to AD 2000.* 1999, British Cement Association, Crowthorne. Ref. M26. 36 pp.

Glass, J. *Ecoconcrete: the contribution of cement and concrete to a more sustainable built environment.* 2001, RCC/ British Cement Association, Crowthorne. Ref. 97.381. 20 pp.

The Pantheon in Rome: built in AD 127, using early lightweight concrete, it is still a major tourist attraction.



Kumata - one of the many sculptures by artist Carol Vincent who works in coloured concrete.

PORTLAND CEMENTS

Portland cements are made by burning together limestone and clay, or other chemically similar suitable raw materials, in a rotary kiln to form a clinker rich in calcium silicates. This clinker is ground to a fine powder with a small proportion of gypsum (calcium sulfate), which regulates the rate of setting when the cement is mixed with water. Over the years several types of Portland cement have been developed. As well as cement for general use (which used to be known as ordinary Portland cement), there are cements for rapid hardening, for protection against attack from freezing and thawing or by chemicals, and white cement for architectural finishes. All Portland cements are produced to provide special performance and properties that are of value in appropriate applications. They all contain the same active compounds - only the proportion of each is different. The main compounds in Portland cements are given in Table 1.

Table 1: Main compounds of Portland cements (typical percentage composition).

Compound		Rate of hardening	CEM I 42,5N	SRPC	White Portland cement
Tricalcium silicate	C_3S	Rapid	56	64	65
Dicalcium silicate	C_2S	Slow	16	10	22
Tricalcium aluminate	C_3A	Rapid	8	2	5
Tetracalcium aluminoferrite	C_4AF	Extremely slow	9	14	1

NOTES
1. The abbreviated chemical notation given for the above compounds is based on C = CaO S = SiO_2 A = Al_2O_3 F = Fe_2O_3
2. Only main compounds are listed; therefore they do not total 100%.

By incorporating other materials during manufacture, an even wider range of cements is produced, including air-entraining cement and combinations of Portland cement with mineral additions. Cements are also made, for special purposes, from materials other than those used for Portland cements, but the use of these non-Portland cements is outside the scope of this publication.

The setting and hardening of cement results from a chemical reaction between cement and water, not from a drying process. This reaction is called hydration. It produces heat and is irreversible. Setting is the gradual stiffening whereby the cement paste changes from a workable to a hardened state. Subsequently the strength of the hardened mass increases, rapidly at first but becoming progressively less rapid. This gain of strength will continue indefinitely provided moisture is present.

All British cement manufacturers declare that their products conform to the appropriate British and European Standard by marking their cement test reports and either the bags or delivery notes with the name, number and date of the relevant Standard. In addition, cement is currently manufactured and supplied to the nationally-recognized third-party product certification scheme - the BSI Kitemark Scheme for Cement. In the course of replacing British Standards for cement by harmonized European standards, these principles of declaration and certification will be verified by affixing the European CE marking.

Portland cement CEM I

The cement most commonly used was formerly known as OPC in British Standards and, more recently, PC to BS 12. It is now known as Portland cement CEM I manufactured to conform to BS EN 197-1.

CEM I 42,5 and CEM I 52,5 strength class products account for all UK CEM I cement production and their main active chemical compounds are proportioned so that they have medium to high strength development and heat evolution. CEM I in bags is generally a 42,5N cement whereas CEM I for bulk supply tends to have a higher strength classification such as 42,5R or 52,5N.

CEM I can include up to 5% of minor additional constituents such as limestone fines.

Within a 30-year period from around 1960 to 1990, the 28-day strength of this cement can be seen to have shifted from just below the bottom of what is now termed strength class 42,5N towards strength class 52,5N. This was a consequence of continued improvements in the production process and quality control. In addition, early strength and the heat of hydration also increased as a result of the higher reactivity of the product. Since around 1990, however, the introduction of the strength classification system into British Standards has led to stability in the strength of Portland cements. This stable situation should continue into the long term, providing users with a more predictable product regardless of their location in the UK.

Cements are now classified in terms of both their standard strength, derived from their performance at 28 days and at an early age, normally 2 days, using a specific laboratory test based on a standard mortar prism. This is termed their strength class; for example CEM I 42,5N where 42,5 denotes the standard strength and N indicates a normal early strength.

It is important to recognize that cement strength classes do not limit the strength of concrete that may be produced using these cements: they simply represent a cement classification system based on prisms of mortar tested in a laboratory.

The most common standard strength classes for manufactured cements are 42,5 and 52,5 with 32,5 used less often. These can take either N (normal) or R (rapid) identifiers depending on the early strength characteristics of the product. Another standard strength class (22,5) also exists but this tends to be associated with particular special cements.

If cement clinker is ground more finely, the greater surface area of the finer cement produces a faster rate of early strength development. This is often used to advantage by precast concrete manufacturers in order to achieve a more rapid turn round of moulds, or on site where it may be desirable to reduce the time for which formwork must remain in position. Cements that have these rapid-hardening properties, formerly known as rapid-hardening Portland cement (RHPC), are now produced in the UK within the 52,5 strength classes of CEM I. They generate more early heat than CEM I 42,5 and can often be useful in cold weather.

CEM I 52,5 can also be used as an alternative to CEM I 42.5 when high strength may be an advantage, particularly at early ages.

The term 'rapid-hardening' should not be confused with 'quick-setting'. Concrete made, for example, with CEM I 52,5N stiffens and initially hardens at a similar rate to a CEM I 42,5N; it is after the initial hardening that the strength increases more rapidly.

A low early strength identifier (L) also exists in British Standards, but is reserved for blastfurnace cements with strength properties outside the scope of BS EN 197-1, and is not applied to CEM 1.

It is worth noting that the setting times specified in standards relate to the performance of a cement paste of standard consistence in a particular test under closely controlled temperature and humidity conditions; the stiffening and setting of concrete on site are not directly related to these standard setting regimes, and are more dependent on workability, the cement content, any admixture used, the temperature of the concrete and ambient conditions.

Sulfate-resisting Portland cement SRPC

Sulfate-resisting Portland cement (SRPC) is a form of Portland cement with a low tricalcium aluminate (C_3A) content. BS 4027, the British Standard for SRPC, limits the C_3A content to 3.5%. This limitation is achieved by adding iron oxide, thereby decreasing the proportion of alumina in the raw feed material; this favours the formation of calcium aluminoferrite (C_4AF) over C_3A in the cement kiln. This higher iron content tends to give SRPC a darker colour.

When concrete made with CEM I cement is exposed to sulfate solutions that are found in some soils and groundwaters, a reaction may occur between the sulfate and the hydrates from the C_3A in the cement, causing deterioration of the concrete. By limiting the C_3A content in SRPC, a cement with superior resistance to conventional sulfate attack is produced. However, resistance to sulfate attack depends on the cement content and impermeability of the concrete as well as on the composition of the cement. Details of requirements can be found in BS 5328, BS EN 206-1, BS 8500 and BRE Special Digest 1.

SRPC is normally a low-alkali cement, but otherwise is similar to other Portland cements in that it is not resistant to strong acids. Further details about durability and sulfate resistance are given on page 21 under *Durability of concrete.* The strength properties of SRPC are similar to those of CEM I 42,5N and it should be stored and used in the same way. SRPC normally produces slightly less early heat than CEM I 42,5N. This may be an advantage in massive concrete and in thick sections.

It is not normal practice to combine SRPC with pulverized-fuel ash or ground granulated blastfurnace slag. See *Cements and mixer combinations incorporating mineral constituents or additions* (below) for further information on these additional cementitious materials.

White Portland cement

White Portland cement is made from specially selected raw materials, usually pure chalk and white clay, containing only a very small quantity of iron. In addition, manufacturing processes are modified so that discolouring materials are not included during firing or grinding.

White Portland cement generally available in the UK is a 52,5 strength class product, which means it has a higher early strength and higher standard 28-day strength than a CEM I 42,5N but with similar setting properties.

It is made to satisfy the requirements of CEM I to BS EN 197-1, so there is no separate British Standard. It is used for concrete where a white or light colour finish is desired, often in conjunction with special aggregates. Extra care must be taken in handling white cement to avoid contamination, and in the batching, mixing and transportation of the concrete to ensure that all equipment is kept clean It is equally important to make sure that the finished concrete is protected, because it gets dirty very easily in the early stages of its life and is almost impossible to clean later

Careful selection is required of the type of release agent and, if used, the sprayed-on curing membrane The use of damp hessian is not recommended as it may stain the concrete

Cements and mixer combinations incorporating mineral constituents or additions CEM II and CII, CEM III and CIII, CEM IV and CIV

These are cements that are either interground or blended with mineral materials at the cement factory or combined in the concrete mixer with additions The mineral materials and additions most frequently used in the UK and to which British Standards apply are pulvenzed-fuel ash (pfa) to BS 3892, fly ash to BS EN 450, ground granulated blastfurnace slag (ggbs) to BS 6699 and limestone fines to BS 7979

Other additions include condensed silica fume, extracted during the smelting process of ferrosilicon alloy, and metakaolin, produced from China clay (kaolin) These are intended for specialised uses of concrete beyond the scope of this publication

The two methods of incorporating the mineral additions make little or no difference to the properties of concrete and, until recently, it was considered unnecessary to distinguish between them In 2000 a new notation system for cements was introduced with BS EN 197-1 and for mixer combinations with BS 8500 in 2002, giving a unique code identifying both composition and method of production

It is convenient to be able to identify cements by their notation and to consider them separately either as manufactured cement or mixer combinations It should be emphasised, however, that the controlled ways by which mineral additions have to be introduced ensure that the quality of concrete is unaffected by differences in their production methods

Technical benefits

The incorporation of pfa, fly ash or ggbs with CEM I has been particularly useful in massive sections of concrete where they have been used primarily to reduce the temperature rise of the concrete, and thus to reduce temperature differentials and peak temperatures The risk of early thermal contraction cracking is thereby also reduced

One of the options available for minimizing the risk of damage due to alkali-silica reaction, which can occur with certain aggregates, and for increasing the resistance of concrete to sulfate attack, is to use additions with Portland cement or CEM II or CEM III cements

Most additions do not react very quickly at early ages at normal temperature, and at reduced temperature the reaction - particularly in the case of ggbs - can be considerably retarded and make little contribution to the early strength of concrete Provided that the concrete is not allowed to dry out they can increase the long-term strength and impermeability of concrete

Table 2: Early-age properties of concrete incorporating pfa or ggbs - summary of comparisons with Portland cement CEM I

Property	Pfa	Ggbs	Comment
Workability/ consistence	Increased for same w/c ratio. Possible to keep same consistence but reduce w/c ratio	Small differences	
Setting times	Increased	Increased. Substantially increased with high ggbs content	Still within BS limits
Formwork pressures	Increased by about 10-20 kN/m^2	May be increased	See Concrete Society Report CS030 and CIRIA Report 108
Bleeding	Generally reduced (some exceptions)	Small differences	
Quality of finish	Improved quality with lean mixes. Not much difference with rich mixes. Darker colour.	Much the same. May give temporary blue/green colour.	
Time interval to finishing	Increased	Substantial increase if ggbs content is high and concrete temperature is low	Increased time until finishing can be a disadvantage in cold conditions and an advantage in hot weather
Plastic settlement cracking	Generally reduced where bleeding is reduced	Greater risk, which increases as the ggbs content increases	Re-vibration at the correct time will remove plastic settlement cracking. An alternative is to reduce bleeding
Plastic shrinkage	Increased	May be increased	Prompt curing will prevent plastic shrinkage cracking
Early age strength a) Equal binder content b) Equal 28-day strength	 Reduced Small reduction (about 10%)	 Substantially reduced. Lower strengths with increasing % ggbs Significantly reduced e.g. after 3 days at 20°C, a 40% ggbs mix will have about half the strength of CEM I	 Particular problems with ggbs based cements in thin sections in cold weather
Formwork striking times a) Equal binder content b) Equal 28-day strength	 Increased Small increase in thin sections; much the same in large sections	 Increased Increased in thin and medium sections	See CIRIA Report 1 36 Other methods such as pull-out testing or temperature-matched curing can be used
Early-age thermal cracking	Risk reduced in sections between 500 mm and 2.5 m thick.		Using aggregate with low coefficients of thermal expansion is more effective
Curing	Increased sensitivity to poor curing but larger potential for recovery. Longer curing periods needed	Increased sensitivity to poor curing. Longer curing periods needed	Views differ on this subject. See BS 8110 for curing periods
Air-entrainment	Considerable increase in admixture dosage likely to be required	Small differences	Special admixture may be required where pfa is used

When the terms 'water/cement ratio' or 'cement content' are used in British Standards, these are understood to include combinations. Sometimes the word 'binder' is used which is interchangeable with the words 'cement' or 'combination'.

Tables 2 and 3 indicate the differences that can be expected between concrete made with CEM I and concrete incorporating pfa or ggbs.

Blastfurnace slag cements

Granulated blastfurnace slag (ggbs) is a by-product of iron smelting. It is made by quenching selected molten blastfurnace slag to form granules. The granulated slag may be interground or blended with Portland cement clinker at certain cement works to produce:

- Portland-slag cement CEM II/A-S with a slag content of 6 - 35% conforming to BS EN 197-1
- Or, more commonly, blastfurnace cement CEM IIIA, which contains 36 - 65% ggbs, conforming to BS EN 197-1.

Alternatively, the granules may be ground down separately to a white powder with a fineness similar to that of cement and combined in the concrete mixer with CEM I cement to produce a blastfurnace cement.

Mixer combinations of typically 40 - 50% ggbs with CEM I have the notation CIIIA and, at this level of addition, 28-day strengths are similar to those obtained with CEM I 42,5N.

As ggbs has little hydraulic activity of its own but is activated by the calcium hydroxide and other alkaline solutions produced by the hydration of Portland cement, it is referred to as 'a latent hydraulic binder'. Cements incorporating ggbs generate less heat and gain strength more slowly. The strengths at early ages are lower than those obtained with CEM I.

Table 3: Properties of hardened concrete incorporating pfa or ggbs - summary of comparisons with Portland cement CEM I

Property	Pfa	Ggbs	Comment
Long-term strength (as a proportion of 28-day strength)	Greater with good curing	Greater with good curing	Depends on materials used and curing
General physical properties of hardened concrete (modulus, creep)	Similar properties	Similar properties	Primarily depends on concrete strength at loading
Resistance to carbonation-induced corrosion	Similar resistance	Similar resistance up to 50%	Depends on concrete strength class, exposure and curing conditions
Resistance to chloride-induced corrosion	Greater resistance	Greater resistance	For equal w/c and well cured
Seawater attack	Similar performance	Similar performance	Primarily depends on concrete quality
Sulfate resistance	Greater resistance with 25 - 40%	Greater resistance with over 60%	See BRE Special Digest 1
Freeze-thaw resistance	Similar performance except at early age	Similar performance except at early age	Depends on strength at time of exposure to freezing
Abrasion resistance	Similar performance except at early age	Similar performance except at early age	Depends on strength at time of exposure to abrasion
Alkali-silica reaction	Often used for minimizing risk of damage	Often used for minimizing risk of damage	Requires selection of suitable proportion of pfa or ggbs
NOTE The durability of concrete depends on the correct proportions of pfa or ggbs incorporated. Guidance is given in BS 5328, BS EN 206-1, BS 8500 and in BRE Special Digest 1.			

Blastfurnace cement, either the manufactured CEM III/A or the mixer combinations CIIIA, may be used for all purposes for which CEM I is used but, because it has a lower early development of strength, particularly in cold weather, it may not be suitable where early removal of formwork is required. It is a moderately low-heat cement and can, therefore, be used to advantage to reduce early heat of hydration in thick sections.

When the proportion of ggbs is 66 - 80% the notation CEM III/B applies for the manufactured cement and CIIIB for a mixer combination. This was previously known as high slag blastfurnace cement and is specified because of its lower heat characteristics or to impart resistance to sulfate attack.

Because the reaction between ggbs and lime released by the Portland cement is dependent on the availability of moisture, extra care has to be taken in curing concrete containing these cements or combinations in order to prevent premature drying out and to permit the development of strength.

BS 146 continues in revised form to allow for UK provisions not included in the European Standard EN 197-1 for blastfurnace slag cements. There is currently no equivalent EN relating to ggbs as an addition and, accordingly, BS 6699 continues to apply.

Pulverized-fuel ash cements and fly ash cements

The ash resulting from the burning of pulverized coal in power station furnaces is known in the concrete sector as pulverized-fuel ash (pfa) or fly ash.

This ash is fine enough to be carried away in the flue gases and is removed from the gases by electrostatic precipitators to prevent atmospheric pollution.

The precipitated material is a fine powder of glassy spheres that can have pozzolanic properties, i.e. when mixed into concrete it can react chemically with the calcium hydroxide (lime) that is released during the hydration of Portland cement. The products of this reaction are cementitious, and in certain circumstances pfa or fly ash can be used to replace part of the Portland cement in concrete.

The properties of fly ash for use as a cementitious component in concrete are specified in BS EN 450 with additional UK provisions for pfa made in BS 3892: Part 1. Pfa conforming to Part 2 of the same BS (Part 2 ash) is more coarse and is generally regarded as an inert addition used, for example, to modify properties of aggregate such as their gradings.

Fly ash, in the context of BS EN 450, means 'coal fly ash' rather than ash produced from other combustible materials. Fly ash conforming to BS EN 450 can be coarser than that conforming to BS 3892 : Part 1. However, fly ash to BS EN 450 can be used, in accordance with BS EN 206-1 and BS 8500 as a 'Type II addition' (pozzolanic or latent hydraulic material) in order to improve certain properties or to achieve special properties.

Substitution of these types of cement for Portland cement is not a straightforward replacement of like for like, and the following points have to be borne in mind when designing pfa concrete:

- Pfa reacts more slowly than Portland cement. At early age and particularly at low temperatures pfa contributes less strength; to achieve the same 28-day compressive strength the amount of cementitious material may need to be increased - typically by about 10%. The potential strength after three months is likely to be greater than CEM I provided the concrete is maintained in a moist environment, such as in underwater structures or concrete in the ground

PORTLAND CEMENTS

A guide to the notation of cements and combinations

Manufactured cements are those made in a cement factory. Where a mineral material is included, it is generally added to the cement clinker at the grinding stage. These manufactured cements are all identified by the prefix letters CEM.

Where a concrete producer adds an addition such as pfa or ggbs to CEM I Portland cement in the mixer, the resulting cement is known as a mixer combination identified by the prefix notation C.

CEM I was described earlier. However, when the letters CEM (or C) are followed by the numbers II, III or IV these relate to an increasing proportion of addition:

- CEM II (and CII) include up to 35% of mineral addition
- CEM III (and CIII) include higher proportions of blastfurnace slag
- CEM IV (and CIV) include higher proportions of pozzolana (such as pfa).

Cement type CEM I consists almost entirely of Portland cement clinker and gypsum set regulator. Notation for the other types includes a letter that in a simple way identifies the relative proportion of clinker. High proportions are represented by A, moderate proportions by B whilst C means a lower proportion of clinker. Of course, where the proportion of Portland cement clinker is high, the proportion of the second constituent, the addition, is relatively low.

Cement type CEM II (or CII) is the only one in which the type of addition needs to be identified and the following letters are used for this group:

V - siliceous fly ash (such as pfa)

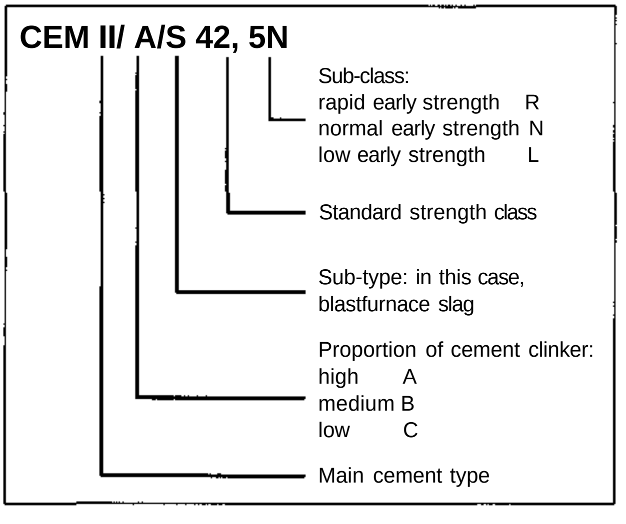
S - blastfurnace slag

D - silica fume

L and LL - limestone

M - more than one of the above

The strength class and strength development characteristics, explained earlier, have their identifiers added to the end of the notation so that the full title, for example, of a manufactured cement with a relatively low proportion of ggbs would be Portland-slag cement BS EN 197-1 CEM II/A-S 42,5N as shown below.



The types of cement and combinations in most common usage are shown with their notation in Table 4.

Table 4: Cements and combinations in general use

Cement/ combination type	Notation of manufactured cement conforming to BS EN 197-1	Notation of mixer combination conforming to BS 8500 : Part 2
Portland cement	CEM I	-
Sulfate-resisting Portland cement	SRPC conforms to BS4027.	—
Portland-fly ash cement incorporating 21 - 35% pfa	CEM II/B-V	CIIB-V
Portland-slag cement incorporating 6 - 20% ggbs	CEM II/A-S	CIIA-S
Portland-slag cement incorporating 21 - 35% ggbs	CEM II/B-S	CIIB-S
Blastfurnace cement incorporating 36 - 65% ggbs	CEM III/A May also conform to BIII/A of BS146	CIIIA
Blastfurnace cement incorporating 66 - 80% ggbs	CEM III/B May also conform to BIII/B of BS 146	CIIIB
Portland-limestone cement incorporating 6 - 20% limestone	CEM II/A-L CEM II/A-LL	CEM IIA-L CEM IIA-LL

- The water demand of pfa for equal consistence may be less than that of Portland cement
- The density of pfa is about three-quarters that of Portland cement
- The reactivity of pfa and its effect on water demand, and hence strength, depend on the particular pfa and the Portland cement with which it is used. A change in the source of either material may result in a change in the replacement level required
- Where pfa concrete is to be air-entrained, the admixture dosage rate may have to be increased, or an alternative formulation that produces a more stable air bubble structure should be used
- Portland-fly ash cement comprises, in effect, a mixture of CEM I and pulverized-fuel ash
- When the ash is interground/blended with Portland cement clinker at an addition rate of 20 - 35% the manufactured cement is known as Portland-fly ash cement CEM II/B-V conforming to BSEN 197-1
- Where this combination is produced in a concrete mixer it has the notation CIIB-V conforming to BS 8500 : Part 2.

PORTLAND CEMENTS

Typical proportions are 25 - 30% ash and these cements can be used in concrete for most purposes. It is likely to have a lower rate of strength development compared with CEM I. When the cement contains 25 - 40% pfa or fly ash it may be used to impart resistance to sulfate attack and can also be beneficial in reducing the harmful effects of alkali-silica reaction.

Where higher replacement levels of ash are used for improved low-heat characteristics, the resulting product is pozzolanic (pulverized-fuel ash) cement CEM IV/B manufactured to conform to BS EN 197-1 or, if combined in the concrete mixer, CIVB-V conforming to BS 8500 : Part 2.

Because the pozzolanic reaction between pfa or fly ash and free lime is dependent on the availability of moisture, extra care has to be taken in curing concrete containing mineral additions in order to prevent premature drying out and to permit the development of strength.

Portland-limestone cement CEM II/A/L and CEM II/A-LL

Cement that incorporates 6 - 35% of carefully selected fine limestone powder is known as Portland-limestone cement conforming to BS EN 197-1. Where a 42,5N product is manufactured, the typical proportion of limestone is 10 - 20%, with the notation CEM II/A-L or CEM II/A-LL. It is most popular in continental Europe and its usage is growing in UK. Decorative precast and reconstituted stone concretes benefit from its lighter colouring and it is also used for general-purpose concrete in non-aggressive and moderately aggressive environments.

Delivery and storage of cement

Cement may be delivered in bulk or in bags. Bulk cement is delivered by tanker, usually in loads of more than 25 tonnes and blown into storage silos by compressed air. Bagged cement is usually supplied in bags containing 25 kg or, very rarely 50 kg, whilst 1 tonne bags are also available from some suppliers for special purposes. It is often convenient to use bags on a smaller site, but cement is cheaper in bulk.

Cement should be kept dry during storage as moist air leads to the phenomenon of air-setting, which results in the formation of lumps of hydrated cement. Air-set cement should not be used, as concrete made from it could have a much reduced strength.

Silos have to be weatherproof but, during prolonged periods of storage, some air setting may occur due to condensation in the silo. This is minimized by aeration, which should be done frequently in periods of prevailing damp weather. In addition, the weatherproofness of the silo should be checked if there is any evidence of the formation of lumps in the cement.

Regular maintenance of cement silos is essential. All moving parts should be kept free from coatings of cement by cleaning at least at the end of every day. Weigh hoppers should also be cleaned every day, both inside and out, since a build-up of cement can result in top little cement being dispensed, and weigh gear checks should be carried out at least once a month. Silo air filters must be cleaned after every cement delivery to prevent them from becoming choked; this is done by giving them a thorough shaking or, preferably, by replacing old filters with reverse-air jet units that prevent contamination of the environment.

Bagged cement should be stored on a raised floor in a weather-tight shed in order to prevent deterioration. Failing this, it should be, stacked on a raised timber platform and covered by waterproof covers with generous overlaps (Figure 1). The bags should be used in the order in which they are received; thus each delivery should be kept separate to avoid confusion. To avoid 'warehouse set', which results from the compaction of cement, bags should not be stacked higher than about 1.5 m. The paper bags used for packing cement are not vapour proof, so undue exposure should be avoided. Even when stored under good conditions, bagged cement may lose 20% of its strength after two months' storage. To avoid risk of accidental confusion, cements of different types should be stored separately.

Sampling and testing of cement

The testing of cement requires the resources of a well-equipped laboratory with strictly controlled temperature and humidity, which are seldom achieved on site. Manufacturers in the UK produce cement whose conformity is certificated by a third party in a scheme based on a strict regime of inspection and independent audit testing. Cement test reports showing results of physical and chemical tests are forwarded to users of the cement and it is general practice for concrete producers to monitor cement quality by continuously assessing the data and thereby avoiding unnecessary duplication of costly tests on cement.

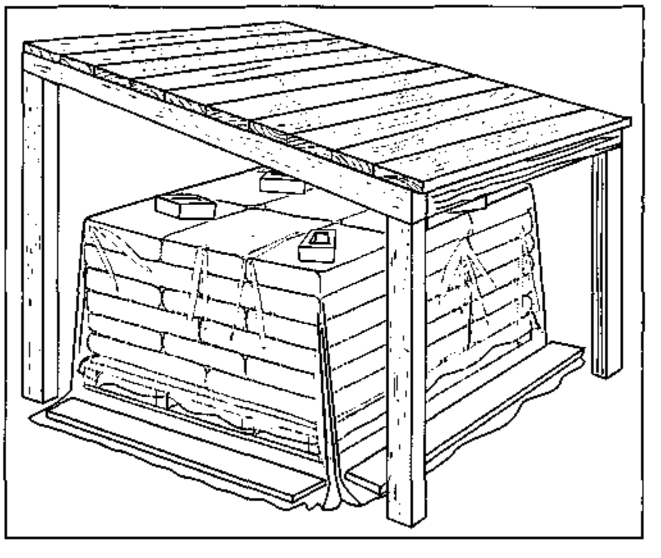


Figure 1: Correct storage of bagged cement on site: note raised timber platform and plastic sheeting.

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AGGREGATES

The term 'aggregates' is used to describe the gravels, crushed rocks and sands that are mixed with cement and water to make concrete. As aggregates form the bulk of the volume of concrete and can affect its performance, the selection of suitable material is important.

Sand includes natural sand, crushed rock or crushed gravel which is fine enough to pass through a sieve with 5 mm apertures. Coarse aggregate comprises larger particles of gravel, crushed gravel or crushed rock. The size of the sieve used to distinguish between sand and coarse aggregate is expected to be changed to 4 mm throughout Europe.

Most concrete is made from natural aggregates that are usually specified to conform to the requirements of BS 882 and BS EN 12620 together with the UK National Annex. Manufactured lightweight aggregates are sometimes used (see page 12).

Sizes of aggregate

The maximum size of coarse aggregate, D_{max} is governed by the type of work to be done. For reinforced concrete it should be such that the concrete can be placed without difficulty, surrounding all reinforcement thoroughly, particularly in the cover zone, and filling the corners of the formwork. It is usual in the UK for coarse aggregate for reinforced concrete to have a maximum size of 20 mm.

Aggregate of D_{max} 40 mm can be used for foundations and mass concrete and similar sections where there are no restrictions to the flow of concrete. It should be noted, however, that concrete with D_{max} 40 mm aggregate is not always available from producers of ready-mixed concrete. The use of a larger aggregate results in a slightly reduced water demand and hence a slightly reduced cement content for a given strength and workability.

Smaller aggregate, usually D_{max} 10 mm, may be needed for concrete that is to be placed through congested reinforcement for example. In this case the cement content may have to be increased by 10 - 20% to achieve the same strength and workability as with a 20 mm maximum-sized aggregate concrete because the sand content and water content normally have to be increased to produce a cohesive mix.

Quality requirements

Durability

Aggregates should be hard and should not contain materials that are likely to decompose or change in volume when exposed to the weather. Examples of undesirable materials are lignite, coal, pyrite and lumps of clay. Coal and lignite may swell and decompose leaving small holes on the surface of the concrete; lumps of clay may soften and form weak pockets; and pyrite may decompose, causing iron oxide stains to appear on the concrete surface. When exposed to oxygen, pyrite has been known to contribute to sulfate attack. High-strength concretes may call for additional special properties. The mechanical properties of aggregates for heavy-duty concrete floors and for pavement wearing surfaces may have to be specially selected. Most producers of aggregate are able to provide information about these properties, and reference, when necessary, should be made to BS 882 / BS EN 12620.

There are no simple tests for durability or freeze/thaw resistance, and assessment of particular aggregates may be based on experience of the properties of concrete made with the type of aggregate in question with a knowledge of its source. Some flint gravels with a white porous cortex may be frost-susceptible because of the high water absorption of the cortex, which results in pop-outs on the surface of the concrete when subjected to freezing and thawing.

AGGREGATES

Cleanness

Aggregates should be clean and free from organic impurities; aggregate containing organic material makes poor concrete. The particles should be free from coatings of dust or clay, as these prevent the proper bonding of the material. An excessive amount of fine dust or stone 'flour' may prevent the particles of stone from being properly coated with cement and thus lower the strength of the concrete. Gravels and sand are usually washed by the suppliers to remove excess fines (clay and silt, for example) and other impurities, which, if present in excessive amounts, result in a poor-quality concrete. However, excessive washing can remove all fine material passing the 300 µm sieve. This may result in a concrete mix lacking in cohesion and, in particular, being unsuitable for placing by pump. Sands deficient in fines also tend to increase the bleeding characteristics of the concrete, which can result in poor vertical finishes due to water scour.

Limits on the amount of fines are given in BS 882 when determined in accordance with the wet sieving method specified in BS812.

An approximate guide to the fines content of gravel sand can be obtained from the field settling test. Results of this test cannot be used as the basis for accepting or rejecting material but they are nevertheless useful by detecting changes in the cleanness of sand. More details are given on page 54 under *Testing materials, aggregates.*

Where colour of surface finish is important, supplies of aggregate should be obtained from one source throughout the job whenever practicable. This is particularly important for the sand - and for the coarse aggregate if an exposed-aggregate finish is required.

Grading of aggregates

The proportions of the different sizes of particles making up the aggregate are found by sieving and are known as the 'grading' of the aggregate: the grading is given in terms of the percentage by mass passing the various sieves. Continuously graded aggregates for concrete contain particles ranging in size from the largest to the smallest; in gap-graded aggregates some of the intermediate sizes are absent. Gap-grading may be necessary in order to achieve certain surface finishes. The sieves used for making a sieve analysis should conform to BS 410 or BS EN 933-2. The tests should be carried out in accordance with the procedure given in BS 812 or BS EN 933-1

An aggregate containing a high proportion of large particles is referred to as being 'coarsely' graded and one containing a high proportion of small particles as 'finely' graded. Grading envelopes for sand of grading M and for 20 mm graded coarse aggregate are shown in Figure 2.

Grading limits for 'all-in' aggregates are also given in BS 882/ BS EN 12620. All-in aggregate, composed of both fine and coarse aggregate, should not be used for structural reinforced concrete work because the grading will vary considerably from time to time and hence from batch to batch, resulting in excessive variation in the consistence and the strength. To ensure that the proper amount of sand is present, the separate delivery, storage and batching of coarse and fine aggregates is essential.

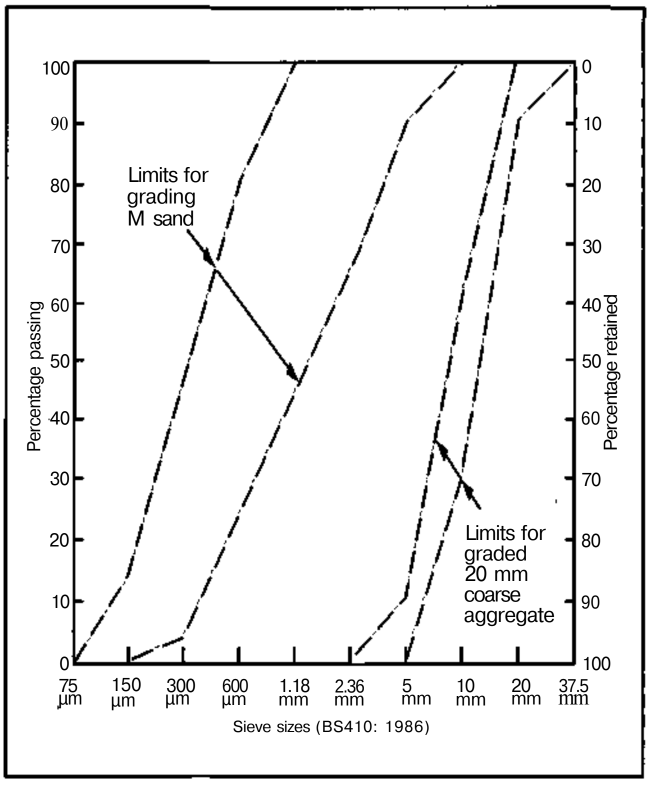

Figure 2: Grading envelopes for grading M sand and 20 mm graded coarse aggregate (as given in BS 882 : 1992).

Coarse aggregates

For a high degree of control over the production of concrete, and particularly where high-quality surface finishes are required, it is necessary for the coarse aggregate to be delivered, stored, and batched using separate single sizes rather than a graded coarse aggregate.

The sieve sizes in general use are 50, 37.5, 20, 14, 10, 5 and 2.36 mm for coarse aggregate. The grading limits are shown in Table 5.

Graded coarse aggregates which have been produced by layer loading - (filling a lorry with, say, two grabs of 20 - 10 mm and one grab of 10 - 5 mm) - are seldom satisfactory because the materials are unmixed and will not be uniformly graded. Graded coarse aggregate should be mixed efficiently by the producer before loading lorries.

Table 5: Grading limits for coarse aggregate (from BS 882 : 1992).

Sieve size (mm)	Percentage by mass passing BS sieves for nominal sizes						
	Graded aggregate			Single-sized aggregate			
	40 mm to 5 mm	20 mm to 5 mm	14 mm to 5 mm	40 mm	20 mm	14 mm	10 mm
50	100	-	-	100	-	-	-
37.5	90 - 100	100	-	85 - 100	100	-	-
20	35 - 70	90 - 100	100	0 - 25	85 - 100	100	-
14	25 - 55	40 - 80	90 - 100	-	0 - 70	85 - 100	100
10	10 - 40	30 - 60	50 - 85	0 - 5	0 - 25	0 - 50	85 - 100
5	0 - 5	0 - 10	0 - 10	-	0 - 5	0 - 10	0 - 25
2.36	-	-	-	-	-	-	0 - 5

AGGREGATES

Sand

The sieve sizes in general use are 10, 5, 2.36, 1.18 mm and 600, 300 and 150 µm. The fines content is determined by wet sieving through a 75 µm sieve.

The C-M-F system of classification for sand in Table 6 is useful for selecting appropriate proportions of fine and coarse aggregates in a mix, because the optimum proportion of sand is partly related to its fineness. Good concrete can be made with sand within the overall limits shown in Table 6. Where the variability of grading needs to be restricted further for the design of particular mixes or for the adjustment of sand content of prescribed concrete mixes, this can be achieved by reference to one or more of the three additional grading limits C, M or F. Sand with grading F should normally be used only after trial mixes have been made with the proposed combination of sand and coarse aggregates and cement to determine their suitability for the particular purpose. There may be occasions, such as when a high degree of control is required, and when high-quality surface finishes have to be achieved, when it is necessary to specify sand gradings to closer limits than those permitted in BS 882/BS EN 12620 and shown in Table 6. On the other hand, sand whose gradings fall outside the Standard limits may produce perfectly satisfactory concrete. It is not so much the grading limits themselves that are important, but that the grading is maintained reasonably uniform.

Table 6: Grading limits for sand (from BS 882 : 1992).

Sieve size	Percentage by mass passing BS sieve			
	Overall limits	Additional limits for grading C	M	F
10 mm	100	-	-	-
5 mm	89 - 100	-	-	-
2.36 mm	60 - 100	60-100	65 - 100	80 - 100
1.18 mm	30-100	30- 90	45 - 100	70 - 100
600 µm	15 - 100	15- 54	25- 80	55-100
300 µm	5- 70	5- 40	5- 48	5- 70
150 µm	0- 15*	-	-	-

*Increased to 20% for crushed rock sand except when they are used for heavy-duty floors

NOTE
Sand not conforming to this table may also be used provided that the supplier can satisfy the purchaser that such materials can produce concrete of the required quality. For heavy-duty concrete floor finishes, the sand should conform to gradings C or M.

Marine-dredged aggregates

Large quantities of aggregates are obtained by dredging marine deposits, and they have been widely and satisfactorily used for making concrete for many years.

If present in sufficient quantities, hollow and/or flat shells may affect the properties of the fresh and hardened concrete. Limits on shell content are given in BS 882:

- For 20 mm and larger coarse aggregates (single-sized, graded or all-in) the limit is 8%
- For 10 mm to 5 mm coarse aggregate the limit is 20%
- For sand there is no limit.

In order to reduce the risk of corrosion of embedded metal, limits are specified in BS 5328, BS EN 206-1 and BS 8500 for the chloride content of the concrete. To conform to these limits it is necessary for marine-dredged aggregates to be carefully and efficiently washed with frequently changed fresh water to reduce the salt content. Chloride contents should be checked frequently throughout aggregate production in accordance with the method given in BS 812 : Part 117.

Appendix C in BS 882 gives maximum chloride contents for the combined aggregates; these limits have been derived from those given in BS 5328 but do not necessarily ensure conformity to BS 5328 for all concrete mixes, particularly those with a low cement content. For reinforced concrete made with CEM I, in tests for the total maximum chloride content, expressed as percentage chloride ion by mass of combined aggregate, no result should be greater than 0.08% and 95% of the test results should not be more than 0.05%. For concrete made with sulfate-resisting Portland cement the maximum chloride content of the combined aggregate should not be more than 0.03%. For prestressed concrete and steam-cured structural concrete BS 882 recommends that the maximum total chloride content expressed as percentage of chloride ion by mass of combined aggregate should not exceed 0.01 %.

Some sea-dredged sands tend to have a preponderance of one size of particle and a deficiency in the amount passing the 300 µm sieve. This can lead to mixes prone to bleeding unless mix proportions are adjusted to overcome the problem. An increase in the cement content by 5 - 10% will often offset the lack of fine particles in the sand.

Beach sands are generally unsuitable for good-quality concrete, since they are likely to have high concentrations of chloride because of the accumulation of salt crystals above the high-tide mark. They are also often single-sized, which can make the mix design difficult.

Lightweight aggregates

In addition to natural gravels and crushed rocks, a number of manufactured aggregates are available for use in concrete. Lightweight aggregates such as sintered pfa are required to conform to BS 3797/BS EN 13055-1.

Lightweight aggregates have been used in concrete for many years - the Romans made use of pumice in some of their construction work. Small quantities of pumice are imported and still used in the UK, mainly in lightweight concrete blocks, but most lightweight aggregate concrete is made using manufactured aggregates. All lightweight materials are relatively weak because of their higher porosity, which gives them reduced weight. This imposes a limitation on strength, though this is not often a serious problem because the strength that can be obtained is comfortably in excess of most structural requirements. Lightweight aggregates are used to reduce weight in structural elements or to give improved thermal insulation.

Delivery of aggregates

Quality control of concrete should start with a visual inspection of the aggregates as they are delivered, combined with some quick, simple testing if there is any doubt about their quality or grading.

The cleanness of sands can be checked quickly by hand. If a sample of sand is rubbed between the palms of the hands, staining of the palms may be an indication that an excessive amount of clay and silt are present, due to inadequate washing.

Confirmation or denial of this indication can be determined by the field settling test described under *Cleanness* on page 54. Coarse aggregates should be inspected visually for clay lumps and clay coatings, grading and particle shape. Clay lumps are not always obvious and careful inspection of deliveries is advised. Loads containing such lumps should be rejected before discharge.

As previously mentioned on page 11, layer loading of lorries produces an aggregate that is unmixed, and problems will occur in obtaining a uniform concrete. Such loads should be rejected.

A further problem with gravel coarse aggregates may occur when oversized material is crushed. Such material tends to be of an angular particle shape, rather than rounded or irregular, and a load of all crushed material or a load containing a large part of crushed as well as uncrushed, can lead to variations in the water demand, consistence and strength unless adjustments are made to the mix. Coarse aggregate should have a uniform particle shape for production of high quality concrete.

A useful means of detecting changes in grading or shape is by the loose bulk density test in accordance with BS 812 : Part 108.

Storage of aggregates

Aggregates should be stored so that they are kept as uniform as possible in grading and moisture content, and protected from intermingling and contamination by other materials.

It is best to put down a layer of concrete over the areas where the aggregates will be stored. The concrete should be laid to fall away from the mixer to allow free drainage of water from the aggregate, and should extend well out from the mixer set-up so that all deliveries can be tipped onto it. If a clean, hard base is not provided, the bottom 300 mm of each aggregate pile should not be used, since dirt and water can accumulate there.

It is essential to provide substantial partitions to separate the different aggregate sizes and to prevent spillage from one bay to another. Such partitions can be made using concrete, brick or block retaining walls, or by driving H-section steel members into the ground and laying heavy timber sections between them.

Stockpiles should be as large as possible, as this helps to ensure uniformity of moisture content. Variations in the moisture content of coarse aggregates as delivered, or in the stockpiles, are usually not sufficient to have much effect on the control of free water/cement ratio. However, the variations that commonly occur in the moisture content of sand will require adjustment to be made in order to control the free water/cement ratio.

Ideally, stockpiled sand should be allowed to stand for 12 hours before use so that, apart from the lower part of the stockpile, the moisture content will be reasonably uniform at about 5 - 7%. When sand is very wet (as sometimes happens with fresh deliveries, or after it has been raining) the moisture content can be as high as 12-15%. Unless adjustments are made to the water added at the mixer, excessive variations in workability, strength and durability will result.

For large batching plants the aggregate would probably be lifted by a conveyor system to covered overhead storage hoppers discharging directly into weigh-batchers.

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WATER

Quality

The water used for mixing concrete should be free from any impurities that could adversely affect the process of hydration and, consequently, the properties of concrete.

For example, some organic matter can cause retardation whilst chlorides may accelerate the stiffening process and also cause embedded steel such as reinforcing bars to corrode. Other chemicals such as sulfate solutions and acids may have harmful long-term effects by weakening the cement paste by dissolving it.

It is important, therefore, to be sure of the quality of water. If it comes from an unknown source such as a pond or borehole it should be checked by making trial mixes. The British Standard 3148 specifies the quality of water and gives the procedures for checking its suitability for use in concrete. BS EN 1008, which supersedes BS 3148, had not been finalised at the time this handbook was published.

Drinking water is suitable, of course, and it is usual simply to obtain a supply from the local water utility. But some recycled water is being increasingly used in the interests of reducing the environmental impact of concrete production, and seawater has been used successfully in mass concrete with no embedded steel. The use of seawater does not normally affect the strength of plain Portland cement concrete, but it must not be used for concrete containing embedded metal because of the danger of corrosion of the steel from the chloride content of the water, nor should it be used where white efflorescence could mar the appearance of the work.

Reclaimed and recycled water

Recycled water systems are usually found at large-scale permanent mixing plants such as precast concrete factories or ready-mixed concrete depots where water used for cleaning the plant and washing out mixers after use can be collected, filtered and stored for re-use. Some processes are able to reclaim up to a half of the mixing water in this way.

When reclaiming water for use as recycled mixing water care needs to be taken to avoid impurities including harmful chemicals, oil or organic matter, and any traces of powerful admixtures such as air-entraining agents, retarders or pigments must be diluted to such an extent that they will have no effect. Any polypropylene or steel fibres need to be filtered out and a careful check kept on the amount of suspended fines carried in the water: after all the effort and cost of obtaining clean aggregates, it is not sensible to put an excessive quantity of fines back in the form of dirty water.

Large-volume settlement tanks are normally required. They do not need to be particularly deep but should have a large surface area and, ideally, the water should pass through a series of tanks, becoming progressively cleaner at each stage. Alternatively, the water may be chemically treated, particularly where space is limited, in order to make it suitable for re-use or for discharge into drains in a condition that conforms to statutory requirements.

Measuring the quantity of water

Mixing water is usually measured by volume but, in some plants, it may be more convenient for it to be batched by weight. One litre of clean water weighs exactly one kilogram and so the quantity of water remains numerically the same regardless of whether it is measured by volume or by mass, but corrections should be applied when water contains fines.

The important, and most difficult, issue is the correct assessment of how much water is required. In the sections dealing with aggregates and batching, the variability of moisture content is discussed and in the quest to control free water/cement ratio it is essential to allow for water contained in aggregates. Because such a large proportion of concrete consists of aggregates, a small shift in the moisture content makes a big change in the quantity of water to be added.

Devices based on advanced electronics technology exist for measuring the moisture content of a batch of aggregates and for calculating the free water/cement ratio of concrete during mixing, but most producers rely on the experience of the batcher to judge the point at which the amount of water is correct from the way in which the concrete moves and the sound it makes in the mixer. Any equipment that is capable of indicating the consistence of concrete while it is being mixed assists the batcher in gauging the mixing water with greater speed and accuracy. Where the mixer is powered by an electric motor an ammeter or kilowatt meter accurately indicates the power consumed in mixing the concrete - less power is demanded as concrete becomes more workable. Similarly, truckmixer drums that are turned by hydraulic drive can have the consistence of concrete indicated by a pressure gauge (Figure 3).

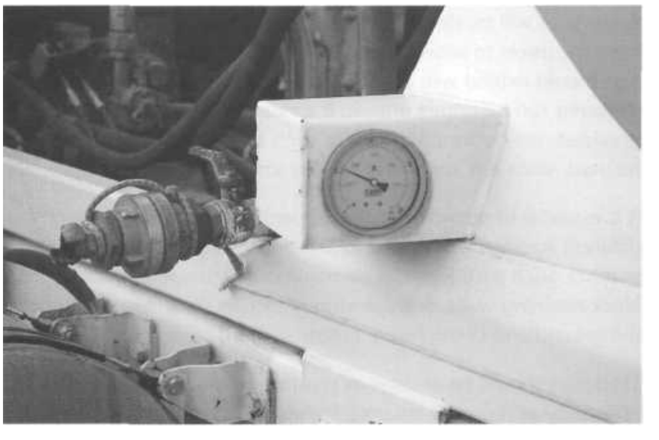

Figure 3: Pressure gauge indicating the consistence of the concrete in a truckmixer.

Regardless of the method of gauging the mixing water, it is recommended that the concrete is finally checked by a batcher and/or driver to see that it has the specified consistence and a uniform appearance. This is the most effective way of ensuring that the concrete is thoroughly mixed and has the designed free water content. When the free water content is closely monitored and cement content accurately weighed, the free water/cement ratio is controlled and, therefore, strength, durability and many other essential properties of the concrete are assured.

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ADMIXTURES

An admixture is a material, usually a liquid, which is added to a batch of concrete during mixing in order to modify the properties of the fresh or hardened concrete in some way.

Most admixtures benefit concrete by reducing the amount of free water required for a given level of consistence, often in addition to some other specific improvement. Permeability is thereby reduced and durability increased. There are occasions when the use of an admixture is not only desirable but also essential.

Because admixtures are added to concrete mixes in small quantities, they should be used only when a high degree of control can be exercised. Incorrect dosage of an admixture - either too much or too little - may adversely affect the strength and other properties of the concrete.

BS EN 934-2 replaces BS 5075 in specifying the requirements for the main types of admixture:

- Normal water-reducing
- Accelerating water-reducing
- Retarding water-reducing
- Air-entraining
- Superplasticizing / high range water reducing.

Normal water-reducing admixtures (plasticizers, workability aids)

Water-reducing admixtures act by reducing the inter-particle attraction between cement particles and produce a more uniform dispersion of the cement grains. The cement paste is better 'lubricated', and hence the amount of water needed to obtain a given consistence can be reduced.

This effect may be beneficial in one of three ways:

1. Added to a normal concrete at normal dosage, they produce an increase in slump of about 50 mm. This can be useful with high-strength concrete, rich in cement, which would otherwise be too stiff to place.

2. The water content can be reduced while maintaining the same cement content and consistence; this results in a reduced water/cement ratio (by about 10%), and therefore increased strength and improved durability. This can also be useful for reducing bleeding in concrete prone to this problem, or for increasing the cohesion and thereby reducing segregation in concrete of high consistence class, or in harsh mixes sometimes arising with angular aggregates, or low sand contents, or when the sand is deficient in fines.

3. A given strength and consistence class can be achieved with a reduced cement content. The water/cement ratio is kept constant, and with a lower water content the cement content can be reduced accordingly. This property should never be used if the cement content would thereby be reduced below the minimum specified.

Overdosing may result in retardation and/or a degree of air-ehtrainment, but does not necessarily increase the workability and therefore may not be of any benefit in fresh concrete.

Accelerating water-reducing admixtures

Accelerators increase the initial rate of chemical reaction between the cement and the water so that the concrete stiffens, hardens, and develops strength more quickly. They have a negligible effect on consistence, and 28-day strengths are seldom affected.

Accelerating admixtures have been used mainly during cold weather when the slowing down of the chemical reaction between cement and water due to low temperature could be offset by the increased speed of reaction resulting from the use of the accelerator. The most widely used accelerator for some time was calcium chloride but, because the presence of chlorides, even in small amounts, increases the risk of corrosion, the use of admixtures containing chlorides is now prohibited in all concrete containing embedded metal.

Accelerators are sometimes marketed under other names such as hardeners, anti-freezes on frost-proofers, but no accelerator is a true anti-freeze and the use of an accelerator does not avoid the need to protect the concrete from the cold by keeping it warm (with insulation) after it has been placed.

NOTE: Accelerators are ineffective in **mortars** because the thickness of mortar, either in a joint or on a rendering, is such that any heat generated by the faster reaction is quickly dissipated.

Retarding water - reducing admixtures

These are chemicals that slow down the initial reaction between cement and water by reducing the rate of water penetration to the cement and slowing down the growth of the hydration products. The concrete therefore stays workable longer than it would otherwise.

The length of time during which a concrete remains workable depends on its temperature, consistence class, and water/cement ratio, and on the amount of retarder used. Although the occasions justifying the use of retarders in the UK are limited, these admixtures may be helpful when one or more of the following conditions apply:

- In warm weather, when the ambient temperature is higher than about 20°C, to prevent early stiffening ('going-off') and loss of workability, which would otherwise make placing and finishing difficult
- When a large pour of concrete will take several hours and must be constructed without already placed concrete hardening before subsequent concrete is merged with it (i.e. without a cold joint)
- When the complexity of slipforming demands a slow rate of rise
- When there is a delay of half an hour or more between mixing and placing - for example, when ready-mixed concrete is being used and when there may be traffic delays and/or long hauls. This can be seriously aggravated during hot weather, especially if the concrete has a high cement content.

The amount of retardation can be varied - usually up to about four to six hours - by altering the dosage, but longer delays can be obtained for special purposes.

While the early strength of concrete is reduced by using a retarder, which may affect formwork striking times, the 7- and 28-day strengths are not likely to be significantly affected.

Retarded concrete needs careful proportioning to minimise bleeding due to the longer period during which the concrete remains fresh.

ADMIXTURES

Air-entraining admixtures

These may be organic vinsol resins or synthetic surfactants that entrain a controlled amount of air in concrete in the form of small air bubbles. The bubbles need to be very small, about 0.05 mm (50 microns) in diameter and well dispersed.

The main reason for using an air-entraining admixture is that the presence of tiny air bubbles in the hardened concrete increases its resistance to the action of freezing and thawing, especially when aggravated by the application of de-icing salts and fluids. Saturated concrete - as most external paving concrete will be - can be seriously affected by the freezing of water in the capillary voids, which will expand and tend to burst it. But if the concrete is air-entrained, the small air bubbles, which intersect the capillaries and remain unfilled with water even when the concrete is saturated, act as pressure relief valves and cushion the expansive effect by providing voids into which the water can expand as it freezes, without disrupting the concrete. When the ice melts, surface tension effects draw the water back out of the bubbles.

Air-entrained concrete should be specified and used for all forms of external paving, from major roads and airfield runways down to garage drives and footpaths, which are likely to be subjected to severe freezing and to de-icing salts. These may either be applied directly or come from the spray of passing traffic or by dripping from the underside of vehicles. Figure 4 shows the difference in freeze/thaw resistance between air-entrained and non air-entrained concrete.

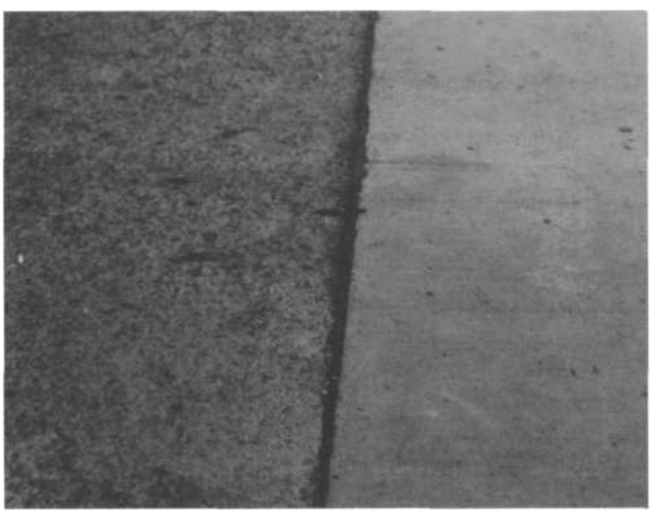

Figure 4: Adjacent slabs of plain (left) and air-entrained concrete that have been subjected to freeze/thaw action.

The volume of air entrainment relates to maximum aggregate size D_{max} (see Table 7). With a reduction in D_{max}, the specified air content increases. Air content should be specified by minimum value. Thus most heavy-duty concrete pavements, including roads and airport runways with their D_{max} of 40 mm, require a minimum air content of 2.5%. The specified minimum air content increases to 3.5% for 20 mm and 5.5% for 10 mm D_{max} sizes. The maximum permitted air content is generally 4% greater than the minimum.

Air-entrainment also affects the properties of the fresh concrete. The minute air bubbles act like ball bearings and have a plasticizing effect, resulting in higher consistence. Concrete that is lacking in cohesion, are harsh, or which tends to bleed excessively, is greatly improved by air-entrainment. Air-entrainment also reduces the risk of plastic settlement and plastic shrinkage cracks. There is also evidence that uniformity of colour is improved and surface blemishes reduced.

Table 7: Air contents of air-entrained concrete in accordance with BS EN 206-1.

Nominal maximum aggregate size, D_{max}	Minimum volume of entrained air	Maximum volume of entrained air
40 mm	2.5%	6.5%
20 mm	3.5%	7.5%
10 mm	5.5%	9.5%

One factor which has to be taken into account when using air-entrained concrete is that the strength of the concrete is reduced, by about 5% for every 1% of air entrained. However, the plasticizing effect of the admixture means that the water content of the concrete can be reduced, which will offset most of the strength loss which would otherwise occur, but even so some increase in cement content is likely to be required as well.

The amount of air entrained for a given dosage can be affected by several factors: changes in sand grading, variation in temperature and mixing time. These may call for adjustments to the dosage for uniformity of air content to be maintained. When pfa is present in the concrete, a considerably increased dosage of air-entraining admixture may be required. The measurement of air content in the fresh concrete is described in BS 1881 : Part 106 and BS EN 12350-7. Brief details are given on page 57 under *Air content test.*

Superplasticizing/high-range water-reducing admixtures

These are chemicals that have a very great plasticizing effect on concrete. They are used for one of two reasons:

1 To increase greatly the consistence of a mix so that 'flowing' concrete is produced that is easy both to place and to compact; some are completely self-compacting and free from segregation.

2 To produce high-strength concrete by reducing the water content to a much greater extent than can be achieved by using a normal plasticizer (water-reducing admixture).

Flowing concrete is usually obtained by first producing a concrete in S2 consistence class (50 mm - 90 mm slump) and then adding the superplasticizer, which will increase the slump to over 200 mm (see Figures 5 and 6). This high consistence lasts for only a limited period of time; stiffening and hardening then proceed normally. Because of this limited duration of increased consistence, when ready-mixed concrete is used it is usual for the superplasticizer to be added to the concrete on site rather than at the batching or mixing plant.

Flowing concrete can be more susceptible to segregation and bleeding, so it is essential for the mix design and proportions to take account of the use of a superplasticizer.

As a general guide, if a conventionally designed mix is modified by increasing the sand content by about 5%, satisfactory flowing concrete can be produced by the addition of a superplasticizer. A high degree of control over the batching of all the proportions is essential, especially the water, because if the consistence is not correct at the time of adding the superplasticizer, excessive flow and segregation will occur.

The fluidity of flowing concrete is such that little or no vibration is required. Beams, walls and columns can be compacted manually by rodding, although it is desirable to have an immersion vibrator (poker) available. For slabs, the concrete is more easily moved using rakes or pushers than by conventional shovels, and the surface can be finished with a skip float drawn across it. Excessive vibration may cause segregation and bleeding and, accordingly, some formulations of superplasticizer contain a viscosity modifier to produce a self-compacting concrete that, in the right mix, is free from segregation.

Figure 5: A typical S2 consistence class concrete with a cement content of 300 kg/m^3.

Figure 6: A similar concrete to that shown in Figure 5, but after the addition of a superplasticizer.

The use of flowing concrete is likely to be restricted to work where the advantages in ease and speed of placing offset the increased cost of the concrete - considerably more than for other admixtures. Typical examples are where the reinforcement is particularly congested, making both placing and vibration difficult, and where large areas such as slabs, would benefit from a flowing, easily placed concrete.

The fluidity of flowing concrete increases the pressures on formwork, which should be designed to resist full hydrostatic pressure. Guidance on design pressures is given in CIRIA Report 108.

When used to produce high-strength concrete, a reduction in water content of as much as 30% can be obtained using a superplasticizer, compared with a water reduction of only about 10% when using a normal plasticizer; 1-day and 28-day strengths can be increased by as much as 50%.

High-strength water-reduced concrete containing a superplasticizer is used both for high performance in-situ concrete construction and for the manufacture of precast units where the increased early strength allows earlier demoulding.

Other admixtures

There are a number of other admixtures that may occasionally be used for special purposes. These include bonding aids, pumping aids, expanding agents, damp-proofing and integral waterproofers, fungicidal admixtures and corrosion inhibitors. For details of these reference should be made to specialist literature.

Storage of admixtures

Most admixtures are stable, but they may require protection against freezing, which can permanently damage them, and may also require stirring. The manufacturer's instructions should be followed.

Dispensing

Because admixtures are usually added in small quantities, generally 30 -1000 ml per 50 kg cement, accurate and uniform dispensing is essential. This is best done using manual or automatic dispensers so that the admixture is thoroughly dissolved in the mixing water as it is added to the concrete.

Superplasticizers for flowing concrete, however, are usually added just before discharge and the concrete should then be mixed for a further one minute per m but not less than five minutes, in accordance with BS EN 206-1.

Trail mixes

Preliminary trials are essential to check that the required modification of the concrete property can be achieved. The use of an admixture is likely to require some adjustment of the mix proportions. For example, when using an air-entrained concrete, the additional lubrication produced by the small air bubbles permits a reduction in the water content, and it is usually advantageous at the same time to reduce the sand content by about 5%. The correct adjustments can be determined only by trial mixes.

Although the admixture manufacturer's instructions will usually include recommended dosages, the optimum dosage will often depend on the cement type, the mix proportions, the grading of the fine aggregate and the temperature.

The programme for trial mixes should include some with deliberate double and treble over-dosages to determine the effect on both the fresh and hardened concrete so that the dangers arising from mistakes can be appreciated by all concerned

References/further reading

BS 1881, *Testing concrete* : Part 106: 1983, *Methods for determination of air content of fresh concrete.* British Standards Institution, London.

BS 5328: 1997, *Concrete.* British Standards Institution, London.

BS 8500 : 2002, *Complementary British Standard to BS EN 206-1.* British Standards Institution, London.

BS EN 206-1 : 2000, *Concrete - specification, performance, production and conformity.* British Standards Institution, London.

BS EN 934: 2001, *Admixtures for concrete, mortar and grout:* Part 2. *Concrete admixtures - definitions, requirements, conformity, making and labelling.* British Standards Institution, London.

CIRIA Report 108, *Concrete pressure on formwork.* 1985, Construction Industry Research and Information Association, London.

CONCRETE PROPERTIES

The properties of concrete are too many and varied to be dealt with fully in this publication: further information is available in specialist textbooks. Therefore, only the main properties of concrete in the fresh, hardening and hardened states are considered here. Fire resistance, elasticity and other properties, which may be essential in some circumstances, have been omitted.

For methods of testing concrete, refer to the section titled *Testing concrete and concreting materials* on page 52 and to relevant Standards, in particular BS 1881, BS EN 12350 for testing fresh concrete and BS EN 12390 for hardened concrete.

Fresh concrete

It is essential that the correct level of workability is chosen to match the requirements of the construction process. The ease or difficulty of placing concrete in sections of different sizes, the type of compaction equipment, the complexity of reinforcement, the size and skills of the workforce are amongst the items to be considered. In general, the more difficult it is to work the concrete, the greater should be the level of workability. But the concrete must also have some cohesiveness in order to resist segregation and bleeding. Concrete needs to be particularly cohesive if it is to be pumped, for example, or allowed to fall from a great height.

Workability and cohesion cannot be considered in isolation because they are affected by each other: in general, more workable concrete requires extra care to be taken with the mix design if segregation is to be avoided.

The workability of fresh concrete is increasingly referred to in British and European standards as consistence. It is useful to think of consistence as a combination of workability with cohesion. Although cohesiveness cannot at present be measured, some of the test methods indicate whether a concrete is likely to segregate.

The slump test is the best-known method for testing consistence and the recognized slump classes are listed in Table 8.

Table 8: Consistence classes in BS EN 206-1 for slump tests conforming to BS EN 12350-2.

Slump class	Range of slump (mm)
S1	10- 40
S2	50- 90
S3	100-150
S4	160-210

Three further test methods are recognized in BS EN 206-1, all with their unique consistence classes. They are the Vebe, degree of compactability and flow tests conforming to BS EN 12350 : Parts 3, 4 and 5 respectively. It should be noted that the compactability test to BS EN 12350 : Part 4 is totally different from the compacting factor test to BS 1881: Part 103.

Hardening concrete

Early thermal cracking

The reaction of cement with water - hydration - is a chemical reaction that produces heat. If this development of heat exceeds the rate of heat loss, the temperature of the concrete will rise. Subsequently the concrete will cool and contract. Typical temperature histories of some concrete sections are shown in Figure 7.

If the contraction were unrestrained there would be no cracking. However, in practice there is always some form of restraint inducing tension and hence a risk of cracking. Restraint occurs due to either external or internal influences.

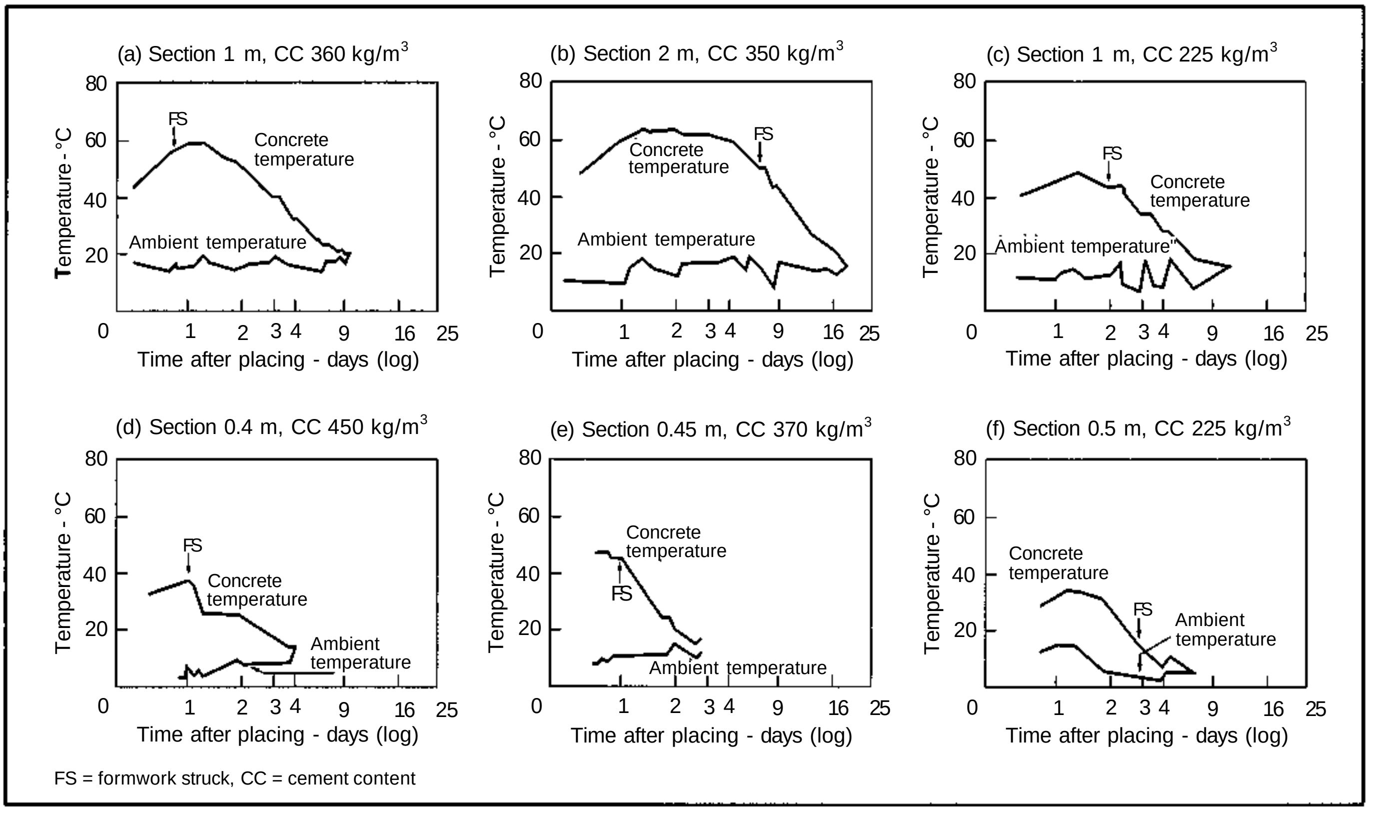

Figure 7: Early temperature history of various concrete walls showing section thickness and cement content.

CONCRETE PROPERTIES

External restraint

Concrete is externally restrained if, for example, it is cast onto a previously hardened base, such as a wall kicker, or if it is cast between two already hardened sections, such as an infill bay in a wall or slab, without the provision of a contraction joint.

Internal restraint

The surfaces of an element of concrete will cool faster than the core, producing a temperature differential, and when this differential is large, such as in thick sections, cracks may develop at the surface. In general, it has been found that by restricting the temperature differential to around 20°C between the core and the surface, little or no cracking will result.

Factors affecting temperature rise

The main factors that affect the rise in temperature are discussed below.

Dimensions Thicker sections retain the heat generated, and will have higher peak temperatures and cool down more slowly. While peak temperatures increase with increasing thickness, above thicknesses of about 1.5 m there is little further increase in temperature.

Cement or combination content The heat generated is directly related to the cement content. For Portland cement concretes in sections of 1 m thickness and more, the temperature rise in the core is likely to be about 14°C for every 100 kg/m^3 of cement. Thinner sections will exhibit lower temperature rises than this.

Cement type Different cement types generate heat at different rates. The peak temperature and the total amount of heat produced by hydration depend upon both the fineness and the chemistry of the cement. As a guide, those cements whose strength develops most rapidly tend to produce most heat. Sulfate-resisting cement generally gives off less heat than CEM I 42,5N and cements that are interground or combined with mineral additions such as pfa or ggbs are often chosen for massive construction because they have the lowest heat of hydration.

Initial temperature of the concrete A higher initial temperature of the concrete results in a greater temperature rise: for example, concrete placed at 10°C in a 500 mm thick section may have a temperature rise of 30°C, whereas the same concrete placed at 20°C may have a temperature rise of 40°C.

Ambient temperature In cooler weather there is likely to be a greater differential between peak and ambient temperatures, i.e. greater cooling and contraction. During hot weather concrete will develop a high peak temperature but the differential may be lower.

Type of formwork Steel and CRP formwork will allow the heat generated to be dissipated more quickly than will timber formwork, which acts as an insulating layer. Timber formwork and/or additional fnsulation will reduce the temperature differential between the core and the surfaces.

Admixtures Retarding water-reducers delay the onset of hydration and heat generation but do not reduce the total heat generated. Accelerating water-reducers increase the rate of heat evolution and increase the temperature rise.

The problem of early thermal cracking is usually confined to slabs over about 500 mm thick and to walls of all thicknesses. Walls are particularly susceptible because they are often lightly reinforced in the horizontal direction and the timber formwork tends to act as a thermal insulator, thus encouraging a larger temperature rise. The problem may be reduced by a lower cement content, the use of a cement with a lower heat of hydration or one containing ggbs or pfa. There is a practical and economic limit to these measures, often dictated by the specification requirements for strength and durability of the concrete itself.

In practice, cracking due to external restraint is best controlled by the provision of crack control reinforcement and the spacing of contraction joints, which should be determined by the designer. It should be noted that reinforcement does not prevent crack formation, although it does control the widths of cracks, and with enough of the right reinforcement, cracks will be fine enough so as not to cause leakage or affect durability. With very thick sections, with very little external restraint, the temperature differential can usually be reduced by insulating, and thereby keeping warm, the surfaces of the concrete for a few days.

Plastic cracking

There are two types of plastic cracks: plastic settlement cracks, which may develop in deep sections and often follow the pattern of the reinforcement; and plastic shrinkage cracks, which are more likely to develop on slabs. Both types form while the concrete is still in its plastic state, before it has set or hardened and, depending on the weather conditions, form within about one to six hours after the concrete has been placed and compacted. They are often not noticed until the following day. Both types of crack are related to the extent to which the fresh concrete bleeds.

Bleeding of concrete

Fresh concrete is a suspension of solids in water, and after it has been compacted there is a tendency for the solids (both the aggregates and the cement) to settle. This sedimentation displaces the water, which is pushed upwards, and, if the process is excessive, the water appears as a layer on the surface. This bleed water may not always be seen, as it may evaporate on hot or windy days faster than it rises to the surface. The tendency of a concrete to bleed is affected by the materials and their proportions. Bleeding can generally be reduced by increasing the cohesiveness of the concrete by one or more of the following means:

- Increasing the cement content
- Increasing the sand content
- Using finer sand
- Using less water
- Air-entrainment
- Using a rounded natural sand rather than an angular crushed one.

The rate of bleeding will be influenced by drying conditions, especially wind, and bleeding will take place for longer on cold days. Similarly, due to the slower stiffening rate of the concrete, concrete containing a retarder has a tendency to bleed for a longer period of time and their use will, in general, increase the risk of plastic cracking.

Plastic settlement cracks

Plastic settlement cracks are caused by differential settlement and are directly related to the amount of bleeding. They tend to occur in deep sections, particularly deep beams, but they may also develop in columns and walls. This is because the deeper the section the more sedimentation or settlement that can take place. However, cracks will form only where something prevents the concrete 'solids' from settling freely. The most common cause of this is the reinforcing steel fixed at the top of deep sections; the concrete will be seen to 'break its back' over this steel and the pattern of cracks will directly reflect the layout of the steel below (Figure 8).

Settlement cracks may also occur in trough and waffle slabs (Figure 9) or at any section where there is a significant change in the depth of concrete.

Figure 8: Plastic settlement cracks mirror the reinforcement.

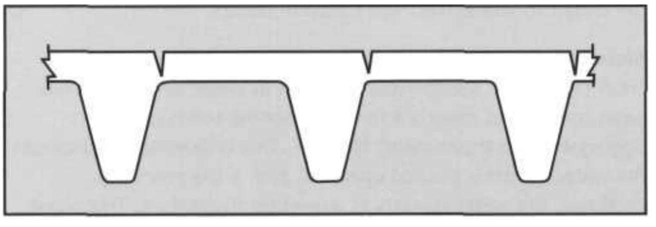

Figure 9: Plastic settlement cracks in trough and waffle floors, at change of depth of section.

If alterations to the concrete, particularly the use of an air-entraining or water-reducing admixture, cannot be made due to contractual or economic reasons, the most effective way of eliminating plastic settlement cracking is to re-vibrate the concrete after the cracks have formed. Such re-vibration is acceptable provided the concrete is still plastic enough to be capable of being 'fluidized' by a poker, and yet not so stiff that a hole is left when the poker is withdrawn. The timing will depend on the weather.

Plastic shrinkage cracks

These cracks occur in horizontal slabs, such as floors and roads. They usually take the form of one or more diagonal cracks at 0.5 to 2 m centres that do not extend to the slab edges, or they form a very large pattern of map cracking. Plastic shrinkage cracks such as those shown in Figure 10 do not usually increase in length or width with the passage of time and seldom have a detrimental effect on the load-bearing capability of suspended slabs or on the carrying capacity of roads. They may occur in both reinforced and non-reinforced slabs.

Plastic shrinkage cracks are most common in concrete placed on hot or windy days because they are caused by the rate of evaporation of moisture from the surface exceeding the rate of bleeding.

It has been found that air-entrainment almost eliminates the risk of plastic shrinkage cracks developing.

Clearly, plastic shrinkage cracks can be reduced by preventing the loss of moisture from the surface of the concrete in the critical first few hours. While sprayed-on resin-based curing compounds are very efficient at curing concrete that has already hardened, they cannot be applied to fresh concrete until the free bleed water has evaporated. This is too late to prevent plastic shrinkage cracking,

Figure 10: Plastic shrinkage cracks in a concrete road

so the only alternative is to protect the concrete for the first few hours with polythene sheeting (Figure 11). This is essential on hot and/or windy days.

Figure 11: Polythene sheeting supported clear of a concrete slab by means of blocks and timber. Note that all the edges of the polythene are held down to prevent a wind-tunnel effect.

Remedial measures

The main danger resulting from plastic cracking is the possible ingress of moisture leading to the corrosion of reinforcement. With both plastic settlement and plastic shrinkage cracks, if the affected surface will be protected subsequently either by more concrete or by a screed, no treatment is usually necessary.

Often the best repair is simply to brush dry cement (dampened down later) or wet grout into the cracks the day after they form and while they are still clean; this encourages natural or autogenous healing.

Hardened concrete

Compressive strength

The strength of concrete is normally specified by strength class, that is the 28-day characteristic compressive strength of specimens made from the fresh concrete under standardised conditions. The results of strength tests are used routinely for both control of production and contractual conformity purposes.

Characteristic strength is defined as that level of strength below which a specified proportion of all valid test results is expected to fall. Unless otherwise stated, this proportion is taken to be 5%.

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Test cubes - either 100 mm or 150 mm - are the specimens normally used in the UK and most other European countries, but cylinders are used elsewhere. Because their shapes are different, the strength test results, even from the same concretes of the same ages, are also different, cylinders being weaker than cubes. For normal-weight aggregates, cylinders are about 80% as strong as cubes, whereas cylinders made from lightweight aggregates have 90% of the corresponding cube strength.

Accordingly the strength classes recognized in BS EN 206-1 / BS 8500 are classified in terms of both values, with the cylinder strength followed by the cube strength. The standard compressive strength classes are listed in Table 9.

Table 9: Concrete compressive strength classes taken from BS EN 206-1.

Concrete compressive strength classes	
Concrete made with normal-weight aggregates	**Concrete made with lightweight aggregates**
C8/10	LC8/9
C12/15	LC12/13
C16/20	LC16/18
C20/25	LC20/22
C25/30	LC25/28
C28/35	LC30/33
C30/37	LC35/38
C32/40	LC40/44
C35/45	LC45/50
C40/50	LC50/55
C45/55	LC55/60
C50/60	LC60/66
C55/ 67	LC70/77
C60/75	LC80/88
C70/85	
C80/95	
C90/105	
C100/115	

In principle, the compressive strength may be determined from cores cut from the hardened concrete. Core tests are normally made only when there is some doubt about the quality of concrete placed, for example, if cube strengths have been unsatisfactory - or to assist in determining the strength and quality of an existing structure for which records are not available.

Great care needs to be taken in the interpretation of the results of core testing: core samples drilled from the in-situ concrete are expected to be lower in strength than the cubes made, cured and tested under standard laboratory conditions.

For more information see *Test cores* on page 58. The standard reference for core testing is BS EN 12504-1 and a useful guide is given in Concrete Society Digest No. 9

Flexural and indirect tensile strength

The tensile strength of concrete is generally taken to be about one-tenth of its compressive strength, but different aggregates cause this proportion to vary and a compressive test is therefore only a very general guide to the tensile strength

The indirect tensile strength (cylinder splitting) is seldom specified nowadays. Flexural testing of specimens, to measure the modulus of rupture, may be used on some airfield runway contracts where the method of design is based on the modulus of rupture, and for some precast products such as flags and kerbs.

Durability of concrete

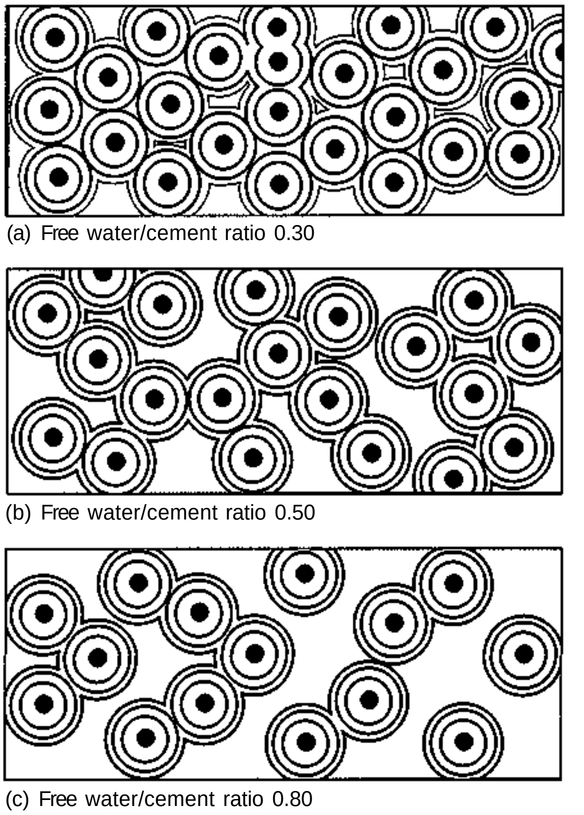
Concrete has to be durable and resistant to various environments ranging from mild to most severe, including weathering, chemical attack, abrasion, freeze/thaw attack and fire. In addition, for reinforced and prestressed concrete, the cover concrete must provide protection against the ingress of moisture and air, which would eventually cause corrosion of the embedded steel.

The strength of the concrete alone is not necessarily a reliable guide to the durability of concrete; many other factors also have to be taken into account. Of all the factors influencing the durability of concrete the most important is that of impermeability. The degree of impermeability is mainly dependent on:

- Constituents of the concrete, and in particular the free water/cement ratio
- Compaction, to eliminate air voids
- Curing, to ensure continuing hydration.

Constituents

Concrete has a tendency to be permeable due to the presence of capillary voids in the cement paste matrix. In order to obtain workable concrete it is usually necessary to use far more water than is actually necessary for hydration of the cement; this excess water occupies space and when later the concrete dries out capillary voids are left behind. Provided the concrete has been fully compacted and properly cured these voids are extremely small and their number and size decrease as the free water/cement ratio is reduced. At high free water/cement ratio the particles of cement along with their hydration products will tend to be spaced widely apart (Figure 12c) and the capillaries will be greater compared with a mix at a lower free water/cement ratio (Figures 12b and 12a). The more open the structure of the paste, the more easily it will permit the ingress of air, moisture and harmful chemicals. It will also be very sensitive to the drying regime, both at early ages and in the more mature hardened state.



(a) Free water/cement ratio 0.30

(b) Free water/cement ratio 0.50

(c) Free water/cement ratio 0.80

Figure 12: The effect of initial cement particle spacing upon the permeability of concrete.

CONCRETE PROPERTIES

Table 10: Typical relationships between free water/cement ratio, aggregate type, consistence class and Portland cement content.

Free w/c ratio	Type of aggregate	Consistence/slump class					
		Low S1(10 - 40 mm)		Medium S2 (50 - 90 mm)		High S3 (100-150 mm)	
		Free water demand (litres/m^3)	Cement content (kg/m^3)	Free water demand (litres/m^3)	Cement content (kg/m^3)	Free water demand (litres/m^3)	Cement content (kg/m^3)
0.7	Uncrushed	160	230	180	260	195	280
	Crushed	190	270	210	300	225	325
0.6	Uncrushed	160	265	180	300	195	325
	Crushed	190	315	210	350	225	375
0.5	Uncrushed	160	320	180	360	195	390
	Crushed	190	380	210	420	225	450
0.4	Uncrushed	160	400	180	450	195	490
	Crushed	190	475	210	525	225	565

NOTES
1. 20 mm maximum aggregate size.
2. Uncrushed - natural gravels and natural sands.
   Crushed - crushed gravel or rock and crushed sand.
3. For a given consistence class, cement content = $\frac{\text{water demand}}{\text{free w/c ratio}}$
4. Where concrete contains a water-reducing admixture the relationship will be different.

S. Actual free water demands may vary from the above values by ±10 litres/m^3 and corresponding adjustments to the cement contents may be required.

Table 11: Exposure classes.

Class designation	Class description
XO	Concrete without reinforcement or embedded metal Concrete with reinforcement or embedded metal in very dry conditions All exposures with no freeze/thaw, abrasion or chemical attack
XC	Corrosion induced by carboration
XC1	Dry or permanetly wet
XC2	Wet, rarely dry
XC3	Moderate humidity or cyclic wet and dry
XS	Corrosion induced by chloride from seawater
XS1	Exposure to airborne salt but not in direct contact with seawater
XS2	Permanently submerged
XS3	Tidal, splash and spray zones
XD	Corrosion induced by chloride other than seawater
XD1	Moderate humidity
XD2	Wet, rarely dry
XD3	Cyclic wet and dry
XF	Freeze/thaw attack
XF1	Moderate water saturation without de-icing agent
XF2	Moderate water saturation with de-icing agent
XF3	High water saturation without de-icing agent
XF4	High water saturation with de-icing agent
XA	Chemical attack. Sulfate classification is given in BS 8500

Although free water/cement ratio is the main factor affecting impermeability, and hence durability, it cannot easily be measured either in the fresh or hardened concrete. However, for a particular aggregate type and grading, the water demand for the same consistence class is more or less constant and is independent of the cement content. Therefore, by knowing the water demand for a particular consistence class the cement content can be evaluated for the required and specified free water/cement ratio. This is illustrated in Table 10.

Exposure Classes

It is recommended that exposure classes be given 'X' codes, ranging from XO for mild exposure through the following codes for exposure to different causes of deterioration:

- XA for exposure to chemical attack
- XC for risk of corrosion induced by carbonation
- XS for exposure to the sea and sea spray
- XD for exposure to chlorides from sources other than the sea
- XF for risk of freeze/thaw attack (with and without salt present.

CONCRETE PROPERTIES

Each group (apart from X0, mild exposure class) has a ranking system from 1 to 3 or 4 depending on the severity of the exposure. The exposure classes and their descriptions are listed in Table 11. Guidance on limiting values recommended as being suitable for resisting these exposure classes is given in BS 8500.

With increasing severity of exposure the free water/cement ratio needs to be decreased since durability is related to the concrete's impermeability. It should also be noted that requirements for exposure classes tend to include requirements for lowest strengths of concrete. In the past, specified strengths tended to be lower than the minimum recommended for durability because the earlier specifications were largely related to structural rather than durability requirements.

Compaction

In addition to the capillary voids (pores), which are dependent on the water/cement ratio, air pockets or voids and even large cavities or 'honeycombing' may also be present if the concrete has not been fully compacted. Concrete that has not been properly compacted because of bad workmanship or because the mix design made compaction difficult can result in a porous concrete, which may, for example, allow water seepage as well as easy ingress of air and chemicals harmful to concrete. Well-compacted concrete should not contain more than 1 % of entrapped air.

This subject is considered in more detail in the section entitled *Placing and compaction* on page 34.

Curing

The importance of curing in relation to durability is seldom fully appreciated. It is essential that proper curing techniques are used to reduce the permeability of concrete by ensuring the continued hydration process. The formation of the reaction products, which fill up the capillary voids, ceases when the concrete dries to below 80% relative humidity.

Detailed information is given in Table 17 on page 46, from which it should be noted that longer curing periods are required when cements containing additions are used.

Cover

Many defects in reinforced concrete are the result of insufficient cover, leading to reinforcement corrosion. Too often, not enough care is given to the fixing of reinforcement to ensure that the specified minimum cover is achieved. The position of the reinforcement, and its cover, should be checked before and during concreting, and may need to be checked after the concrete has hardened. Further information about cover is given in the section titled *Reinforcement* on page 41.

Carbonation

Reinforcement embedded in good concrete with an adequate depth of cover is protected against corrosion by the highly alkaline pore water in the hardened cement paste. Loss of alkalinity of the concrete can be caused by the carbon dioxide in the air reacting with and neutralising the free lime. This reaction is called carbonation and if it reaches the reinforcement, corrosion will occur in moist environments.

Carbonation is a slow process progressing from the surface and dependent on the permeability of the concrete and the humidity of the environment. Provided that the depth of cover and quality of concrete are correctly specified and achieved to suit the exposure conditions, corrosion due to carbonation should not occur during the lifetime of the structure.

Resistance to freezing and thawing

The freeze/thaw resistance of concrete depends on its impermeability and the degree of saturation when exposed to frost; concrete with a higher degree of saturation is more liable to damage. The use of salt for de-icing roads greatly increases the risk of freeze/thaw damage.

The benefits of air-entrained concrete have been referred to on page 16 under *Air-entraining admixtures* where it was recommended that all exposed horizontal paved areas, from motorways to garage drives, footpaths and marine structures, should be air-entrained. Alternatively, the strength of concrete should be SO N/mm^2 or more. Whilst C50 concrete is suitable for many situations, it does not have the same freeze/thaw resistance as air-entrained concrete. Similarly, those parts of structures adjacent to highways and in car parks, likely to be splashed or come into contact with salt or salt solution used for de-icing, should also be air-entrained.

Particular care needs to be taken to ensure that the concrete is properly cured (see the section on *Curing* on page 45).

Resistance to chemical attack

Portland cement concrete is attacked by acids and by acid fumes, including organic acids, which are often produced when foodstuffs are being processed. Vinegar, fruit juices, silage effluent, sour milk and sugar solutions all attack concrete. In general, concrete made with Portland cement is not recommended for use in acidic conditions where the pH is 5.5 or less without careful consideration of the type of exposure and the intended construction. Alkalis have little effect on concrete.

For construction exposed to made-up ground, including contaminated and/or industrial material, specialist advice should be sought so that the Design Chemical (DC) class can be correctly determined and a suitable concrete specified.

The most common form of chemical attack that concrete has to resist is the effect of solutions of sulfates that may be present in some soils and groundwaters.

In all cases where concrete is subject to chemical attack, resistance is related to the free water/cement ratio, cement content, the type of cement and the degree of compaction. Well-compacted concrete will always be more resistant to sulfate attack than one which is less well compacted, regardless of cement type.

BS 5328 and BS 8500 incorporate a primary set of recommendations specific to concrete exposed to sulfate-containing groundwater and chemically-contaminated brownfield sites.

Alkali-silica reaction

Alkali-silica reaction (ASR) in concrete is a reaction between certain siliceous constituents in the aggregate and the alkalis - sodium and potassium hydroxide - that are released during the hydration of cement. A gelatinous product is formed, which imbibes pore fluid and in so doing expands, inducing an internal stress within the concrete. The reaction will cause damage to the concrete only when the following three conditions occur simultaneously:

- A reactive form of silica is present in the aggregate in critical quantities
- The pore solution contains sodium, potassium and hydroxyl ions and is of a sufficiently high alkalinity
- Water is available.

If any one of these factors is absent, then damage from ASR will not occur and no precautions need be taken.

CONCRETE PROPERTIES

It is possible for the reaction to take place in the concrete without inducing expansion. Damage may not occur, even when the reaction product is spread throughout the concrete, and the gel may fill cracks induced by some other mechanism.

Recommendations are available for minimizing the risk of damage from ASR in new concrete construction, based on ensuring that at least one of the three factors listed above is absent.

Reference/further reading

BRE Digest 330, *Alkali-silica reaction in concrete.* 1999, Construction Research Communications, London.

CSTR30, *Alkali-silica reaction: minimising the risk of damage to concrete.* 1999, The Concrete Society, Crowthorne. 72 pp.

BRE Special Digest 1, *Concrete in aggressive ground.* 2000, Construction Research Communications, London.

CS020, Digest No. 9. *Concrete core testing for strength.* 1988, The Concrete Society, Crowthorne. 8 pp.

CSTR 11, *Core testing for strength.* 1987, The Concrete Society, Crowthorne. 44 pp.

CSTR 22, *Non-structural cracks in concrete.* 1992, The Concrete Society, Crowthorne. 48 pp.

CSTR 44, *The relevance of cracking in concrete to corrosion of reinforcement.* 1995, The Concrete Society, Crowthorne. 32 pp.

Plastic cracking of concrete. 1991, British Cement Association Crowthorne. Ref. 45.038. 4 pp.

Minimum requirements for durable concrete. Edited by D W Hobbs. 1998, British Cement Association, Crowthorne. Ref. 45.034. 172 pp.

BS 5328: 1997, *Concrete.* British Standards Institution, London.

BS 8500 : 2002, *Complementary British Standard to BS EN 206-1.* British Standards Institution, London.

BS EN 12504, *Testing concrete in structures.* British Standards Institution, London.

Part 1 : 2000, *Cored specimens - Taking, examining and testing in compression.*

CONCRETE SPECIFICATION

Two essential properties of hardened concrete are durability and strength. Both properties are affected by the voids and capillaries in the concrete, which are caused by excessive water or by incomplete compaction.

In principle the lower the free water/cement ratio the stronger and more durable the concrete will be. The concrete should be fully compacted if it is to retain or exclude water and provide corrosion protection to reinforcement.

Within the UK, the producer is normally required to take action to prevent damaging alkali-silica reaction and therefore provisions in the specification are not normally required.

The required consistence needs to be known at the time of specification so that the concrete can be proportioned to give the required strength and durability. High-strength concretes can be designed and proportioned to a very high or self-compacting consistence so overcoming conditions that make placing or vibration difficult.

The methods of specification and what to specify are given in BS 8500-1. Three types of concrete - designed, prescribed and standardized prescribed concretes - are recognized by BS EN 206-1, but BS 8500 adds two more: designated and proprietary concretes.

Designed concretes

These are concretes for which the producer is responsible for selecting the mix proportions to meet the required performance as communicated by the specifier. Therefore it is essential that the specifier, in compiling the specification, takes account of:

- The uses of the fresh and hardened concrete
- The curing conditions
- The dimensions of the structure; this affects heat development
- The environmental exposure conditions
- Surface finish
- Maximum nominal aggregate size
- Restrictions on suitability of materials.

The most common form of designed concrete is that defined by the characteristic compressive strength at 28 days and identified by the strength class. For example, strength class C25/30 concrete is one having a characteristic compressive cube strength of 30 N/mm^2 at 28 days. (The same concrete would have a characteristic cylinder strength of 25 N/mm^2 at 28 days if cylinders were used for testing, as in certain European countries.) To understand the meaning of the term 'characteristic' see *Strength* on page 26.

However, strength alone does not necessarily define the required durability, and for structural concrete BS 8500 indicates minimum strength class, the maximum free water/cement ratio and minimum cement content that are required for different degrees of exposure. The maximum free water/cement ratio, minimum cement content and types of constituent materials are the main factors influencing durability.

If a specification for designed concrete is to be compiled correctly the following details need to be included:

- A requirement to conform to BS 5328, or BS EN 206-1 and BS 8500-2
- The compressive strength class
- The limiting values of composition e.g. maximum free water/cement ratio, minimum cement content or the design chemical class where appropriate

CONCRETE SPECIFICATION

- Type of cement or combination
- The maximum aggregate size
- The chloride class
- The consistence class.

Optional items may be included such as the target density of lightweight concrete, heat development or other technical requirements listed in BS 8500 : Part 1.

At the time of publication, the use of Form A in BS 5328 : Part 2 is recommended when specifying designed concretes. A copy is reproduced in this publication in Appendix 1 a, which can be used for this purpose by ringing the appropriate items.

Conformity of designed concretes is usually determined by strength testing of 100 mm or 150 mm cubes and in BS 8500 this is the responsibilty of the producer. Recommendations about the required rate of sampling are given in BS 5328 and BS EN 206-1.

The producer will respond to the specification by producing a mix design that satisfies all of the specified requirements. Mix design methods are described in several publications and the subject will not be dealt with in any great detail here.

Prescribed concretes

These are concretes where the specification gives the mix proportions in kilograms of each constituent in order to satisfy particular performance requirements. Such concretes seldom need to be used but may be required for special surface finishes or where particular properties are required. The specifier should include details of the cement content, the type and strength class of cement and either the free water/cement ratio or consistence class.

At the time of publication, the use of Form B in BS 5328 : Part 2 is recommended when specifying prescribed concretes. A copy is reproduced in this publication in Appendix 1 b, which can be used for this purpose by ringing the appropriate items. Methods for checking conformity of prescribed concretes are given under *Checking conformity* on page 26.

Standardized prescribed concretes

Standard mixes conforming to BS 5328 are now called standardized prescribed concretes and are described in BS 8500 : Part 2.

Whilst strength testing is not intended to be used to judge conformity for standard or standardized prescribed concrete, the characteristic compressive strength, as shown in Table 12, may be assumed for the purposes of design.

For these concretes it is necessary to specify:

- The mix title (ST1, ST2, ST3, ST4 or ST5)
- The class of concrete as reinforced or unreinforced
- The maximum aggregate size
- The consistence class.

Admixtures are not permitted in standard mixes but are permitted in standardized prescribed concretes and, whilst numerous cement types are permitted, it is not intended that properties normally associated with some of those cements - such as low heat or sulfate resistance, for example - will be produced in the concrete.

The concrete producer is responsible for ensuring that the materials used conform to those specified and that the batched weights are based on the proportions given in the appropriate standard. A guide to the correct selection of standard/standardized prescribed concretes is reproduced in Table 12.

Conformity with the specification for standard mixes and standardized prescribed concretes is judged against supply of concrete with the correct materials and proportions as defined in BS 5328 : Part 2, or BS 8500 : Part 2. Strength testing does not form part of the assessment of standard mixes, or standardized prescribed concretes. Because the proportions of standardized prescribed concretes have been selected to take into account different types of aggregate and variations in cement strengths, cube compressive strengths would be likely to exceed by as much as 12 N/mm^2 the assumed characteristic strengths associated with

Table 12: Guide to the selection of standard/standardized prescribed concrete in housing and general applications.

Standard/ standardized prescribed concrete title	Assumed characteristic cube strength (N/mm^2)	Application in conditions where Design Chemical class 1 concrete is appropriate	Recommended consistence class
ST1	8	Kerb bedding and backing	S1
ST2	10	Pipe bedding and drainage works to give immediate support Other drainage works Strip footings Mass concrete foundations Trench fill foundations Blinding and mass concrete fill Oversite below suspended slabs House floors with no embedded metal - permanent finish (e.g. screed) to be added	S1 S3 S3 S3 S4 S3 S3 S2
ST3	15	House floors with no embedded metal - direct finish	S2
ST4	20	Garage floors with no embedded metal Wearing surfaces - light foot and trolley traffic	S2 S2
ST5	25	House floors with embedded metal	S2

NOTES
1. See *Resistance to chemical attack* on page 23.
2. See BS 8500 for details of Design Chemical classes.
3. Concrete containing embedded metal should be regarded as reinforced.

the respective strength classes. This compensates for the lack of strength testing and the fact that standardized prescribed concretes are intended for site production with basic equipment and control.

At the time of publication, the use of Form C in BS 5328 : Part 2 is recommended when specifying standard concretes. A copy is reproduced in Appendix 1c, which can be used for this purpose by ringing the appropriate items.

Checking conformity

BS 5328 and BS EN 206-1 / BS 8500 give options for checking the conformity of prescribed, standard and standardized prescribed concretes, indicating that they may be assessed by one of the following methods:

- Observation of the batching
- Examination of the records of batch weights used
- Analysis of the fresh concrete in accordance with procedures defined in British Standards.

Designated concretes

This group of wide-ranging concretes provides for almost every type of concrete construction. They have developed from the original designated mixes introduced in 1991 to BS 5328 and, being specific to the UK, are perpetuated in BS 8500. Divided into four sub-groups, designated concretes are deemed to be fit for the following specific purposes:

1. General purpose low grade applications (GEN concretes)
2. For use as foundations in sulfate-bearing ground conditions (FND concretes)
3. Air-entrained concretes for pavement quality concrete (PAV concretes)
4. Normal structural classes for reinforced concrete applications (RC concretes).

Full specifications for all designated concretes are given in BS 8500 : Part 2. The use of the designation e.g. RC35, is an instruction to the producer to conform to the specification in BS 8500 : Part 2.

The producer of designated concretes must operate a recognized accredited, third-party certification system, and ensure that the concrete conforms to the specification given in BS 8500 : Part 2, including:

- Characteristic strength
- Minimum cement content
- Maximum free water/cement ratio.

For these concretes it is assumed that the nominal maximum aggregate size will be 20 mm; it is necessary simply to state that the concrete is required to conform to BS EN 206-1 / BS 8500 : Part 2 and to specify the designation. The consistence class is selected by the user of the concrete and this information is passed to the specifier for inclusion in the specification.

Aggregate sizes other than 20 mm may be specified, of course, but this detail would be given along with any further additional requirements such as the use of fibres or a higher than normal air content to allow for any loss of air during pumping, for example. BS 8500 : Part 1 lists the options that may be exercised by specifiers for these special cases.

Because designated concretes are quality-assured, there is no necessity for the purchaser of the concrete to make test cubes. Product conformity is ensured through accredited third-party inspection of the quality procedures.

At the time of publication, the use of Form D in BS 5328 : Part 2 is recommended when specifying designated concretes. A copy is reproduced in Appendix 1d, which can be used for this purpose by ringing the appropriate items.

Proprietary concretes

A new sub-group of concrete is proposed for UK practice to provide for those instances when a concrete producer would give assurance of the performance of concrete without being required to declare its composition. This class of concrete is termed proprietary concrete. However, because the producer is nominated, specification of these concretes may be unsuitable for use by public authorities.

Strength

The strength of concrete is usually defined by the crushing strength of 100 mm or 150 mm cubes at an age of 28 days. However, other types and ages of test and other sizes and shapes of specimen are sometimes used.

Test procedures are described under *Testing of hardened concrete* on pages 57 - 59. The strength of a concrete will usually be specified as a characteristic strength. This is the strength below which not more than a stated proportion of the concrete falls. In BS 5328 and BS EN 206-1 this proportion is defined as 5% (1 in 20). To protect the user, an absolute minimum strength of any batch is specified.

The variability in results needs to be considered statistically, and a detailed discussion on this subject is outside the scope of this publication. However, it is briefly mentioned to clarify the consideration of concrete strengths.

Because of the variability of test results, and the inherent variability of the constituent materials, the concrete must be designed to have a mean strength high enough above the characteristic strength to ensure that not more than the expected percentage of results fall below the characteristic strength. The difference between this 'target mean' and characteristic strength is known as the 'margin'. The spread of results from concrete strength tests has been found to follow what is known, in statistics, as a 'normal' distribution, which enables it to be defined by the 'standard deviation[1] of the results. The standard deviation is a measure of the control that has been exercised over the production of the concrete. Where the spread of results and the standard deviation are large, the margin also must be large, but where control over materials, mixing and testing procedures is good, the standard deviation will be smaller and the margin may be reduced, leading to economies in materials. In practice, the margin will usually be about 7-12 N/mm^2.

To use this statistical method reliably for judging conformity to the specification, a large number of test results is needed. Yet conformity is commonly judged by examining the results of smaller numbers of results as outlined below.

BS 5328 conformity rules

In BS 5328, groups of four test results are used, each result being the average of two results of cube tests on concrete from the same batch.

For the highest classes of concrete (C20 and higher) to meet the BS 5328 specification requirements the average strength of a group of four consecutive test results must exceed the characteristic strength by 3 N/mm^2, and the strength of any individual result must not be less than the characteristic strength minus 3 N/mm^2.

In the case of the lowest classes (C15 and below) the BS 5328 specification requirements are deemed to have been met when the average strength of a group of four consecutive test results exceeds the specified characteristic strength by 2 N/mm^2 and the strength of any individual test result is not less than the characteristic strength minus 2 N/mm^2.

Additionally, for all strength classes, the rules for the very first sets of test results for a particular concrete on a new project permit the average of the first two and the first three test results to be lower than the requirements for the mean of four by 2 N/mm^2 and 1 N/mm^2 respectively.

EN 206-1 conformity rules

During the initial stages of production, that is, until at least 35 test results have been obtained, the results are assessed in overlapping or non-overlapping groups of three results. The mean strength of each group of three test results must be not less than 4 N/mm^2 greater than the specified characteristic strength whilst the occasional individual test result is permitted to be 4 N/mm^2 less than the specified characteristic strength.

After 35 test results have been generated within a period of not more than 12 months the initial production period is over and continuous production is achieved. The standard deviation is calculated, the test results are assessed in groups of at least 15 and the minimum requirement is that the mean strength of each group of results must be not less than the specified characteristic strength plus 1.48 x standard deviation. As with the initial production period, the occasional individual test result is permitted to be 4 N/mm^2 less than the specified characteristic strength.

Conformity may be established using individual concretes or defined concrete families. The 'members' of each family would typically be concretes that use the same type and strength class of cement from a single source, their aggregates would be demonstrably similar and they would all either contain an admixture or not contain one. Test results are collected over the full range of consistence classes and a limited range of strength classes, enabling statistical evaluation to be made in determining whether a concrete remains within its family or must be removed from it.

During any contract the materials will vary, and by keeping continuous records of test results it is possible to vary the margin so as to make the best use of the materials while conforming to the specification. Any changes that are made must not conflict with the specific limiting values. The cement content, for examples, must not be reduced below the specified minimum figure.

Effect of concrete constituents

Cement

The effects of different types of cement have already been described in the section on *Cements.* Within one type the properties will vary, but if the supply is derived from one works only, this variation will be small.

Aggregates

The overall grading of the aggregate affects the amount of water that must be added because, in simplified terms, 'fine' gradings require more water than 'coarse' gradings to obtain the same degree of consistence. The aim is to combine the different sizes of aggregate in such a way as to achieve the optimum packing of the particles and so reduce voids to a minimum. The special considerations applicable to air-entrained concrete are discussed on page 16, under *Air-entraining admixtures.*

Aggregate particles that have an angular shape or a rough texture, such as crushed stone, give greater strength for a given free water/cement ratio but need more water than smooth and rounded particles to produce concrete of the same consistence. With smaller sized aggregates, the amount of sand needed to fill the voids increases with a corresponding increase in water demand. To maintain the free water/cement ratio necessary for strength and durability, at the specified consistence, more cement and/or admixture is necessary.

The sand and coarse aggregates need to be proportioned to produce a stable, cohesive mix at the required consistence with the minimum amount of water. Badly proportioned constituents require an excessive amount of water to achieve the required slump, and this will result in concrete of lower strength and durability, as well as resulting in a mix prone to segregation.

Water

Water quality is the most consistent of the constituents of concrete but water quantity, as it affects the free water/cement ratio, is most important for control of consistence, strength and durability. The amount of water used should be the minimum necessary to ensure thorough compaction of the concrete. When deciding how much water is required, allowance must be made for absorption by dry or porous aggregates and for the free surface moisture of wet aggregates, as explained under *Storage of aggregates* on page 1 3 and *Water* on page 14.

Admixtures

Admixtures have been described in the section on *Admixtures.* All admixtures are batched in small quantities and need great care in dispensing and mixing to ensure dispersion through the mix.

Trail mixes

It may be necessary to establish that the proposed mix proportions, including cement content, will produce concrete of the required fresh and hardened properties, or satisfy a requirement to meet a maximum free water/cement ratio. This can be achieved either from examination of previous data or by the use of trial mixes.

It should be noted that, when ready-mixed concrete is supplied with third-party certification, trial mixes by the producer are not needed. Purchasers normally receive certificates for the intended mix designs.

References/further reading

BS 5328, *Concrete.* British Standards Institution, London.
Part 2 : 1997, *Methods for specifying concrete mixes.*
Part 4: 1990, *Specification for the procedures to be used in sampling, testing and assessing compliance of concrete.*

BS 8500 : 2002, *Concrete - complementary British Standard to* BS EN 206-1 : 2000, British Standards Institution, London
Part 1 : *Method of specification and guidance for the specifier.*
Part 2 : *Specification for constituent materials and concrete.*

BS EN 206-1 : 2000, *Concrete - specification, performance, production and conformity.* British Standards Institution, London.

BRE Report 331, *Design of normal concrete mixes.* 2nd edn. 1997. Construction Research Communications, London.

READY-MIXED CONCRETE

About three-quarters of all concrete placed on site in the UK is supplied ready-mixed. To ensure ready-mixed concrete is used successfully, it is essential that there is close liaison and co-operation between the main contractor and the concrete supplier at all stages, from quotation and ordering to discharging the concrete. The use of ready-mixed rather than site-mixed concrete allows for wide variations in demand.

It is recommended that ready-mixed concrete should be supplied from a plant that holds current accredited third-party certification, ensuring that sound practices are followed and systems are in place to maintain high standards of quality and production control.

Batching plants

There are two basic types of batching plant:

'Dry batch' plants

The cement and aggregates are weighed and discharged into the waiting truck-mixer along with most, if not all, of the mixing water, plus any admixture. The concrete is mixed in the truck-mixer drum and any additional water required to obtain the specified consistence may be added either at the plant or, in the case of high consistence concrete, on site.

Thorough mixing is essential to ensure concrete of uniform quality. In transit the mixer drum may rotate slowly at about one or two revolutions per minute to keep the concrete turning over. When the truck-mixer arrives on site, the drum should always be rotated at between 10 and 15 revolutions per minute for at least three minutes and sometimes longer, to ensure thorough mixing before discharge.

Central mixing plants

The cement, aggregates and water plus any admixture are mixed in a central mixing plant before discharge into the truck mixer, which is then used as an agitator. In transit the mixer drum may rotate slowly at about one or two revolutions per minute to keep the concrete turning over. When the truck-mixer arrives on the site the drum should always be rotated at between 10 and 15 revolutions per minute for at least three minutes and sometimes longer, to ensure thorough mixing before discharge.

Exchange of information

Full details of the concrete specification must be submitted by the contractor at the earliest stage, i.e. when quotations are being sought from the supplier.

When several different concrete mixes are used on one contract the essential items to specify for the different types of concrete (designated, designed, prescribed, standard or standardized prescribed) are outlined on pages 24 - 26 and are fully described in BS 5328 / BS 8500.

In addition, the contractor should specify the consistence required for each concrete to suit the proposed placing and compacting techniques. Some concretes of the same strength may need to be supplied at different consistence classes to suit the particular construction. For example, RC30 concrete placed in a sloping ramp may be required at a slump of 40 mm (consistence class S1) whereas the same strength class in a narrow wall may need a slump of 120 mm (consistence class S3). As the consistence will affect the cement content of designated concretes it is essential that the consistence required on site is given at the time of the enquiry. If it is not known, it is recommended that a high consistence class should be specified (S3), see Table 8, page 1 7.

Many specifications will also state maximum free water/cement ratios and minimum cement contents required for durability purposes, and it is essential that the supplier is notified about these requirements.

The benefits of using designated concretes include a simple specification process and an assurance that the concrete conforms to British Standard requirements.

Additional requirements should also be given to the supplier when the concrete is for a high-quality surface finish or has to be pumped, because modifications to the concrete proportions may be needed for what might otherwise be a satisfactory concrete for general purposes.

Quotations submitted will usually be accompanied by the supplier's mix design form. This should be carefully checked to ensure compliance with the contract specification and that the proportions are suitable for the intended use and placing conditions. When high quality finishes are required, particular care needs to be taken in assessing the proposed mix design to ensure that the cement content and aggregate proportions and gradings are in accordance with the basic requirements as indicated under *Concrete for high quality finishes* (page 49).

When a maximum free water/cement ratio is specified, it is essential to check that the amount of water in the design represents a realistic amount appropriate to the consistence required.

On all jobs the contractor and the supplier need to establish a formal communication system and to discuss the planning and ordering procedures in good time before delivery of concrete. This is best done by the contractor nominating one person to be directly responsible for ordering the concrete on a day-to-day basis and for making sure that all is ready on site for the delivery.

Day-to-day ordering

Details of all the concrete to be used on site should always be given to the supplier well in advance. This will help to ensure that when individual loads are ordered, the supplier's dispatch clerk (shipper) will know precisely what is wanted. Orders should be placed at least 24 hours before delivery is required; large pours involving several hundred cubic metres require much longer notice so that the supplier can organize and plan accordingly. When making an order by 'phone, the information given should include the following items:

- Name of the purchaser
- Name and location of site and order reference number if there is one
- Mix reference: each concrete should be given an unambiguous reference that is linked to the full set of specified requirements, designated, designed, prescribed, standard or standardized prescribed concretes are simply referred to by their BS titles. Where prescribed concretes are required, this should be clearly indicated
- Consistence class
- The total amount of concrete of each type required to be delivered
- The time at which deliveries are required
- The rate at which deliveries are required and particular requirements for continuity of any pour.

READY- MIXED CONCRETE

Provision of access

The route(s) from the site entrance to the point(s) of discharge need to be planned in advance. A fully loaded six-wheeled truck-mixer weighs 26 tonnes and eight-wheelers weigh 32 tonnes, so access roads must be strong enough to carry the load, even in wet conditions.

In many cases truck-mixers have to reverse into position to discharge so an adequate turning space on firm ground may be needed near to the discharge point; a turning circle of about 18m is necessary for a typical truck. To avoid contamination of the site, an area should be designated for hosing down chutes and cleaning wheels.

Delivery

Before discharging any batch of concrete the delivery ticket should be checked to confirm that the concrete is of the correct class and conforms to what was ordered. This checking is best done by the contractor's authorised and nominated representative who also is responsible for the ordering.

If all the details are correct the driver should be instructed to remix the load to ensure uniformity - for at least three minutes when the concrete has been plant-mixed, or for at least 4 - 5 minutes (40 - 60 drum revolutions) when any water is added on site.

Concrete mixed at a depot, either in a central mixer or in a truck-mixer, should arrive on site with the ordered consistence, and no extra water should need to be added. Some suppliers using dry batching plants add a quantity of water when the truck arrives on site. It is then the driver's responsibility to add only the amount of water as instructed, to achieve the specified consistence as shown on the delivery ticket.

When the site asks for additional water to make the concrete more workable, this will have to be signed for on the driver's copy of the delivery ticket and, in such a case, the supplier cannot be held responsible for the concrete failing to meet the specified strength.

The slump of concrete delivered in a truck can be measured using a spot sample obtained from the initial discharge, but note that such a sample is not representative for cube making. After allowing a discharge of about 0.3 m^3, six standard scoopsful should be collected from the moving stream to provide a sample of about 20 kg, the scoopsful being taken as quickly as possible and preferably from the next 0.2 m^3 of the discharge. The discharge should then be stopped, the slump measured, and if it is within the specified consistence class, the remaining part of the load may then be discharged.

If the concrete does not conform to the requirements either by slump, ticket details or visual inspection, it must be refused and may be returned to the depot. The reasons for return should be written on the delivery ticket and the truck number and time of rejection be recorded. However, under certain circumstances, it may be permissible for water to be added to a load of stiff ready-mixed concrete in order to achieve the specified target consistence class. This is in accordance with BS 5328 and BS 8500 and applies when:

- The slump is less than the lower limit of the consistence class
- The quantity of added water is controlled by being measured accurately and recorded
- The stiffness is not due to an excessive delay since batching.

Discharge

The truck-mixer can discharge at a rate of about 0.5 m^3 per minute. While it may not always be possible to handle the concrete as fast as this due to limitations of placing and compaction rates, it is to the advantage of the site and the supplier for the concrete to be discharged as quickly as possible - delays longer than 30 minutes from arrival on site to completion of discharge may be charged for.

For construction at or below ground level, the quickest and most efficient way to discharge concrete is directly from the truck. The maximum discharge height for the chute is about 1.5 m above the ground and, with extensions, chutes can cover a radius of about 3 m from the back of the truck. If discharging into trenches or pits, it is essential that the excavation sides are properly shored to prevent collapse from the weight of the vehicle. If the concrete is to be placed by crane and skips, a lot of time can be saved by using two skips; the empty one can be filled while the other is in use.

Samples of ready-mixed concrete for compressive strength tests should be representative of the whole load, with increments being taken from different parts of the discharge. Cubes must be made from incremental samples, not from soot samples.

Figure 13: Ready-mixed concrete being placed by pump into a ground supported slab.

References/further reading

The essential ingredient - Quality. 1992, British Cement Association, Crowthorne. Ref. 97.323. 23 pp.

The essential ingredient - Production and transport. 1993, British Cement Association, Crowthorne. Ref. 97.326. 20 pp.

Dewar, J D and Anderson, R. *Manual of ready-mixed concrete.* (2nd edn). 1992, London, Blackie. 245 pp.

SITE BATCHING & MIXING

Although most concrete nowadays is delivered ready-mixed, there may be occasions when it is more economic and practicable for the concrete to be batched and mixed on site. There are many different types and sizes of batching plants and mixers; the following general recommendations apply to all mixer set-ups, and may also be relevant to ready-mixed concrete.

The main objective is to produce every batch with the required consistence, strength and other specification requirements.

Storage of materials

Materials must be stored so that they are not harmed in any way during storage.

Cement must be kept dry either in silos or, if in bags, kept under cover and off the ground as described on page 9 under *Delivery and storage of cement.*

Aggregates should be handled and stored so as to avoid segregation and contamination by other aggregates, or by fuel, mud, etc. Each site will impose its own conditions and will have to be considered individually, but factors to be taken into account include:

- Access for delivery
- Adequate storage area available in relation to the quantity to be stored
- Drainage
- Avoidance of double handling
- Convenience in relation to subsequent use.

Further information on aggregate storage is given on page 1 3 under *Storage of aggregates.*

Storage of water is not usually a problem if a normal mains supply is used. If water is taken from a stream, well or lake, some storage may be needed in addition to the tank provided on the batching and mixing plant. Water-heating facilities may be required if concreting is to continue during cold weather.

Special arrangements should be in place to prevent contamination of the site when cleaning down plant and equipment.

Concrete mixers

Concrete mixers are designated by a number representing the nominal batch capacity in litres and a letter indicating the type of mixer, as follows:

- Tilting drum, type T
- Non-tilting drum, type NT
- Reversing drum, type R
- Forced action, type P (commonly known as a pan mixer).

Thus a 200 litre tilting drum mixer is designated as 200T.

A concrete mixer must be accurately levelled, and checked regularly to see that it stays so; inaccurate levelling results in poor mixing and increases mechanical wear as well as affecting weighing accuracy.

Mixers should not be overloaded beyond their rated capacities, otherwise spillage of materials will occur and the mixing will be less efficient, leading to lack of uniformity within the batches of concrete; mechanical wear will also be increased.

When bagged cement is to be used, the selection of the size of mixer should be related to the number of whole bags required for each batch.

Batching

For all but the smallest of jobs and for all strength classes of concrete over 20 N/mm^2, all materials should be weigh-batched. Provided the weighing mechanisms are carefully maintained and regularly calibrated, reasonable accuracy should be achieved in the material proportioning.

There are many different types and sizes of batching plant and the choice for a particular job will usually depend on the amount of concrete to be produced, daily and in total.

For large quantities of concrete the aggregate weigh hoppers are likely to be fed from overhead storage bins and then discharged directly into the mixer, or onto a conveyor belt feeding the mixer. The cement from a silo with its own weigh hopper is usually fed directly into the mixer.

On smaller sites, where the output may be 20 - 50m^3 a day, the materials are often weigh-batched into a loading hopper that is integral with the mixer (Figure 14). When in the lowered position the hopper rests on a load cell or hydraulic capsule connected to a weighing dial, which should be in a position such that it can easily be seen by both the mixer driver and the drag-line skip operator. The cement will be weighed in the cement silo dispenser and fed directly into the mixer or into the mixer hopper.

Figure 14: Typical site batching and mixer set-up with drag-line skip for loading the hopper.

The method and order in which the materials are fed into the mixer can affect the uniformity of the concrete; this applies particularly to the water. Ideally, the cement, sand and coarse aggregate should be fed into the mixer simultaneously; this produces a more uniform concrete than when the materials are introduced one after another. Similarly, the water and admixtures should enter the mixer at the same time and over the same period as the other materials. This is not always possible, in which case it is advisable to start the flow of water a little in advance of the other ingredients. If all the water is added before or after the other ingredients, the batch of concrete is liable to vary in consistence from part to part.

Where the loading hopper turns upside down to discharge into the mixer, it is best if the coarse aggregate goes into the hopper first so that it pushes the sand and cement out in front of it and gives a clean discharge of the hopper. When the cement is fed into the hopper from the silo dispenser, it is best for it to be sandwiched between the coarse and fine aggregates.

SITE BATCHING & MIXING

If bagged cement is used, the weights of sand and coarse aggregate should be adjusted to suit a whole number of bags. Attempting to judge half or quarter bags by splitting them leads 1 large errors and variability between batches.

On the rare occasions when volume batching of aggregates is unavoidable it should be done with buckets or gauge boxes, and on no account should batching by the 'shovelful' be permitted. Allowance should also be made for bulking of the sand; sand increases in volume, up to 20 - 30%, as the moisture content rise to about 5 - 6%. Further increases in moisture content result in a decrease in bulking until, when the sand is completely saturated, its volume is almost the same as it was in a dry condition. Unless tests are made, it is usual to assume an average value of 20% for the bulking of damp sand.

Operation of site mixers

It is the mixer operator's responsibility to ensure that the concrete is properly mixed, uniform throughout each batch and at the required consistence. He must see that the materials are being accurately batched and, when a loading hopper is in use, that they are loaded in the right order and that the hopper is uniformly loaded (non-uniform loading can lead to weighing inaccuracies).

Adding the right amount of water to each batch is the mixer driver's main responsibility, so that consistence is maintained from batch to batch. The free water content should be the same for each batch. However, as described on page 1 3 under *Storage of aggregates,* the moisture contents of the aggregates are likely to vary so that the actual amount of water to be added may also have to be varied in order to keep the free water in each batch the same. This is best dealt with by adding most of the water, estimated from the average moisture contents of the aggregates, but keeping a little back to add later if it is needed. A skilled mixer driver can tell by looking at the concrete in the mixer as it gets to the end of mixing whether enough water has been added to give it the right consistence. An ammeter or kilowatt meter connected to the mixer motor also give a good indication. Normally, the amount of water to be added from batch to batch will not vary much, only by about 5-10 litres/m^3.

Mix proportions are usually based on the saturated surface-dry weights of aggregates. For weigh-batching purposes an allowance has to be added for the moisture contents.

Batch weights of aggregate need to be adjusted to allow for variations in their moisture contents in order to reduce variations in consistence and strength, and if aggregate deliveries can be seen to have widely different moisture contents and they are to be used immediately, batch weights may require adjustment; similarly, after rain has fallen on exposed stockpiles, adjustments may be necessary. If, on the other hand, the weather is settled and stockpiles and deliveries are known not to have widely varying moisture contents, such adjustments are not necessary because of their smallness in comparison with the total batch weights.

Thorough mixing of concrete is essential. Mixing times will vary according to the mix, the mixer and whether or not it is being filled to capacity. A uniform colour is usually the best guide to whether the mixing has been efficient. For rotating drums up to about 1 m^3 capacity, the mixing time needs to be 1½ - 2 minutes after all the materials have been fed in. Very small mixers used on building sites and some large free-fall mixers require longer times. For pan mixers, because of the forced action, 30 - 45 seconds is usually enough.

When the concrete is mixed it should be discharged in one operation before loading the next batch.

With a clean mixer - at the beginning of a day's concreting, for example - some of the finer material from the first batch will stick to the mixer sides and blades and the batch will be discharged harsh and stony, short of sand and cement. To make up for this loss of fine material, the amount of coarse aggregate in the first batch should be reduced by about half and the water addition reduced to maintain the required consistence.

The mixer drum must be thoroughly cleaned out after the end of concrete mixing for the day, and before long stoppages such as meal breaks, by filling the mixer with coarse aggregate and water and allowing it to rotate for about five minutes before emptying; this will remove any build-up of hardened mortar on the blades or sides of the mixer.

Weigh hoppers should be cleaned daily to prevent any build-up of material, especially if the cement is being put into the hopper, otherwise dial gauge readings may be inaccurate. There is also a risk of aggregate spillage building up around the weighing mechanism under the hopper, resulting in inaccurate weighing, and any such build-up should be removed daily.

TRANSPORTING CONCRETE

A number of methods for transporting concrete on site are available, ranging from hand wheelbarrows to concrete pumps. The choice of method will depend on the size and complexity of the project, and factors such as ground conditions and distance to be covered and the availability of cranes or other plant. On many jobs several different methods, or even a combination of methods may be required. In all cases the concrete must be moved to the point of placing as quickly and economically as possible without allowing segregation, loss of any constituents, contamination with water or any other material after it has left the mixer.

Pumping

Pumps were first used to transport and place concrete in this country in the 1930s, and their use has grown to the extent that some 20% of concrete is now placed in this way. Many pumps are capable of moving up to 100 m^3 per hour, depending on the pump type, the horizontal and vertical length of the pipeline, the number of bends, and the consistence of the concrete. In practice, the output is usually about 30 m^3 per hour due to supply and organisational limitations. Most pumps can transport concrete more than 60 m vertically or 300 m horizontally (shorter distances when pumping both horizontally and vertically). Some high-pressure pumps have achieved heights in excess of 400 m and horizontal distances greater than 1000 m.

Most mobile pumps can place concrete directly to where it is required (Figure 15), removing the need for other forms of transport and pumping is particularly beneficial when access is difficult or restricted. Standard boom sizes are 16 m, 22 m, 24 m, 32 m, 40 m and 52 m whilst greater distances require a static pipeline which bypasses the boom altogether. There is usually little or no waste. Labour costs are generally minimized since only one person is usually needed to place the concrete, with others compacting and finishing, although the workforce must be adequate to cope with the fast rate of placing. For high-rise construction, pumping permits placing rates to be maintained regardless of the height, without any increase in labour costs.

In order to make best use of the pump, the concrete mix design may have to be adjusted to make it suitable for pumping without using excess pressure. Essentially the concrete should not be prone to segregation or excessive bleeding and should have a low enough frictional resistance for the pump to be able to push the concrete along the delivery line. It is sometimes necessary to increase the sand content by a few per cent, along with an increase in the cement content, in order to provide sufficient fine material and to achieve an overall aggregate grading that is continuous and without gaps.

In this context the consistence of the concrete is an important factor, since a very low consistence class may result in increased resistance to pumping. A target slump of 70 - 90 mm is generally considered to be about the right level and the addition of a plasticizing admixture avoids a higher free water/cement ratio.

Discussion at an early stage with the ready-mixed concrete supplier and/or the concrete pumping subcontractor is therefore recommended in order to ensure that a satisfactory pumpable concrete is obtained.

For trouble-free pumping the concrete must be consistent, since minor variations in the mix proportions are sufficient to make an otherwise pumpable concrete difficult to pump or even completely unpumpable. If only a small part of a load proves to be unpumpable the pump may become blocked, leading to a time-consuming and expensive delay while the pump and/or line is stripped down and the blockage removed.

Figure 15: Placing by pump.

In order to make the most economical and efficient use of pumping, it is important to understand that the decision to utilize a concrete pump ought to be made at the planning stage of a project. Bringing the pump onto site to solve placement problems, when other alternatives have proved unsuccessful, is likely to result in additional costs.

Each site where pumping is proposed will require careful individual planning but a number of considerations, likely to be common to all sites, can be identified. The concrete placing gangs must be able to cope with the pump output for the duration of the pour, without skimping on compaction, finishing or curing. The pump should not be allowed to stand idle waiting for concrete to be delivered and a steady supply of concrete to the pump should be planned, consistent with the rate of placing which can be accommodated. For large or important pours, standby pumps should be arranged. The siting of the pump should be such that delivery vehicles have easy access and two vehicles can be accommodated at the pumps so that the second one can start discharging as soon as the first one finishes, maintaining a continuous flow of concrete. The choice of pump location should also take into account the need to keep pipelines as short and as straight as possible. Good communication between the pump operator and the placing gang is essential.

TRANSPORTING CONCRETE

Most mobile concrete pumps are fitted with folding booms, which are an advantage for placing concrete in difficult situations. However, a boom is not necessarily the best method of placing. There are circumstances where a static pipeline is better, this system having less resistance to flow than a delivery boom of the same diameter.

The pour should be planned so that pipes may be removed as it progresses - pipes should never be added. All couplings should be completely free from leakage, otherwise loss of fine material from joints is likely to result in problems due to blockage. In hot, sunny weather, it may be necessary to protect the pipeline from overheating. In such conditions, concrete in the pipeline must be kept moving.

Concrete in pump pipelines is often under considerable pressure, so that the safety of site staff must be considered. The pump should be stopped, and if possible reversed, while pipes are being disconnected. Flexible end sections of pipes may move violently when a cleaning plug is passed through and operatives should be kept well clear. Falsework should be designed to accommodate the vibration and additional loading caused by pipelines resting on it.

Crane and skip

The crane is still probably the most common method of handling concrete for combined vertical and horizontal movement. A crane is frequently needed on site for handling formwork and reinforcement, and its further use in transporting concrete may be both economic and convenient. However, when concreting requirements dictate the choice of crane capacity, or if the crane is likely to be fully occupied with other tasks, it may be more economic to transport the concrete by other means.

Skips generally range in capacity from 0.2 to 1.0 m^3 (but there are many variations in detail), and are of two broad types (Figures 16 and 1 7):

- Lay-back or roll-over skips
- Constant attitude skips.

Figure 16: Roll-over skip with wheel-controlled discharge mechanism.

The openings of skips should be large enough to allow easy discharge and the consistence class needs to be adequate to allow for controlled discharge into difficult sections. When concrete with a low consistence class is placed by skip, poker vibrators may have to be used to assist discharge.

Skips should be properly maintained if they are to function efficiently. After a day's concreting the skip should be thoroughly cleaned and washed down and the gate operating mechanism should be oiled and greased. A build-up of hardened concrete on the outside of the skip may be prevented by rubbing it over, before it is used, with a light coating of oil or chemical release agent to prevent adhesion.

Dumpers

Dumpers, generally of about 0.5 m^3 capacity, are a common form of transport on many construction sites. They may be discharged either forward or sideways and are best when hydraulically operated so that the discharge can be controlled. The main disadvantage of gravity discharge is the sudden uncontrolled surge of concrete - the heavy impact can displace reinforcement and other objects in the formwork. For small sections it may be necessary to discharge onto a banker board first and then shovel in the concrete by hand.

If the haul routes are so long that segregation becomes a problem, agitator trucks, or lorry-mounted transporters fitted with screws or paddles to remix the concrete as it is discharged, may be preferred.

Other methods

There are several other less common methods of transporting concrete, including pneumatic placers, monorails and the railcars sometimes used in tunnel work, which are not covered in this publication.

References/further reading

Concrete on site — 4: Moving concrete. 1993, British Cement Association, Crowthorne. Ref. 45.204. 9 pp.

The essential ingredient - Site practice. 1994, British Cement Association, Crowthorne. Ref. 97.341. 23 pp.

PLACING & COMPACTION

The successful placing and compaction of concrete can be achieved only if there has been careful forethought and planning.

Because they are done almost simultaneously, placing and compaction are interdependent, and the two operations need to be considered together. The rate of delivery of the concrete should match the rate at which the concrete can be both placed and compacted.

The consistence of the concrete at the point of placing needs to suit both the placing technique and the means of compaction available.

Placing

Before concrete placing begins, the insides of the forms should be inspected to make sure they are clean and have been treated with release agent. If the forms are deep, temporary openings and lighting may have to be provided for this inspection. Rubbish, such as sawdust, shavings and reinforcement tying wire, should be blown out with compressed air. Any rainwater at the bottom of the form should be removed. Similarly, the reinforcement should be inspected to see that it complies with the drawings, and that the correct spacers have been used and there are enough of them.

The main objective with placing is to deposit the concrete as close as possible to its final position, quickly and efficiently and in such a way that segregation is avoided (Figure 17). Moving the concrete with poker vibrators should generally be avoided.

Particular care is necessary when using a skip for placing in thin walls and other narrow sections in order to avoid heaps and sloping layers. The skip discharge needs to be carefully controlled and the skip moved so that a ribbon of concrete is placed. The concrete should be placed in uniform layers not more than 500 mm thick or less, depending on the length of the poker blade. Otherwise compaction may be impeded by the weight of concrete on top. Provided that the concrete has been well designed and proportioned and is sufficiently cohesive, there is generally no need to restrict the height from which the concrete is dropped. This assumes that the concrete is unimpeded and does not ricochet off formwork or reinforcement, which may cause segregation of the mix.

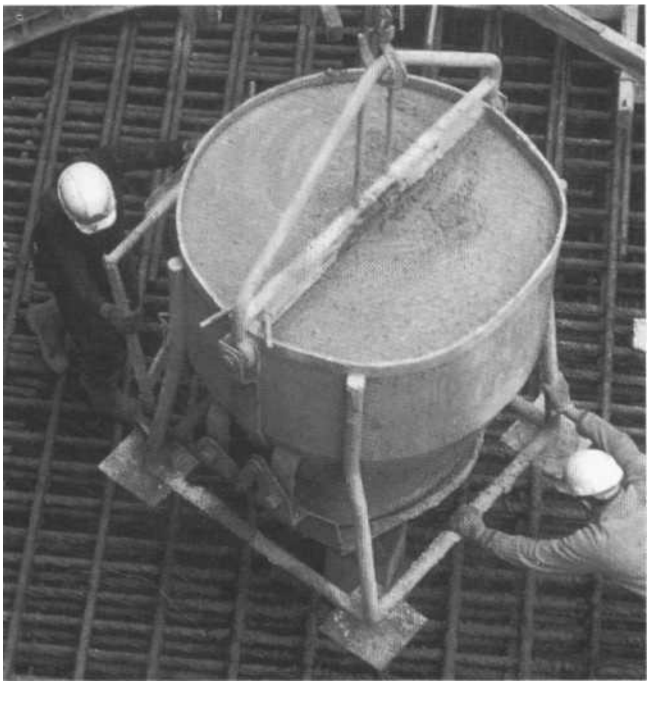


Figure 17: Placing concrete from a constant attitude skip.

In deep lifts of columns and walls, delays and interruptions should be avoided to prevent colour variations on the surfaces; the rate should exceed 2 m height per hour. The correct rate of rise will have been calculated by the temporary works co-ordinator and must be observed in the interests of avoiding excessive formwork pressure and achieving satisfactory surface finish. On columns and walls, care should be taken so that the concrete does not strike the face of the formwork, otherwise the surface finish may be affected; care also needs to be taken to avoid displacing reinforcement or ducts and to ensure that the correct cover is maintained.

Compaction

After concrete has been mixed, transported and placed, it contains entrapped air in the form of large voids. The object of compaction is to get rid of as much of this air as possible. Before compaction, concrete of consistence class S2 may contain 5% entrapped air, while concrete of S1 consistence class may contain as much as 20%.

If this entrapped air is not removed by proper compaction the presence of these large voids will:

- Reduce the strength of the concrete - more than 5% loss of strength for every 1 % air
- Increase the permeability and hence reduce the durability and protection to the reinforcement
- Reduce the bond between concrete and reinforcement
- Result in visual blemishes such as excessive blowholes and honeycombing on formed surfaces.

Fully compacted concrete will be dense, strong, impermeable and durable.

Vibration

Most concrete is compacted by means of internal poker vibrators that 'fluidize' the concrete and permit the entrapped air to rise to the surface. Pokers vary in size, usually from 25 - 75 mm in diameter. Table 13 gives a broad indication of poker sizes, and their characteristics and typical applications.

The radius of action will determine the spacing and pattern of insertions. As a guide, a spacing up to 500 mm centres is about right for a 60 mm diameter poker with concrete of medium consistence (see Table 13).

The poker should be inserted vertically and quickly and should penetrate some 100 mm into any previous layer; thereby stitching the two layers together. It should remain in the concrete until the air bubbles cease to come to the surface. Figures 18, 19 and 20 illustrate the process.

Being able to judge when the concrete has been fully compacted is largely a matter of experience. Sometimes the sound can be a useful indicator, in that the pitch (whine) becomes constant when the concrete is compacted. In addition, a thin film of glistening mortar on the surface is a sign that the concrete is compacted, as is cement paste showing at the junction between the concrete and the formwork. The poker should be withdrawn slowly so that the concrete can flow back into the space occupied by the poker.

External vibrators are occasionally used, but their usefulness is limited on site by the heavy formwork needed to resist the stresses and shaking they produce. Their use is mainly confined to precast concrete elements, but they may be necessary for heavily reinforced walls and the webs of deep beams where it is difficult or impossible to insert a poker.

PLACING & COMPACTION

Table 13: Characteristics and uses of internal poker vibrators.

Diameter of head (mm)	Radius of action (mm)	Approximate rate of compaction, assuming rapid placing (m^3/h)	Uses
20-30 (needle)	80 - 150	0.8-2	Concrete with class S3 consistence and above in very thin sections and confined places. May be needed in conjunction with larger vibrators where reinforcement, ducts and other obstructions cause congestion
35-40	130-250	2-4	Concrete with S2 consistence and above in slender columns and walls and confined places
50-75	180-350	3-8	Concrete with class S1 consistence and above in general construction free from restrictions and congestion

Slabs are best consolidated by vibrating beam compactors. These combine the action of a screed and a vibrator, but they are only effective for a limited depth. In general, a slab more than 150 mm thick should be compacted with poker vibrators and finished with a vibrating beam. The edges of all slabs butting up to side forms should always be poker vibrated. Construction joints need particular attention (see the next section).

Figure 18: Inserting a poker in fresh (stiff) concrete in a beam.

Figure 19: The concrete is fully compacted in the immediate vicinity of the poker

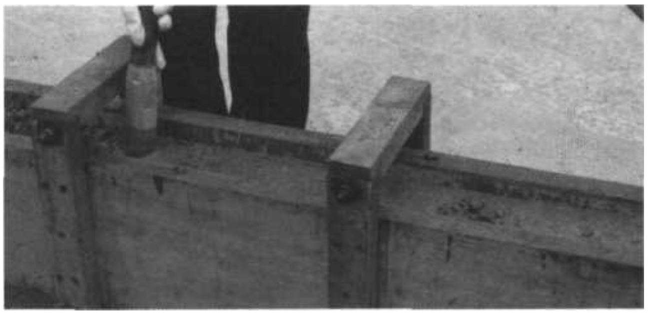


Figure 20: The poker has now been moved about 500 mm along the mould.

Over-vibration

The dangers and problems arising from under-vibration are far greater than any supposedly arising from over-vibration, since it is virtually impossible to over-vibrate a properly designed and proportioned concrete.

Re-vibration

Provided that it is still workable, no harm will be done if concrete that has already been compacted is re-vibrated. In fact, tests have shown that the strength is likely to be slightly increased.

Re-vibration of the top 75 - 100 mm of deep sections can minimize plastic settlement cracks or close them if they have been seen to develop.

Similarly, the re-vibration of the tops of columns and walls can often reduce the tendency of blow-holes to occur in the top 600 mm or so.

References/further reading

Concrete on site - 5: Placing and compacting. 1993, British Cement Association, Crowthorne. Ref. 45.205. 16 pp.

The essential ingredient - Site practice. 1994, British Cement Association, Crowthorne. Ref. 97.341. 23 pp.

CONSTRUCTION JOINTS

A construction joint, or day-work joint, is one where fresh concrete has to be placed on or against concrete that has already hardened. This type of joint is different from contraction and expansion joints, which are used to accommodate movement, and from joints incorporating water bars.

Some construction joints do not need to be fully bonded, the reinforcement across the joint being adequate to transmit tensile or shear stresses across the slight gap that may occur due to contraction. But many construction joints may require the concrete to be bonded so that shear and tensile stresses are transmitted across the joint, in which case the risk of a shrinkage gap is to be avoided.

In both cases it needs to be recognized that joints always show, no matter how well they are made, so they should always be made to form a clean line on the surface. If appearance is important, such as with high-quality finishes, there are advantages in making a feature of the joints.

Location of construction joints

The position of construction joints should be settled before any concreting begins. As a general rule, joints in columns are made as near as possible to the underside of beams; joints in beams and slabs are normally made at the centre, or within the middle third, of the span.

Preparation of construction joints

The first requirement for a good bond is that the hardened concrete surface must be clean, free from laitance and have an exposed-aggregate appearance.

After concrete has been vibrated, bleeding occurs by surplus water rising to the surface. The bleed water brings with it a small amount of cement and fines, and these are left on the surface after the water has evaporated. This layer of laitance is weak and, as well as being porous and not watertight, will not give a good bond for fresh concrete.

Similarly, concrete cast against vertical formwork also has a skin of cement paste on the surface, which, although not quite as weak as that at the top of a horizontal joint, is still likely to affect the bond when fresh concrete is placed against it.

Laitance from both horizontal and vertical surfaces must be removed if and when a good bond or watertightness is required of the concrete itself. However, if watertightness is to be achieved by the incorporation of a water bar, removal of the laitance may not be necessary.

Horizontal surfaces

There are a number of ways of removing laitance from the top of cast concrete to provide a surface with an exposed-aggregate appearance:

- The easiest way is to brush off the laitance while the concrete is still fresh but has stiffened slightly. The timing for this is critical because it depends on the weather and the concrete - in warm weather concrete stiffens faster than in cold weather and a rich concrete stiffens faster than a lean one. The best time will usually be about 1 - 2 hours after the surface water has evaporated. A small brush is used to remove the laitance while gently spraying the surface with water (see Figure 21). It is worth having two brushes handy - one with soft bristles and one with harder bristles in case the concrete has stiffened more than expected. Brushing should be done gently so that pieces of the coarse aggregate are not undercut or dislodged - just the tips of the aggregate showing is correct
- If the laitance has hardened but the concrete is still 'green' - say the following morning - a wire brush and some washing will usually be enough to remove it. The surface should be well washed afterwards to remove the dust
- Pressure washing can be done up to about 48 hours after placing, but timing is again critical and will also depend on the pressure, otherwise the aggregate particles may be dislodged
- If the surface has been allowed to harden, then mechanical scabbling must be used. Small hand-held percussion power tools such as those used for tooling exposed-aggregate finishes, or a needle gun, are the best to use. The danger with this method is that it can shatter and weaken coarse aggregate at the surface or loosen the larger particles, so it should not be done until the concrete is more than three days old, and then only carefully. It is a slow and expensive method
- Wet or dry abrasive blasting is usually suitable only when large areas have to be treated, such as in floor surfaces.

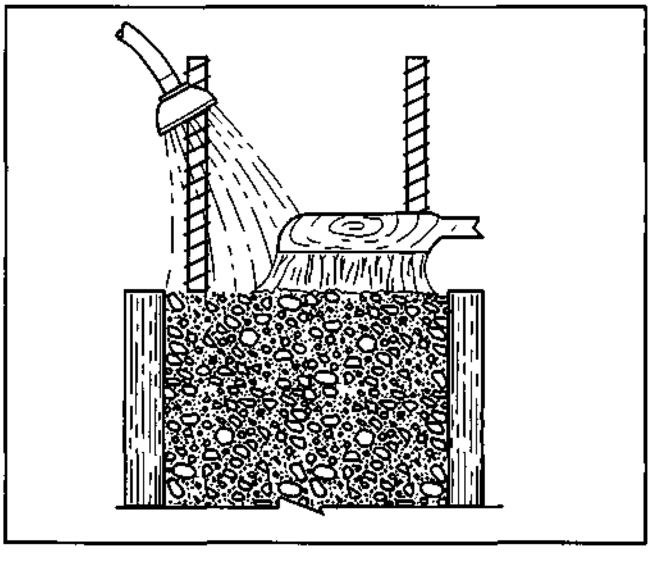


Figure 21: Washing and brushing to remove laitance about two hours after placing.

A method used occasionally is to spray a retarder onto the surface of the concrete to 'kill' the set, so that the laitance can be brushed off the following day or later. This method is not recommended because it is difficult to be sure that all the retarded concrete has been removed - if not, fresh concrete cast against it will have a poor bond. The bond with reinforcement may also be affected.

Vertical surfaces

Vertical construction joints in walls, beams and slabs will usually have been formed against a stop-end. Stop-ends should be located where the reinforcement is least dense; they should be well made, easily strikable, and fixed to avoid grout loss. A typical stop-end detail is shown in Figure 22.

Most vertical construction joints do not require any surface treatment, plain smooth surfaces being quite satisfactory. Only when a joint is subject to high shear forces (and the engineer must decide this) or when a monolithic watertight joint is required will the surface need preparation. Suitable methods are as follows:

- If the stop-end can be removed some 4 - 6 hours after concreting without disturbing the main formwork and

CONSTRUCTION JOINTS

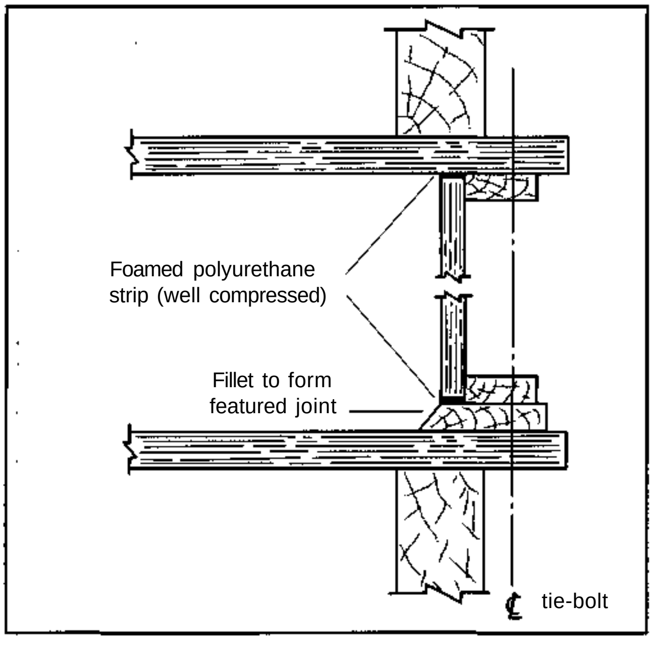


Figure 22: Stop-end detail at a vertical construction joint. The essential requirements are simplicity of construction and sealing to prevent grout loss.

reinforcement, a spray-and-brush method as described in method 1 above for horizontal surfaces can be used.

- If the stop-end is removed the following morning, the concrete will usually still be green enough for the cement skin to be removed to a depth of about 2 mm using a wire brush. The surface should be brushed immediately after striking the stop-end
- If the surface has hardened, then light scabbling, pressure washing or abrasive blasting are likely to be necessary to obtain the right texture
- Expanded metal mesh, suitably framed, is particularly useful for stop-ends, especially when the reinforcement is congested. In some situations, such as where watertightness at the joint is not essential, expanded metal can be left in. If it is removed the following day by pulling it off, the surface should then be sufficiently rough and laitance-free for no further treatment to be required. Where the joint line and appearance are important, the expanded metal should be kept about 40 mm away from the face to avoid breaking off the corners or arrises along the face.

When horizontal or vertical joints are featured or a good clean line is required, care must be taken, especially when tooling, to avoid chipping or breaking the arrises along the joint line. It is a good idea to leave untreated a margin of about 25 - 40 mm.

Concreting at construction joints

It is essential for the fresh concrete to be placed and compacted s that it bonds with the prepared surface.

Poorly compacted concrete or honeycombed concrete at the bottom of a lift in a wall or column leaves a joint which is both weak and unsightly.

First, any dirt, dust or rubbish (e.g. sawdust, pieces of wood, nails and bits of tie wire) must be removed from the surface of the concrete. This can best be done by blowing out all the dirt and rubbish with a compressed air hose. If compressed air is not available, then thorough brushing out is necessary. This cleaning out should be done before the formwork is erected, but if there is still some debris left after erection it should be removed by taking out one of the stop-ends.

On prepared concrete surfaces the use of mortars or grouts or wetting the face of a joint is **not** recommended for the following reasons:

- Tests have shown that the bond between the hardened and fresh concrete is not significantly increased
- The restricted access to a horizontal joint at the bottom of a lift for which the formwork has been erected makes it difficult to ensure the grout or mortar has been uniformly applied; in any case, it would need to be scrubbed into the surface to be effective
- It is virtually impossible to apply mortar or grout to a vertical joint - especially when the formwork is in place
- There is a danger the grout or mortar will dry out before the concrete is placed; any drying out puts back the laitance, which had been carefully removed
- The appearance of the joint may be spoilt by a line of different colour.

Succesful construction joints are achieved simply by careful placing and thorough compaction of concrete against a properly prepared surface.

Horizontal joints

The first layer of concrete must not be deficient in fine material. If there is any danger of losing mortar from the concrete by leakage while transporting or placing it, the first batch should ideally be made richer than subsequent batches by reducing the coarse aggregate content (see *Operation of site mixers* on page 31). With ready-mixed concrete there may be a tendency for the beginning of the discharge to be rather coarse, in which case the first barrow-full may be discarded.

The first layer should be spread uniformly over the surface to a thickness of only about 300 mm. For small columns it will probably be necessary to use shovels to avoid putting in too thick a layer. Discharging a 0.5 m^3 skip into a 600 mm square column, for example, will result in honeycombing at the bottom. When casting columns and walls the poker should always be put in before the concrete goes in, and be drawn up slowly as the concrete is progressively placed; this avoids compacting the surface layer, which would make it very difficult for the air trapped lower down to be expelled upwards subsequently. If using a skip for walls it should be moved along the top. Baffle boards are useful to make sure the concrete is discharged cleanly to the bottom of the forms. The first layer of concrete must be thoroughly compacted by poker vibrators inserted at close centres, depending on the size of the poker and the consistence class of the concrete (see Table 1 3).

Lighting may be necessary for seeing the concrete at the bottom of the pour to check that it has been properly placed and compacted.

Vertical joints

It is usually undesirable to make concrete flow horizontally using vibration, but at vertical joints some flow of the concrete towards the joints helps to avoid possible lack of compaction. As the layers of concrete are placed in a wall they should be kept back about 150 - 300 mm from the vertical joint and the poker used to make the concrete flow towards the joint; this needs particular care and a well-designed concrete if segregation is to be avoided.

References/further reading

Concrete on site - 7: Construction joints. 1993, British Cement Association, Crowthorne. Ref. 45.207. 8 pp.

CONCRETING IN COLD WEATHER

It is well known that water expands when it freezes. This can cause permanent damage and disruption if freezing is allowed to occur within fresh concrete, or in hardened concrete that has not developed much strength. For practical purposes it has been found that, provided the concrete has achieved a strength of 5 N/mm^2, it can resist the expansive forces caused by the freezing of the water in the concrete. For most concrete this critical strength is reached within about 48 hours when the temperature of the concrete has been kept above 5°C.

The gain of strength is delayed at low temperatures so it is necessary to protect concrete against cold for some time after placing. Thin sections normally require more protection and for a longer period than thicker ones, corners and edges being particularly vulnerable.

Many of the precautions that can be taken to protect concrete from cold make use of the heat that concrete generates as it hardens. However, this is effective only if the concrete temperature is sufficiently high at the time of placing for the heat evolution to start rapidly. To this end the temperature of the concrete **when placed in the form** should never be less than 5°C, preferably not below 10°C. To achieve this, the concrete temperature in the mixer or ready-mixed concrete truck needs to be higher to allow for heat losses during transportation and placing. Some ready-mixed plants can deliver heated concrete.

It should be noted that it is important for prevent water loss from newly laid concrete, see *Curing* on page 46.

Raising the temperature

The easiest way to raise the temperature of the fresh concrete is to heat the mixing water. Aggregates should be free from ice and snow because it requires as much heat to melt the ice as to heat the same quantity of water from 0°C to 80°C. Aggregates should be covered and kept as dry as possible. Heated water should be added to the mixer before the cement so that its temperature will be lowered by contact with the mixer and the aggregates. If this is not done there could be a flash set when hot water comes into contact with the cement.

Sometimes, in very cold weather, aggregates also must be heated to achieve the desired concrete temperature. This can be done by injecting live steam or using hot air blowers, closed steam coils or electric heating mats. Live steam probably produces the most uniform heating, but the increased moisture content needs to be allowed for in determining batch weights.

If concrete with a sufficiently high initial temperature is prevented from losing heat to its surroundings, the heat evolved during setting and hardening will protect it from damage by freezing. Thus, formwork should be insulated (in this respect it should be noted that 19 mm of plywood has fairly good insulating properties on its own) and slabs should be covered with insulating mats immediately after laying (Figure 23). The tops of walls and columns are particularly vulnerable and should be covered with insulating material.

Strength development

Both the early and subsequent strength development in cold weather can be accelerated using a water-reducing admixture or more conveniently by increasing the strength class of concrete.

External in-situ paving is particularly vulnerable to the effect of low temperatures because of the large surface area, which loses heat quickly. In addition, slabs are open to drying winds that can add a chilling factor to the effects of low temperature. There is a variety of materials and methods that can be used for protecting and providing insulation to exposed concrete surfaces, ranging from plastic sheeting and tarpaulins to proprietary insulating mats. As an indication of the relative merits of different methods, tarpaulin or plastic sheeting enclosing a 50 mm dead air space has about the same insulating value as 19 mm thick timber; but proprietary insulation mats (Figure 23) are more effective.

Figure 23: Laying a thermal blanket on a freshly finished slab.

Even when concrete has been protected from freezing during its early life, the subsequent slow gain of strength in cold weather needs to be allowed for. Longer periods than are necessary in warmer weather will be required before forms are struck (see Table 14). The gain of strength of concrete in cold weather can be assessed by tests on cubes cured, as far as possible, under the same conditions as the concrete in the structure. Alternatively, guidance can be obtained from CIRIA Report 1 36.

Table 14: Minimum period before striking formwork (concrete made with CEM I or SRPC).

Mean air temperature (°C)	Sides to beams, walls and columns (hours)	Soffits to slabs, props left under (days)	Props to slabs (days)	Soffits to beams, props left under (days)	Props to beams (days)
3	36	8	14	14	18
10	24	5	8	8	12
16	18	4	6	6	10

NOTES
These times are based on a well-managed concreting operation that includes effective curing.
It may be necessary in cold conditions to instruct the supplier to reduce or eliminate the proportion of any ggbs or pfa
For concretes containing pfa or ggbs recommended striking times should be increased. Full details are given in CIRIA Report 1 36.

CONCRETING IN COLD WEATHER

Minimum striking times

The use of cements with pfa or ggbs in cold weather presents a particular problem because these concretes are more adversely affected than ordinary Portland cement concretes due to their slower gain of strength. It should be noted that Table 14 applies only to concrete made with CEM I or SRPC

Cold weather delays the stiffening of concrete, and ground floor slabs, for example, are likely to take considerably longer than normal before the trowelling operations can be started.

Plant and equipment

Preparations for winter working should be made well in advance of the onset of cold weather, and the necessary plant and equipment made ready for use when required. Modifications in site organisation to help keep work going in winter may not always be applicable, but they should be considered because their cost is usually small in relation to the benefits of a smooth flow of work, a quicker end to the job and no idle labour. One technique that may be considered is the total enclosure of the work area with, for instance, polythene sheeting fixed to the scaffolding, and the use of space heaters within this enclosure. Consideration should also be given to the use of cements of higher strength class such as 42,5R or 52,5 (formerly known as rapid-hardening Portland cement) or the use of a higher strength class of concrete, which will give an increased rate of strength gain leading to the ability to strike forms earlier than would be possible with the concrete originally specified.

Weather records

Keeping weather records and planning with an eye to the weather forecast is necessary for efficient winter working. Records of maximum and minimum temperatures, together with a more continuous record during working hours, will help towards an assessment of maturity and formwork striking times. This assessment should take account of wind and cloud cover because the temperature of the concrete is the factor that matters and this is not always the same as the air temperature. On a windy, cloudless night concrete can be cooled below the air temperature. The weather forecast is available by telephone or via the internet, and is an invaluable guide to the planning of winter work. Freezing conditions can usually be predicted and precautions taken. Specifications frequently call for precautions to be taken at particular temperatures, depending on whether the temperature is rising or falling.

References/further reading

CIRIA Report 1 36. *Formwork striking times - criteria, prediction and methods of assessment.* 1995, Construction Industry Research and Information Association, London. 71 pp.

Concrete on site -11: Winter working. 1993, British Cement Association, Crowthorne. Ref. 45.211. 9 pp.

CONCRETING IN HOT WEATHER

In the UK when temperatures exceed about 20°C, there are two main factors leading to problems with concreting:

- When the temperature of the concrete itself exceeds 20°C, the rate of reaction between the cement and the water is increased and this in turn leads to an increased rate of stiffening and loss of consistence. There is also an increased risk of early-age thermal cracking because the peak temperature will be increased
- High air temperatures, especially when accompanied by a low humidity, can increase the rate at which water evaporates from the concrete. Evaporation of water due to delays between mixing and placing will cause loss of consistence. Evaporation will also be increased from exposed horizontal surfaces after the concrete has been placed.

Loss of consistence

Stiffening due to high temperatures and/or water loss can cause problems by:

- Making it difficult to place and compact the concrete.
- Increasing the risk of 'cold' joints in large pours
- Creating surface finishing problems with floors and paved areas.

The existence of drying conditions makes it more important to ensure that exposed surfaces of concrete after compaction and finishing are protected against loss of moisture by efficient curing methods.

Accelerated stiffening and loss of consistence can best be minimized by placing the concrete as soon after mixing as possible. It is essential that concrete should be of the required consistence at the point of placing, and any delays due to prolonged transportation should be allowed for by designing the concrete so that the consistence of the concrete at the mixer is higher than required at placing to allow for consistence loss.

It should be noted that this higher consistence may require an increased cement content or the use of a plasticizing admixture in order to maintain the correct free water/cement ratio.

Over a delay period of 30 minutes the loss in slump can be 20 - 50 mm and will become progressively worse with cement contents higher than 300 kg/m^3. Rapid stiffening can be minimized by using a retarding admixture and/or cements containing pfa or ggbs, which reduce temperature rise and minimize the risk of early-age thermal cracking.

Another factor which should be taken into account is that the higher the temperature of the batch ingredients (and hence the concrete temperature) the greater will be the quantity of water needed to produce any given consistence class. For example, concrete with S2 consistence class at 20°C is likely to have a consistence class of only S1 at a temperature of 30°C when made with the same free water content.

Moisture loss

The rapid loss of moisture from the surface of exposed concrete increases the risk of plastic cracking, and the concrete should be cured thoroughly as soon as possible after finishing. As soon as the surface has hardened sufficiently, polythene sheeting can be used, or a sprayed-on curing membrane applied, (see Figure 24) preferably using a pigmented type that reflects solar radiation (see *Curing* on page 46).

Concrete that has lost workability due to early stiffening should not be retempered by additional water.

CONCRETING IN HOT WEATHER

NOTE: Low water content makes concrete more susceptible to the adverse effects of the moisture loss.

It is generally considered inadvisable for concrete to be placed when its temperature exceeds about 30°C unless special procedures are followed, such as those that apply in very hot climates.

Figure 24: Applying a sprayed-on curing membrane to freshly laid concrete.

References/further reading

Shirley, D E. *Concreting in hot weather.* 1980. British Cement Association, Crowthorne. Ref. 45.013. 12 pp.

REINFORCEMENT

Reinforcement for concrete may consist of round or deformed steel bars or welded steel mesh fabric. These materials are covered by BS 4449, 4482 and 4483. The requirements for scheduling, dimensioning, bending and cutting of reinforcement are covered by BS 8666.

Bar types and identification

The two grades of steel used for bar reinforcement are mild steel, identified by 'R' on the reinforcement drawings and schedules, and high-yield steel identified by T. The letter 'X' is used to denote other steels, for instance stainless steel.

All plain smooth round bars produced in the UK are hot rolled mild steel, which has a characteristic strength of 250 N/mm^2.

High yield reinforcement is produced by hot rolling a low-alloy steel. It has a characteristic strength of 460 N/mm^2 and is known as 'deformed' steel because of its pattern of raised ribs (Figure 25).

Figure 25: Types of reinforcement in general use: plain mild steel bar (left); high yield bar (right).

Bar sizes and bending

The preferred nominal diameters of bars are 8, 10, 12, 16, 20, 25, 32 and 40 mm. Should a larger diameter bar be required, bars of 50 mm diameter are normally available by special arrangement with the manufacturer. In the case of bars less than 8 mm diameter, a 6 mm type is sometimes obtainable.

Minimum radii for bends are given in BS 8666 and these should be used unless larger radii are detailed. The minimum inside radius for different types of steel is given below.

- Mild steel - twice the bar diameter
- High-yield steel
  - for bars up to and including 20 mm in diameter: three times the bar diameter
  - for bars 25 mm and greater in diameter: four times the bar diameter.

All reinforcement should be bent on proper bar-bending machines and should be to the specified dimensions and within the allowable tolerances. It may be impossible to fit steel in the correct position and with the correct cover if the bars have not been bent accurately; reinforcement in the wrong position may reduce the strength of the unit, and a reduction in the specified cover will reduce durability due to an increased risk of the reinforcement corroding.

REINFORCEMENT

Reinforcement should not be bent or straightened in a way that will fracture or damage the bars. All bars should preferably be bent at ambient temperature, but when the temperature of the steel is below 5°C special precautions such as a reduction in the speed of bending or increasing the radius of bending may be necessary. Alternatively the steel can be warmed to a temperature not exceeding 100°C. Heated bars should never be cooled by quenching. Reinforcement should not be re-bent or straightened without the approval of the engineer.

Standard shapes of bent bar are readily available from suppliers in a range of bar sizes, and most suppliers will also work from the reinforcement schedule to supply steel ready cut and bent to specified dimensions and tolerances.

Fabric

Factory-made sheets of mesh made from welded bars or wires are known as fabric reinforcement. It is used extensively for ground and suspended slabs and for reinforced concrete roads. Fabric is available in a British Standard range of preferred meshes in stock sheets 4.8 m long by 2.4 m wide, but other mesh arrangements and sizes of sheets are also available to order.

The preferred types of fabric designated in BS 4483 are divided into four categories, each classified by a letter, as shown in Table 15.

Table 15: Preferred types of designated steel fabric.

Prefix letter	Type of fabric	Size of mesh (mm x mm)	Typical applications
A	Square mesh	200 x 200	Slabs - suspended and ground
B	Structural mesh	100 x 200	Suspended slabs, walls
C	Long mesh	100 x 400	Roads, paved areas, ground floor slabs
D	Wrapping	100 x100	Sprayed concrete work, concrete encased steelwork.

Each type is available in a limited number of weights, depending on the wire diameter used. References on drawings and schedules use the letter followed by a number denoting the cross-sectional area, in mm^2/per metre width, of the main wires. For example, B503 is a structural mesh with a main wire area of 503 mm^2 per metre width. An 'A' or square mesh has the same cross-sectional area in each direction.

Fabric should be cut and bent to the tolerances and dimensions given in BS 8666.

Prefabricated reinforcement

It is often more convenient to obtain cages and complex reinforcement arrangements already assembled from the supplier's factory. Delivery can be timed to fit in with the construction programme but the same requirements for storage on site apply a: for conventional reinforcement. Some of the assemblies are heavy and will need suitable lifting equipment.

Handling, storage and cleanness

Whether the reinforcement is being delivered uncut (generally in 12 m lengths) or already cut and bent it is essential to off-load it carefully. Pushing bundles of bars off lorries or throwing them onto stacks inevitably leads to bends or kinks.

The bars should be stacked off the ground and well supported to ensure that they do not become covered with mud and dirt. Bars of different types and diameters for bending on site should be stacked separately and well labelled so that the bar bender can identify them easily. Cut and bent steel should be delivered already bundled and labelled with the bar schedule reference and the bar mark to enable the fixers to find the bars they need.

Before concreting, the reinforcement needs to be free from mud, oil, grease, release agents, paint, retarders, loose flaky rust, loose mill scale, snow, ice or any substance that will affect the concrete or steel chemically or reduce the bond between the two materials.

The effect of loose rust and mill scale on the bond between steel and concrete is often a cause of contention on sites.

Tests carried out on rust-free and rusty bars have shown that, provided the cross-sectional area of the bar has not been reduced, the effect of a little rust is not harmful and normal handling will remove loose rust and mill scale; the same effect can be achieved by dropping bars on the ground or giving them a sharp tap, preferably on the end. Where it is suspected that the cross-sectional area of the bars has been reduced by corrosion, the most accurate way of checking, especially with deformed bars, is to weigh a known length. Mortar or grout droppings on bars projecting from concrete do not need removing provided they are firmly bonded to the bars.

Cover to reinforcement

The strength and durability of a reinforced concrete structure depend on, among other factors, the reinforcement being correctly positioned, within allowable tolerances, in the hardened concrete. The most common cause of corroding reinforcement is insufficient cover. The position of reinforcement should be checked before and during concreting to ensure that the correct cover is maintained; further checks should be carried out using a covermeter after the concrete has hardened, as discussed on page 60 under *Electromagnetic covermeter.*

The nominal cover should be given on the working drawings. Nominal cover is the depth of concrete cover shown on drawings to all reinforcement including links. The actual cover should nowhere be less than the nominal cover minus a margin which, in British Standards, is currently 5 mm. If the surface of the concrete is to be tooled or the aggregate exposed, the depth of tooling or exposure must be taken into account. The nominal cover will depend on the conditions of exposure of the particular piece of concrete and the cement content and free water/cement ratio of the specified concrete.

Spacers

Reinforcement should be held off the formwork or blinding (for a slab on the ground) by suitable spacers which should be of the same nominal size as the specified cover.

Spacers are generally made of concrete, fibre cement or plastic, in several shapes and various sizes to give the correct cover (Figure 26).

Circular or wheel type spacers are more suitable for reinforcement in vertical members, such as columns and walls, while the block or trestle types are more suitable for reinforcement in horizontal members. They must be durable, and not cause corrosion of the reinforcement or spalling of the concrete. Those made from concrete should be comparable in strength, durability, porosity and appearance if the finish of the surrounding concrete is important. Site-made concrete blocks must not be used.

Spacers and chairs (Figure 27) should be placed at a maximum spacing of 1 m, or less if necessary. Guidance on using spacers is given in publication CS 101 and BS 7973.

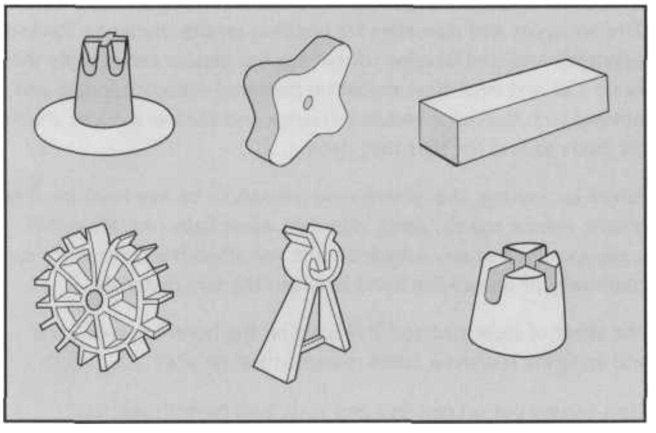


Figure 26: Typical spacers for reinforcement.

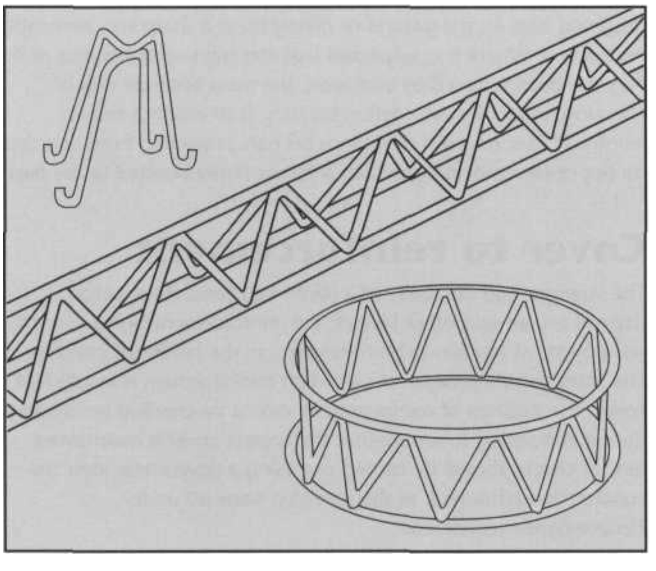


Figure 27: Stool, continuous chair and ring supports for top layers of reinforcement.

Fixing reinforcement

The reinforcement bars should be securely tied together with steel wire, tying devices or by welding, and care should be taken to ensure that projecting ends of ties or clips do not intrude into the concrete cover. Welding on site should be avoided if possible, but provided that suitable safeguards and techniques in accordance with the manufacturer's recommendations are adopted, it may be undertaken with the engineer's approval.

Structural connections between two bars can be made by welding or by the use of mechanical couplers if lapping is not feasible. If there is any uncertainty about the arrangement of the reinforcement, or any discrepancy between the bar schedules and the drawings, the engineer should be consulted.

The reinforcement must be fixed rigidly in the correct position (Figure 28) and with the correct cover in such a way that it is not displaced during concreting. Top layers of reinforcement in slabs

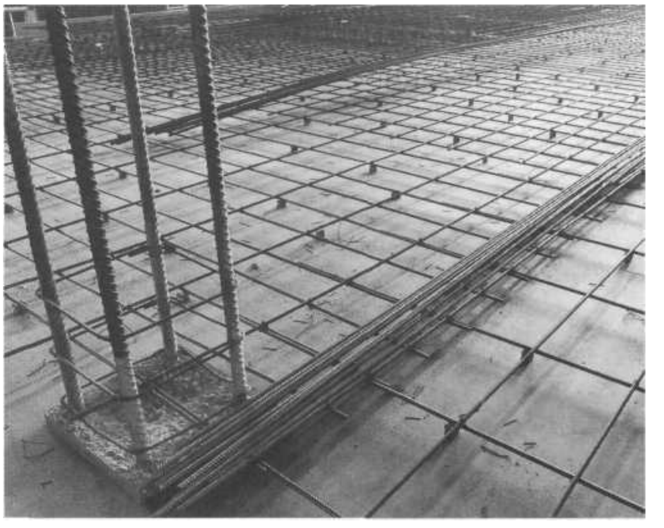


Figure 28: Reinforcement fixed in place for a slab and column.

should be well supported on bent reinforcement, or chairs so that they are not displaced by operatives walking on them or by being used as a storage area for plant or equipment - both practices should be discouraged as far as possible. Special care should be taken in fixing the top tension reinforcement in cantilevers.

References/further reading

BS 4449 : 1997, *Specification for carbon steel bars for the reinforcement of concrete.* British Standards Institution, London.

BS 4482 : 1985, *Specification for cold reduced wire for the reinforcement of concrete.* British Standards Institution, London.

BS 4483 : 1998, *Steel fabric for the reinforcement of concrete.* British Standards Institution, London.

BS 7973 : 2001, *Spacers and chairs for steel reinforcement and their specification.* British Standards Institution, London.
Part 1 : *Product performance requirements*
Part 2 : *Fixing and application of spacers and chairs and tying of reinforcement.*

BS 8666 : 2000, *Specification for scheduling, dimensioning, bending and cutting steel reinforcement for concrete.* British Standards Institution, London.

CS101, *Spacers for reinforced concrete.* 1989, The Concrete Society, Crowthorne. 30 pp.

Concrete on site - 2: Reinforcement. 1993, British Cement Association, Crowthorne. Ref. 45.202. 9 pp.

FORMWORK

The purpose of formwork is to contain freshly placed and compacted concrete until it has gained enough strength to be self-supporting; to produce a concrete member of the required shape and size; and to produce the desired finish to the concrete. To achieve this, the general design and construction requirements of formwork are as follows:

- The formwork should be sufficiently rigid to prevent undue deflection during the placing of the concrete.
- It should be of sufficient strength to carry the working loads and the weight or pressure of the wet concrete, and to withstand incidental loading and vibration of the concrete.
- It should be set to line and level within the specified tolerances and include any camber that may be required.
- Joints should be sufficiently tight to prevent loss of water or cement paste from the concrete, which can have a serious effect on the appearance of the finished concrete.
- The size of panels or units should permit safe and easy handling using the equipment available on site. The design should permit an orderly and simple method of erection and striking.
- The arrangements of panels should be such that they are not 'trapped' during striking, and it should be possible to strike side forms from beams without disturbing the soffit formwork.

Types of formwork

Over the years the number of materials used for formwork has grown considerably, although traditional methods using materials such as timber are still used. Formwork facing materials include timber, plain and resin-faced plywood, steel, alloy, concrete, glass fibre reinforced plastics (GRP), glass fibre reinforced cement (GRC), hardboard and expanded polystyrene. In addition, form liners of rubber, thermoplastics or other sheet materials, including permeable liners, to produce controlled permeability formwork (CPF) systems may be used (see *Influence of formwork* on page 49). Some liners are re-usable but others can only be used once.

Many systems of proprietary formwork are available, and large jobs often make use of special formwork designed as a system for that job (Figure 29). Precast concrete, profiled steel decking units, GRC panels or other materials may be used as permanent formwork; the supplier's instructions regarding bearings, supports and ties must be carefully observed.

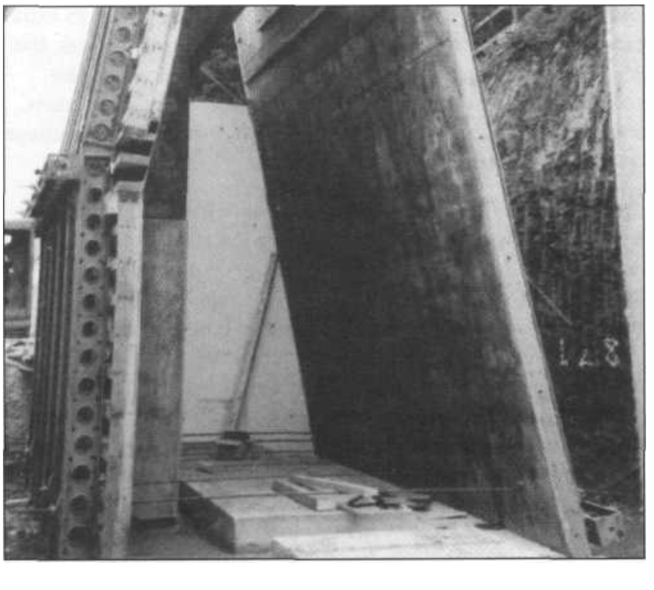


Figure 29: Proprietary panel formwork system for a concrete retaining wall.

The system of falsework supporting the formwork must be designed to withstand the loads imposed on it. Tubular steel scaffolding and adjustable proprietary steel props are the most common forms of support, although heavy-duty shoring and specially designed supporting systems are often required. When adjustable steel props are used, they must be installed so that they are vertical and loaded axially, and the hardened steel pins provided by the manufacturers must be used.

Slipforms are occasionally used for walls, lift shafts and building cores, silos, towers, chimneys and shaft linings. This type of form is moved almost continuously, usually by means of hydraulic jacks, leaving concrete of the required shape and dimensions behind. Slipforming saves time by eliminating the task of striking and resetting formwork and by allowing continuous concreting, but it is not normally an economic solution for vertical structures less than about 15 m high. The design and operation of slipforms require considerable experience and are usually undertaken only by specialist subcontractors.

Design of formwork

Formwork should be designed to withstand all expected loads. These include the self-weight, weight of reinforcement, weight of wet concrete, construction and wind loads, all incidental loads caused by placing and compacting the concrete, and the horizontal pressure of the wet concrete against vertical formwork. Detailed information about these loadings is given in BS 5975, CIRIA Report 108 and the Concrete Society publication, CS030.

Particular care is needed to provide an adequate number of form ties where these are used to link together the opposite panels of a wall form. Whereas slightly inadequate design of other elements of the formwork may lead to large deflections or leakage, the failure of form ties can more easily cause a dangerous collapse. Failure in ties may also occur when they are over-tightened or put into bending rather than simple tension.

The strength of formwork, although very important, is often secondary to its stiffness, which must be sufficient to prevent it deflecting significantly under load, otherwise the resulting concrete surface will show the deformation. When using plywood, it is important to recognize that stiffness parallel to the face grain is less than the stiffness at right-angles to it.

Formwork must be watertight, because small leaks lead to unsightly stains on the concrete surface and large leaks can cause honeycombing. The use of foamed plastic sealing strip or moisture curing gunned silicone rubber provides effective means of sealing joints. Joints may also be sealed by adhesive tape, but it must be accepted that such joints will be apparent on the finished surface. Such patterning is generally acceptable in public spaces such as car parks if it is formalized or set uniformly with the bays of the structure.

Surface treatment

Where the appearance of the concrete is of importance, it is vital that care is taken with the surface of the form. All marks on the form, such as vibrating poker 'burns', as well as varying properties in the form-face material, for example uneven water absorbency in timber, will show on the finished concrete. Loose wire and other debris should be cleaned out of forms prior to concreting; this is usually done with a compressed air hose. It is particularly important that all steel particles are removed as they will rust and spoil the final appearance of the concrete.

FORMWORK

To permit easy striking of the formwork and to reduce the incidence of blowholes, the surface of the form must be coated with a release agent prior to concreting. There are various types of release agent, the merits of which are summarized in Table 16. The most useful are chemical release agents, neat oils with surfactants, and mould cream emulsions. Release agents should be applied to give a very light film. A common fault is the use of too much. If it is thin, application by an airless spray is recommended. Thicker oils may be applied by brush or cloth and spread as far as possible, all excess being removed with a cloth. The use of barrier paints produces a hardwearing surface and may extend the life of timber or plywood forms. If paint is not used, three coats of mould oil should be applied before the form is used for the first time. Some barrier paints are not suitable for use with certain tropical hardwoods, and the manufacturer's advice should be sought on this point. To avoid contamination of reinforcement, the release agent should be applied before the forms are erected, but then it may be necessary to protect the forms from the weather.

Table 16: Types of release agent.

Release agent type	Comments
Chemical release agent	Recommended for all types of formwork. Suitable for high-quality finishes. Based on light, volatile oils that usually dry on the surface of the form to leave a thin coating which is resistant to washing off by rain. The dried coating gives a safer surface to walk on than an oily film, and the release agent does not then transfer from operatives' footwear onto reinforcement. Rate of coverage is greater than for conventional oils. More expensive for a given volume but can be economical if used sparingly.
Mould cream emulsion	Widely used release agent recommended for all types of formwork except steel. Especially recommended for absorbent forms such as timber. Suitable for high-quality finishes. Mix thoroughly before application and use as supplied without further dilution. Avoid using emulsions when there is a risk of freezing. Storage life may be limited. May be spray-applied with care.
Neat oil with surfactant	A useful general-purpose release agent for all types of formwork, including steel. Over-application may result in staining of the concrete. Oil film may be affected by heavy rain.

Unpainted timber forms become progressively less absorbent as the pores of the wood become filled with cement paste during use. This affects the appearance of the finished work - an abrupt colour change will be seen on the concrete - so new and old materials should not be used alongside each other. Similarly, patches of new material in old formwork will produce noticeable colour changes.

In a similar way, forms made from painted timber and various types of plastics having a glazed or glossy surface produce an appearance that changes with the number of uses. In this case the surface glaze is reduced by the first use, and subsequent uses produce a less highly polished surface on the concrete. Some plastic-faced plywoods give a similar effect. The first few uses of these materials can sometimes produce a very hard, dense, and almost black surface to the concrete. This is probably caused by slight movement of the form at a critical time during the hardening process; normally it occurs only with impervious form faces. Similar discolouration of concrete placed against a steel form can usually be attributed to the presence of mill scale on the steel.

Striking of formwork

The period which should elapse before the formwork is struck will vary from job to job and will depend on the concrete used, the weather and the exposure of the site, any subsequent treatment to be given to the concrete, the method of curing and other factors. Formwork must not be removed until the concrete is strong enough to be self-supporting and able to carry imposed loads. Thus, the time of striking should be related to the strength of the concrete, and obviously soffit forms to beams and slabs must be left in place longer than is necessary for the side forms.

Subject to the requirements of the specification and where no other information is available, the periods given in Table 14 under *Strength development* may be taken as a general guide for the removal of formwork. It should be noted that these periods relate to concrete made with Portland cement CEM I 42,5N; shorter periods may apply where a more rapid-hardening cement is used, but considerably longer periods may be required where the concrete contains ggbs or pfa.

When using Table 14, if the surface temperature cannot be obtained, air temperatures may be used. Alternatively, the tables of striking times published in CIRIA Report 1 36 can be used. These take into account the grade of the concrete, the cement type, the dimensions of the section, the type of formwork, the temperature of the concrete at the time of placing and the mean air temperature. Shorter formwork striking times are achievable by measuring the strength development of the in-situ concrete.

Soffit formwork may be struck when the in-situ strength of the concrete is 10 N/mm^2 or twice the stress to which it will be subjected, whichever is the greater. The in-situ strength can be assessed by pull-out tests (see page 60) or from cubes cured, as far as possible, under the same conditions as the in-situ concrete or by temperature-matched curing by which test cubes are immersed in water whose temperature is made to copy that of the structure. Proprietary quick-strip systems permit the removal of soffit formwork without disturbing the propping.

When formwork to beam sides, walls and columns is struck at early ages the concrete will still be 'green' and easily damaged, so extra care is required to avoid damage to arrises and other features; this is particularly important during cold weather. Striking must be carried out with care, to avoid damage to arrises and projections, and it may be necessary to protect some of the work from damage immediately after removing the forms.

Curing should start as soon as the formwork has been removed and, if necessary, the concrete should be insulated as a protection against low temperatures. Timber formwork is a good insulator in its own right, so in winter it is particularly important to avoid thermal shock to the warm concrete when timber or insulated steel forms are removed and the concrete is exposed to the cold air. If the formwork is not required elsewhere, it may be convenient to leave it in place until the concrete has cooled from its high early temperature. The formwork must be removed slowly as the sudden removal of supports is equivalent to a shock load on the partly hardened concrete. Careful removal is also less likely to damage the formwork itself.

FORMWORK

Care of formwork

Formwork frequently accounts for over a third of the cost of the finished concrete, so it should be handled with care. The life of forms can be extended considerably by careful treatment, thus decreasing the overall cost of the job. Rough treatment may make timber and plywood forms useless after one pour, whereas eight or more uses may be obtained by following good site practice.

All formwork should be cleaned as soon as it has been struck. Timber and plywood forms are best cleaned with a stiff brush to remove dust and grout; stubborn bits of grout can be removed using a wooden scraper. With GRP and other plastics, a brush and wet cloth are all that should be needed. The use of steel scrapers should be restricted to steel formwork.

Steel forms should be lightly oiled to prevent rusting if they are not going to be re-used immediately; similarly, timber and untreated plywood should be given a coat of release agent for protection.

Any formwork surface defects such as depressions, splits, nail holes or other unwanted holes should be repaired and made good.

Formwork should be properly stored and protected. Panels and plywood sheets are best stored horizontally on a flat base, clear of the ground, so that they lie flat without twisting, and should be stacked face-to-face to protect the surfaces. Large panels are usually best stored vertically in specially made racks. Stored formwork should be protected from the sun and weather by tarpaulins or plastic sheeting.

References/further reading

BS 5975 : 1996, *Code of practice for falsework.* British Standards Institution, London.

CIRIA Report 108. *Concrete pressure on formwork.* 1995, Construction Industry Research and Information Association, London.

CIRIA Report 1 36. *Formwork striking times - criteria, prediction and methods of assessment.* 1995, Construction Industry Research and Information Association, London.

CS030, *Formwork - a guide to good practice.* 2nd edn. 1995, The Concrete Society, Crowthorne. 306 pp.

Concrete on site - 2: Formwork. 1993, British Cement Association, Crowthorne. Ref. 45.203. 12 pp.

CURING

Curing is the process of preventing the loss of moisture from the concrete while maintaining a satisfactory temperature regime.

Purpose of curing

The hardening of concrete, the development of strength and impermeability depend on the presence of water. At the time the concrete is placed there is always an adequate quantity of water present for full hydration but it is necessary to ensure that this water is retained so that the chemical reaction continues until the concrete has developed the necessary degree of impermeability and strength.

The areas most affected by poor curing are the surface zones, and these are critical with respect to durability. In particular, the protection of reinforcement against corrosion depends on the quality of the concrete in the cover. Similarly, abrasion resistance depends on concrete quality in the top few millimetres. If the curing is inadequate the concrete may not be durable nor provide adequate protection to the reinforcement despite conforming to specification in all other aspects.

Curing should be carried out until the capillary voids are discontinuous, but at present it is not possible to establish the precise times when this occurs. The figures in Table 1 7 (based on Table 6.5 of BS 8110) provide a useful guide but are minimum values and may need to be exceeded. As indicated by the minimum periods in Table 1 7, when some of the Portland cement in a concrete is replaced by ggbs or pfa, curing times are increased by about 50% to compensate for the lower rate of strength development.

The minimum time required for preventing loss of moisture from the surface of the concrete depends on a number of factors including:

- The type of cement or combination
- The cement content and the free water/cement ratio
- The temperature of the surface layer
- The ambient conditions
- The intended use of the concrete.

In addition to these factors, ambient conditions after casting will vary during the period of curing, so it is recommended that curing, either by preventing evaporation or by keeping the surface of the concrete continually damp is carried out for at least:

- 7 days for horizontal surfaces
- 3 days for vertical surfaces.

Specific recommendations for particular elements are given on the following pages.

Concrete also needs to be kept at a favourable temperature - the lower the temperature, the slower is the rate at which concrete hardens and develops strength. If the temperature of the plastic concrete falls below freezing point before adequate strength has developed, the freezing and resulting expansion of the water may cause permanent damage. Refer to pages 38 - 40 for further information relating to cold and hot weather conditions.

Curing increases resistance to abrasion, so effective curing is essential for floors and other surfaces subject to wear. Continuous curing from the time the concrete is placed helps to ensure a hard,dense surface which reduces the risk of crazing and dusting, increases impermeability and improves weathering characteristics. This is of vital importance for the concrete cover to reinforcement.

CURING

Table 17: Minimum periods of curing and protection.

Type of cement	Curing conditions after casting	Minimum periods of curing and protection (days)		
		Average surface temperature of concrete		
		5°C to 10°C	Above 10°C	*t* (any temperature between 5°C and 25 C)
CEM I 42,5N SRPC CEM I 42,5R CEM I 52,5	Average	4	3	$\frac{60}{t+10}$
	Poor	6	4	$\frac{80}{t+10}$
CEM II and CII CEM IIIA and CIIIA CEM IV and CIV	Average			
	Poor	10	7	$\frac{140}{t+10}$
All cement types	Good	No special requirements		

NOTE
Curing conditions are defined as:
Good - damp and protected (relative humidity greater than 80%, protected from sun and wind)
Average - intermediate between good and poor
Poor - dry or unprotected (relative humidity less than 50%, not protected from sun and wind)

Early curing will reduce evaporation of water from the surface of fresh concrete in drying conditions; unless evaporation is checked, 'plastic' cracks may appear while the concrete is still setting. This was discussed on page 19 under *Plastic cracking.*

Methods of curing

Methods of curing can conveniently be considered in two groups:

- Those which keep water or moisture in close contact with the surface of the concrete, such as ponding, spraying/sprinkling, damp sand and damp hessian
- Those which prevent the loss of moisture from the concrete, such as plastic sheeting, building paper, leaving the formwork in place, and sprayed-on curing membranes.

Although tests have shown that the methods in the first group are the most efficient and may be appropriate for some work, they tend to suffer from the practical disadvantages of being expensive in both materials and labour and, perhaps more importantly, it is difficult to ensure that they are done properly; damp hessian, for example, is seldom kept continuously damp.

Curing menbranes

Curing membranes are liquids sprayed onto either fresh or hardened concrete surfaces, which dry leaving a thin film of resin to seal the surface and reduce the loss of moisture (Figure 30). They can be used on both horizontal areas of fresh concrete and vertical surfaces after the removal of formwork. Most sprayed-on curing compounds should be applied immediately after the water sheen which results from bleeding has evaporated.

The resin film remains intact for about four weeks, but then becomes brittle and peels off under the action of sun and weather. Curing membranes were developed for roads and airfield pavements which are difficult and impractical to cure satisfactorily by any other means, and although they are now used extensively for curing structural concrete there are some occasions when they may not be suitable.

Figure 30: Spraying a reservoir wall with a curing membrane.

Most proprietary makes are available in various grades, a standard grade usually having what is termed a curing efficiency of 75%, and a better grade one of 90%; both are pale amber/straw in colour. In addition, both grades are usually available with a white or aluminized pigment, or containing a fugitive dye. The white and aluminium-powder pigmented types are specifically for external paved areas, where the pigments reflect the sun's rays so reducing the amount of heat absorbed by the concrete. Those containing a fugitive dye make it easier to see where the membrane has been applied and that it has been applied uniformly; the dye quickly disappears after application and will not stain the surface provided that it is not applied to a dry concrete surface. Special non-toxic compounds are available for use on concrete that is to contain drinking water. Pigmented and aluminized varieties should be agitated frequently to ensure uniform dispersion of the solids.

Generally, and certainly in the UK, the pigmented higher-efficiency grades should be used for external paved areas, and the non-pigmented lower efficiency grades on structural concrete. In tropical climates, the higher-efficiency grades should be used for all applications.

On any job it is therefore essential to make sure that the right type of curing membrane is used. Further information is available in the BCA publication *Concrete on site - 6: Curing.*

Horizontal surfaces

It is essential for most horizontal surfaces to be well cured. This is particularly important where the concrete will be trafficked, either by foot or by vehicles.

Curing should always start as soon as possible after the concrete has been compacted and finished, generally within 30 minutes of the water sheen (bleed water) disappearing.

Road slabs and other external concrete (paths and drives)

Major concrete roads are usually sprayed with a curing membrane by a machine that is part of the paving train. This is not discussed in this publication. For smaller paved areas where semi-manual methods of construction are used, a curing membrane can be applied using a hand-operated spray of the garden type. A white pigmented or aluminized super grade of compound should be used, taking particular care to ensure an even coat is applied, especially in strong winds.

Although curing membranes can be used for small areas of external concrete, it may be more convenient, and just as good, to use polythene sheeting. The covering should be kept in place for at least seven days, paying particular care at the edges of sheets, as there is a tendency for the concrete to dry out here due to wind tunnelling effects.

Slabs to receive a screed

A curing compound should not be used when a slab will later receive a cement-sand levelling screed, a wearing screed or any other bonded covering, as the bond may be affected.

Polythene sheeting will usually be the most convenient method of curing. Covering with damp hessian is not recommended because of the difficulty of keeping it moist in dry weather, especially overnight and at weekends. The concrete should be covered as soon as possible after finishing, especially in a drying wind.

Direct-finished concrete and wearing screeds

Power-floated finishes and wearing screeds have to be hard-wearing and abrasion-resistant, and particular attention to curing is essential.

After the final trowelling (either by hand or by power trowel) the surface should be firm enough for immediately covering with plastic sheeting or similar, or applying a curing compound.

The surface should not be allowed to dry out before curing. Polythene sheeting should be kept in place for at least seven days. Some loss of moisture may occur at the edges and at laps and it may be necessary every other day to turn back the sheeting and spray with water, and then replace the sheeting.

Resin-based hardeners also act as curing agents.

Cement-sand screeds

Curing compounds are not recommended because of the need for floor covering materials to bond to the screed. After laying, a cement-sand screed should be kept continuously damp for at least seven days, preferably by covering with polythene sheeting.

Vertical surfaces

The curing of columns, walls and beam sides is more difficult than horizontal surfaces. Curing membranes can sometimes be used but are not generally suitable when any subsequent treatment or rendering is to be applied.

While in position, formwork protects the concrete against loss of moisture and it is only after striking that further curing may be necessary.

When formwork has been kept in position for four days there is usually no need for further curing of concrete made with CEM I, even in drying conditions. Concretes containing pfa or ggbs may require a longer moist-curing period, see Table 17 on page 46.

For concrete surfaces not exposed to the weather, which are to receive an applied decorative treatment such as rendering, plaster or paint, or will be tooled or abrasive blasted, no further curing of CEM I concrete is usually necessary, however soon the formwork is struck.

In general, further curing of vertical surfaces of concrete is required in temperate climates only when the formwork is struck within four days of placing the concrete and either:

- The surface will be permanently exposed to the weather; or
- The surfaces have to be uniform in colour, e.g. a number of similar columns or series of pours making up a wall.

Exposed concrete

All vertical surfaces of concrete, including white and coloured, which will be permanently exposed to the weather need extra care with curing. A well-cured surface will be more impermeable and better able to withstand the action of freezing and thawing and wetting and drying; surface crazing will also be reduced. Good curing will also help the long-term appearance of the concrete by reducing dirt collection.

All concrete surfaces that will be permanently exposed to the weather, including those to be abrasive blasted or tooled, should be cured for at least seven days. Although polythene sheeting can be used for this, it will usually be more convenient to use a sprayed-on curing compound.

Uniformity of colour

The colour of concrete can be affected by the age at which formwork is removed and by the weather, both at the time of striking and subsequently.

Where uniformity of colour is important, for example with as struck 'fair-faced' and board-marked surfaces, **either:**

- The formwork should be left in position for four days, in which case no further curing is usually necessary; **or**
- When the formwork is removed in less than four days the concrete should be covered or wrapped in polythene sheeting for at least another three days. Alternatively, but only if the concrete will be permanently exposed to the weather, a curing compound may be applied.

Damp hessian is not recommended because it contains a dye, which can stain the surface. It is also ineffective if it dries out.

CURING

White and coloured concrete

It is not advisable to use a curing compound on white or coloured concrete if there is a risk of discolouration.

Polythene sheeting is the preferred material because it cannot stain the concrete. Sheeting that is firmly fixed and left in place also protects the surface from dust caused by other site work; subsequent removal of dirt and stains is both time-consuming and expensive.

References/further reading

BS 8110 : 1997, *The structural use of concrete.* British Standards Institution, London.

DD ENV 1 3670, *Execution of concrete structures.* British Standards Institution, London.
Part 1 : 2000, *Common rules.*

Concrete on site - 6: Curing. 1993, British Cement Association, Crowthorne. Ref. 45.206. 16 pp.

CONCRETE SURFACE FINISHES

Visual concrete, which is designed to be seen in a completed building or structure, requires special consideration at an early stage, since its appearance will largely determine the quality of the whole job. To produce concrete with a good finish, the formwork, the concrete itself and the way it is placed and compacted must all be to a consistently high standard, following the guidelines outlined in the preceding sections.

Range of finishes

There are two main types of finish:

- Those produced direct from the formwork, often called 'as struck' finishes, comprising plain, smooth finishes, and textured and profiled finishes such as board-marked concrete and ribbed or striated and modelled surfaces
- Those produced indirectly by further treatment after the formwork is removed, including exposed-aggregate and tooled finishes.

The two types are often combined to produce, for example, a striated and tooled finish, or a modelled exposed-aggregate finish (Figures 31 and 32).

Figure 31: An example of an in-situ exposed-aggregate finish obtained with the aid of a surface retarder.

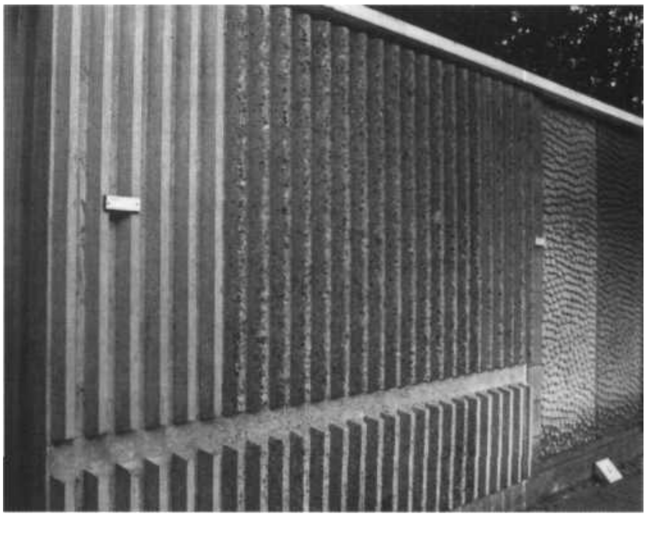


Figure 32: Examples of profiled direct finished and abrasive-blasted finishes.

CONCRETE SURFACE FINISHES

Standard of finish

Concrete can be produced within close dimensional tolerances, but the inherent variations in colour and the presence of some small air bubbles or blow-holes on the surface produce a finish which is seldom entirely blemish-free; it is unrealistic to expect perfection in appearance. It is essential to have a full-size section of part of the structure produced as a sample in order to avoid later dispute about the quality of the work. Guidance on the standards of surface finish is given in the BCA series of publications *Appearance Matters* and Concrete Society Technical Report 52, *Plain formed concrete finishes.* To judge the quality of the finish, the sample should be viewed at the same distance from which the job will be seen.

To provide a reference to the surface finishes Types A and B as specified in BS 8110, sets of panels have been manufactured and installed at seven regional centres throughout the UK. They can be visited freely and should reduce the conflict that can occur due to differing interpretations of the standard. For details see www.construct.org.uk.

Influence of formwork

A concrete surface will reproduce every detail of the form surface from which it was cast. The formwork must remain watertight against the pressure of concrete in order to prevent leakage. Any loss of water from the fresh concrete will result in a dark area on the completed surface, which extends into the concrete and cannot usually be removed by tooling - in fact more often than not tooling makes the blemish more obvious. Caskets may be necessary to maintain watertightness at the joints and, in the case of exposed-aggregate and tooled finishes, the formwork joints may be sealed with adhesive tape, joints in the formwork, even well made ones, will show in the finished concrete; the position of formwork joints should therefore be planned.

The standard of finish specified and the number of uses required for the formwork usually affect the choice of facing material. The surface characteristics of the formwork have a profound effect upon the appearance of the concrete. Unsealed plywood - because it is slightly absorbent - will cause relatively few blow-holes, but variations in the absorbency of the timber grain will produce corresponding variations in the colour of the concrete. On the other hand, impermeable formwork will give rise to more blow-holes, although the colour may be more uniform. A further complication is that concrete cast against smooth impermeable surfaces may have a dark, almost black, surface (as described under *Surface treatment* on page 43). The colour variation may be reduced if the formwork has a matt surface which will retain the release agent, rather than a smooth shiny one from which the release agent is removed during placing and compaction of the concrete.

A thin coating of release agent should be applied to the formwork each time before the concrete is placed to prevent adhesion, and thus make formwork removal easier when the concrete has hardened. Release agents must be applied sparingly otherwise the surface of the concrete could be adversely affected. There are several different types of release agent and it is important to use one that is suitable for the form material in question. Recommendations of types and applications are given earlier (page 43) under the heading *Surface treatment.*

The quality of surface finish may be significantly improved with the use of a controlled-permeability formwork (CPF) system; see *Types of formwork* page 43. Here a patent woven synthetic fabric is securely fixed to the form face and the concrete cast in the normal way. Bleed water that would cause unsightly marking of vertical surfaces is drained away and blow holes of entrapped air are also absorbed into the fabric. The resulting concrete surface benefits both from a blemish-free appearance and, by virtue of having been effectively dewatered, the free water/cement ratio in the cover zone is reduced, making the concrete more durable.

Concrete for high quality finishes

In order to be able to control the quality of the concrete to the standard required for visual concrete, it is essential to have the coarse aggregate stocked and batched separately in two sizes, one of 20 - 10 mm and the other 10-5 mm and to combine them in the concrete in the proportions required, according to the following guidelines:

- A minimum cement content of 320 kg/m^3, but preferably not less than 350 kg/m^3
- A sand content of not more than twice the weight of cement
- Total aggregate not more than six times the weight of cement
- Avoidance of an excessive quantity of 10 - 5 mm aggregate
- Free water/cement ratio of 0.50 or less
- Consistence class normally S2 (50 - 90 mm slump).

The proportion of 1 : 2 for the cement: sand fraction is based on M grade sand. In the case of finer sand, the quantity should be reduced to compensate for its increased surface area.

Trial mixes and sample panels are essential to determine the suitability of the concrete for the particular job in question.

Supervision and workmanship

A high level of supervision is essential, with special attention to the following:

- The formwork should be checked for alignment, level and plumb, for bracing and tightness of all fixings, joints must be watertight to prevent leakage. The formwork should also be checked for accuracy of dimensions
- Reinforcement needs to be checked so that the correct cover will be achieved
- The first part discharged from a truck-mixer should either be used in a visually unimportant part of the work, or set aside and used later after some of the more homogeneous concrete has been placed
- Once begun, placing should be continuous until the pour has been completed; continuity in the supply of concrete is therefore essential
- Placing should proceed at a uniform rate of not less than 2 m height per hour. This requires careful consideration and planning of pour sizes
- The actual rate of placing needs to be restricted by the rate at which the concrete can be compacted.

Plain smooth finishes

Contrary to a widely held belief, plain smooth surfaces are the most difficult to produce to a consistently high standard, because of the inherent variation in the constituent materials and the fact that even the smallest blemishes are readily visible on plain surfaces.

There is still need for a good finish, even when grit blasting or bush hammering is to be used to expose the aggregate. It is not true that bush hammering will make a poor finish acceptable; in practice, any tooling of a poor finish only serves to accentuate the surface defects.

CONCRETE SURFACE FINISHES

Textured and profiled finishes

The simplest textured finishes can be obtained by using formwork made from rough-sawn boards, so that the imprint of the wood grain is reproduced on the surface of the concrete. To be effective, great care is necessary in the design and fabrication of the formwork, particularly the joints and any fixings.

Formwork linings are made in a variety of patterns from materials such as expanded polystyrene (which can only be used once) and flexible rubber-like plastics (which will give repeated use). Manufacturers of these materials usually provide guidance as to their use.

Ribbed finishes are usually produced by fixing timber battens securely to the formwork; fixing should be by both gluing and screwing to prevent grout loss under the battens. The battens must have a generous taper ('draw') to enable them to be struck from the hardened concrete. The formwork for intricately modelled surfaces is often made from glass fibre reinforced plastics.

Guidance on textured and profiled finish is given in the BCA publication *Appearance Matters - 7.*

Exposed-aggregate finishes

Coarse aggregate is exposed by removing cement and sand mortar from the face of the concrete. The variability in the distribution of the coarse aggregate in ordinary concrete tends to give an uneven appearance when that aggregate is exposed. It is therefore necessary to use a special prescribed concrete using gap-graded aggregates containing as large a proportion as possible of the coarse aggregate, and it should be noted that such a concrete will require particular care in transporting and placing. For example, all the coarse aggregate should be between 20-10 mm in size instead of 20 - 5 mm. Trial mixes will have to be produced to determine the mix design, firstly to achieve the finish and secondly to satisfy durability and compressive strength requirements.

One method of exposing the aggregate is to coat the formwork with a chemical retarder, which prevents the cement in contact with it from hardening. When the formwork is removed the surface mortar is brushed away to uncover the aggregate embedded in the hardened concrete. Timing of the operation is fairly critical since some retarders will delay the hardening only while the surface is tightly covered. When the formwork is removed and air gets to the surface, the mortar soon hardens. It is therefore important to organize the work so that the surface can be treated within a short time of the formwork being stripped. Brushing should begin near the bottom of the wall or column, because the concrete will be harder there than towards the top.

The surface mortar can also be removed from hardened concrete by abrasive blasting. In this technique, compressed air is used to carry a stream of selected grit along a flexible hose to a nozzle, where it emerges as a jet and is directed at the surface of the concrete. The operator must wear a helmet with a piped air supply to protect him from the dust which is created, and the working area has to be screened off to avoid endangering other site personnel and passers-by. A deep or heavy exposure, in which the coarse aggregate is exposed by a third of its depth, is best carried out when the concrete is about two days old. If it is left until the concrete is harder, it will take much longer to produce the finish. A medium-depth finish can be carried out at three to four days after placing the concrete, and a light abrasive-blast finish at seven days or later. The operator must have considerable experience of working on concrete but, given this, abrasive blasting is often quicker and less sensitive to variations in the finish than other methods of exposing the aggregate.

Guidance on exposed aggregate finish is given in the BCA publication *Appearance Matters - 8.*

Tooled concrete finishes

Tooled finishes are not produced until the concrete has achieved a compressive strength of at least 20 N/mm^2, so this particular operation can often be left until near the end of a contract. Tooling removes a layer of concrete from the surface - typically 5 mm with bush hammering and 10 mm or even 20 mm with point tooling - and reveals the colour but not necessarily the shape of the aggregate. Care is required when working near the edge of an element, and it is usual to provide a plain margin that is left untooled to minimize the risk of breaking the edges.

Guidance on tooled finishes is given in the BCA publication *Appearance Matters - 9.*

Remedial work

Except for the need to cure the concrete, plain and textured finishes should not need any further attention once the formwork has been removed. However, it will be necessary to fill any tie-bolt holes, and these are best dealt with as soon as possible so that the mortar gains strength at the same rate as the concrete itself. Similarly, if blow-holes are to be filled, these should be 'made-good' as soon as possible.

Making-good is a skilled job that should not be entrusted to a general labourer. The mortar that is used has to be blended by introducing a proportion of white cement, or some white limestone sand, to match the grey of the concrete and smoothness of a formed face.

Remedying a fault such as a locally honeycombed area, which may have to be cut back to sound, well compacted material before being reinstated, may be satisfactory from a structural point of view, but is unlikely to be acceptable in terms of appearance because the patch will often tend to weather differently and become more obvious with time. It is therefore all the more necessary to take particular care in the production of visually important sections of the work.

Further information is available in the BCA publication *Concrete on site - 8: Making good and finishing.*

References/further reading

TR 52, *Plain formed concrete finishes.* 1999, The Concrete Society, Crowthorne. 48 pp.

Appearance matters. British Cement Association, Crowthome.

1: *Visual concrete - Design and production.* 1988, Ref. 47.101.26 pp.

7: *Textured and profiled concrete finishes.* 1986. Ref. 47.107. 12 pp.

8: *Exposed aggregate concrete finishes.* 1985. Ref. 47.108. 16 pp.

9: *Tooled concrete finishes.* 1985. Ref. 47.109. 8 pp.

Concrete on site - 8: Making good and finishing. 1993, British Cement Association, Crowthorne. Ref. 45.208. 12 pp.

FLOOR FINISHES

A good-quality concrete, well laid and finished makes a satisfactory floor for many purposes. The concrete surface can be smooth, easily cleaned, have good resistance to abrasion, be non-slip and have a low maintenance cost. These properties depend largely on the choice of suitable materials, concrete quality and good workmanship in construction and finishing.

Choice of finish

The finish of a concrete floor should be chosen after considering the type of traffic and loading, impact abrasion and chemical resistance, and such factors as hygiene, dust prevention, slipperiness and decorative treatment. Guidance on suitable finishes for various duties is given in a BCA publication *Power trowelling and skip floating.*

In many industrial situations a structural slab of adequate quality may be direct-finished to give a satisfactory wearing surface. The finish may be produced by power trowelling (or hand trowelling if the operatives are sufficiently skilled) or early-age power grinding. Whichever finish method is used, to achieve good regularity of the final surface it is essential to provide accurately set and levelled square-edged side forms, and to give careful attention to concrete placing, compaction and levelling. Compaction and levelling can be done efficiently and speedily by using a double-beam vibrator or a tri-screed (known as a razorback) and flat surfaces can be achieved, even on steep slopes, with a rotating striker tube.

In some heavy industrial situations, especially where fork-lift trucks with solid wheels are used and where heavy abrasion or impact and chemical attack will occur, special applied wearing screeds may be necessary.

Power trowelling

A power-trowelled finish is obtained by first using a power float to smooth and close the previously levelled concrete surface after it has stiffened sufficiently - about three hours after laying. After a further delay to allow excess surface moisture to evaporate, the slab surface is further smoothed and made dense with a power trowel (Figure 33). A power float has a rotating circular disc attachment or large flat individual blades. A power trowel has smaller, tilted individual blades and is used for final finishing. The timing of each application is critical.

Figure 33: Power trowelling an industrial floor slab.

Power grinding

Power grinding is a finishing technique intended to provide an acceptable and durable concrete wearing surface without further treatment. After the concrete has been fully compacted and accurately levelled with a double-beam vibrator, it is further smoothed with a large, metal skip float attached to a long handle. The concrete is allowed to harden and the surface is then ground to a coarse 'sandpaper' texture using a low-speed grinder to remove the top 1 - 2 mm of laitance and minor irregularities left during finishing.

The grinding is not intended to remove gross inaccuracies of level. The age of the concrete at grinding depends on the gain of concrete strength, but for maximum economy grinding is usually carried out between one and seven days after laying, as soon as the concrete can be ground without tearing sand particles from the surface. Some grinders operate dry, but with the bigger machines the concrete is usually well wetted.

Vacuum dewatering

The problems of timing power trowelling - particularly in cold weather - can be largely overcome by using the vacuum dewatering process immediately after initial compaction and levelling of the concrete slab or wearing screed. The concrete surface is covered with a vacuum mat, incorporating filter layers, which is connected to a vacuum pump. By applying a vacuum for about three minutes per 25 mm depth of concrete, excess water is extracted, causing the concrete to stiffen rapidly. The initial power floating can then take place within an hour of the concrete being placed. The process also improves the wear resistance and general durability.

Applied concrete wearing screeds

Where wearing screeds are considered necessary, it is preferable that they are laid monolithically with the base concrete, i.e. within three hours of placing the base. Where screeds are laid separately and bonded, experience has shown that there is a high failure rate, mainly due to lack of care in bonding techniques. Where separate bonding screeds must be used, an extremely high standard of workmanship is necessary to avoid curling and hollowness of the screed through loss of bond.

Curing

If a hard-wearing surface is to be produced, the concrete surface of a direct-finished slab or wearing screed must be continuously cured for at least seven days after being finished.

An efficient and economical method of curing is to cover the floor with plastic sheeting held down in close contact with the surface. Alternatively, a proprietary sprayed resin curing membrane may be applied, provided it is compatible with any later surface sealing and hardening process which may have been specified to reduce the risk of dusting. Curing techniques are dealt with on page 46 under *Methods of curing.*

References/further reading

BS 8204 : Part 2 :1999. *Screeds, bases and in-situ floorings. Concrete wearing surfaces. Code of practice.* British Standards Institution, London.

CSTR 34, *Concrete industrial ground floors - A guide to their design and construction.* 1994, The Concrete Society, Crowthorne. 172 pp.

Power trowelling and skip floating. 1999. BCA Library Reprint, British Cement Association, Crowthorne. 12 pp.

Floor levelling screeds. 1997, British Cement Association, Crowthorne. Ref. 48.061. 16 pp.

TESTING CONCRETE & CONCRETING MATERIALS

Most tests on concrete and concreting materials fall into one of the following categories:

1. Tests, carried out mainly in a laboratory, to assist in deciding whether particular sources of material are suitable for concrete and conform to the specification requirements and, if so, in what proportions they should be combined to produce concrete of the required properties. In the case of site-mixed concrete, these will usually consist of tests on the aggregate followed by trial mixes to establish the proportions for the various concretes to be used. For ready-mixed concrete, suppliers normally provide mix design certificates for the different concrete classes specified along with information about the aggregates and their properties.
2. Routine on-site tests for both control and conformity. Aggregates are tested for grading and moisture content in the case of site mixing, and both site- and ready-mixed concrete are tested for consistence and strength. Site tests are reasonably simple and, although staff do not need special skills, they must know the Standard requirements for those tests which they have to perform. Meaningful results can be obtained only if tests are carried out strictly in accordance with the relevant British Standard method.

This section concentrates on the site tests, though a few references are made to laboratory tests that, on occasions, may be used in the field.

Detailed descriptions of the methods of sampling and testing are given in a number of British Standards that are listed under *References/further reading.*

Sampling materials

The object of sampling is to produce a truly representative quantity of the consignment being sampled and of sufficient quantity for the tests required. Aggregate and concrete are heterogeneous materials, so great care is needed in sampling to ensure that the sample is truly representative if reliable test results are to be obtained. Materials being delivered to site in relatively small lots are best sampled during delivery to stockpiles.

Cement

The requirements for sampling cement are given in BS EN 196. The manufacturer supplies test reports on a regular basis, which should be studied by the concrete producer. Cement testing is rarely required on site.

Aggregates

Details of sampling aggregates are given in BS 812 : Part 102 and BS EN 932-1.

The bulk sample of each type or size of aggregate to be tested should be obtained by collecting increments (scoopsful) to provide the quantity required for all the tests to be made. The minimum number of increments should not be less than those shown in Table 18.

Sampling may have to be done in a wide variety of conditions and it is not possible to describe in detail the procedure for obtaining increments in all circumstances. When sampling from heaps, the increments should be taken from different places in the stockpile, removing at each position the top 150 mm before digging in the scoop. For material being loaded or unloaded from a vehicle, or being discharged from a conveyor belt, the increments should be taken at fairly regular intervals distributed during the movement of the quantity being sampled. It is virtually impossible to obtain a representative sample from lorries, before or after discharge, which have been layer-loaded. When sampling from a stockpile, representative samples should be obtained by first digging holes of various depths from the top.

Table 18: Minimum number of sampling increments for aggregates.

Nominal size of aggregate D_{max}	Minimum number of sampling increments		Minimum sample size for normal density aggregate
	Large scoop	Small scoop	
20 mm and larger	20	-	50 kg
5 mm to 20 mm	10	-	25 kg
5 mm and smaller	10 half scoops	10	10 kg

The bulk sample usually has to be reduced to a smaller quantity, depending on the amounts required for the particular tests. A sample divider (riffle box) is the most convenient method. This is designed so that material poured in the top is divided approximately equally and diverted to two sides; material to one side of the box is discarded and the remainder tested or divided to a smaller sample (Figure 34). Coarse aggregates may be divided while damp, but sand should be surface-dry.

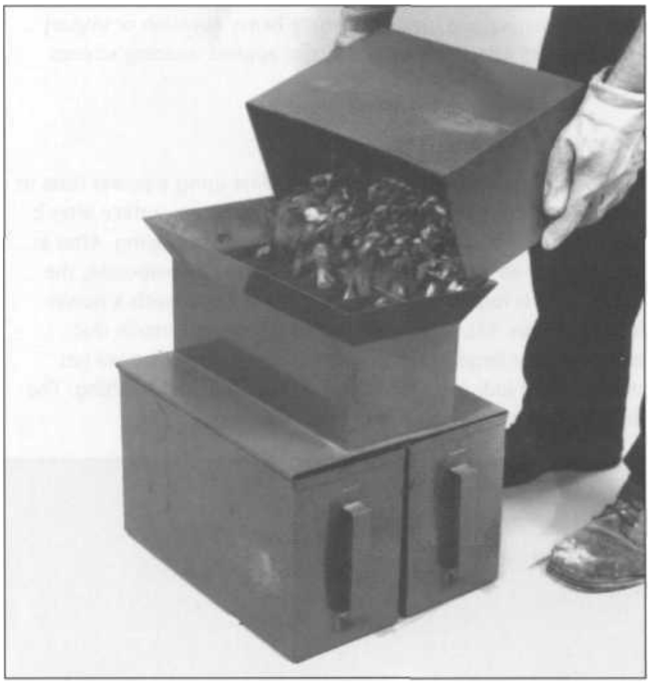


Figure 34: Dividing a sample of aggregate with a riffle box.

Quartering is the alternative method where a sample divider is not available. The bulk sample should be shovelled to form a cone, and turned over to form a new cone, this being done three times. The third cone should be flattened to an even layer 75-100 mm thick and then divided into four equal quadrants with two diagonally opposite quarters being discarded (Figure 35). The procedure is then repeated on the remainder until the desired size of sample remains. When samples of aggregates have to be despatched to a laboratory, they should be packed securely in containers that will prevent loss of fine dust and damage in transit, and should be clearly labelled. Each sample should be accompanied by a certificate, stating that sampling was carried out in accordance with the relevant standard.

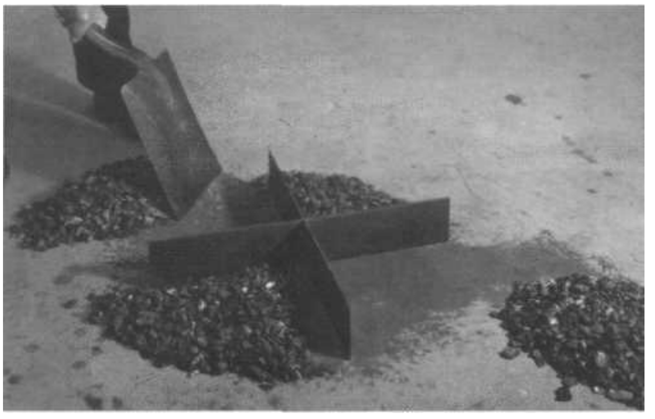


Figure 35: Reducing a sample of coarse aggregate by quartering

Concrete

Correct sampling of concrete is essential to obtain representative test results of a batch of concrete. Sampling is fully described in BS 1881: Part 101 and BS EN 12350-1, which also give the quantities required for the different tests. Whenever possible, the sampling should be done when the concrete is moving in a stream, such as when it flows down the discharge chute of a mixer or is being conveyed on a belt. Concrete may be sampled from a stationary lorry or heap, but this method is less satisfactory. Concrete cannot be sampled satisfactorily from a discharging tipper lorry or dumper.

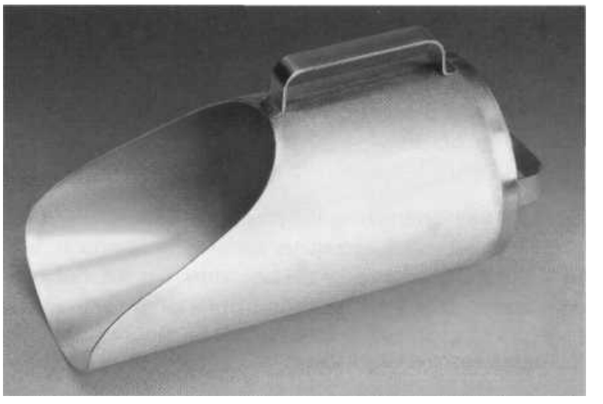
A sample consists of a number of standard scoopsful taken from a batch; Table 19 gives the required number of scoopsful for some of the more usual tests. Figure 36 shows a suitable scoop that will provide about 5 kg of normal-weight concrete. As a general rule, the sample size should be about 1½ times the quantity required for testing.

Table 19: Quantities of concrete required.

Test or specimen	Number of standard scoopsful
Slump	4
Compacting factor	6
Degree of compactability	12
Air content	4
100 mm cube (per pair of cubes)	4
150 mm cube (per pair of cubes)	4
NOTE Take sufficient scoopsful for tests to be made on different samples	

The batch should be nominally divided into a number of parts equal to the required number of scoopsful. For samples taken from a moving stream, such as a batch-mixer or ready-mixed concrete truck-mixer, the scoopsful should be taken at equally spaced intervals; avoiding the very first and very last parts of the discharge. Thus, when four scoopsful are needed to make up the required test sample, they should be taken about the time when one-fifth, two-fifths, three-fifths and four-fifths have been discharged, the scoop being passed through the whole width and thickness of the stream in a single movement.

When sampling from lorries or heaps, the scoopsful should be distributed through the depth of concrete as well as over the exposed surface.



Scoop dimensions

Dimension	Small scoop Use for sampling aggregates only	Large scoop Use for sampling aggregates and concrete
Length	200 mm	250 mm
Diameter	100 mm	125 mm

Figure 36: Sampling scoop.

Where the point of mixing and the point of placing are some distance apart, there is the choice of taking samples at either place. Sampling and testing at the mixer has the advantage of enabling adjustments to the concrete to be made more quickly, but consistence tests can be more easily related to the placing conditions if done at the point of placing. On some jobs it may be useful to carry out a few tests at both places so as to ascertain, for example, the change in consistence during transport in hot weather or when long delays, of half an hour or so, occur between mixing and placing.

In the case of ready-mixed concrete an alternative method of sampling is permitted for the slump test only. For this, six standard scoopsful should be collected in a bucket or other suitable container after about 0.3 m^3 has been allowed to discharge, so that the load can be tested before the main discharge takes place.

For all tests the sample, consisting of a number of scoopfuls in one or more buckets, will require thorough mixing. This should be done by emptying it from the container onto a non-absorbent surface, preferably a 900 mm square metal tray, and shovelling it to form a cone, which should be turned over to form a new cone three times. When forming the cones each shovelful should be placed on the apex of the cone so that the portions that slide down the sides are distributed as evenly as possible. BS 1881: Part 101 requires each sample to be accompanied by a certificate from the person responsible for taking the sample stating that the sampling was done in accordance with British Standard. Appendix 2 shows a suitable certificate.

Testing materials

Cement

The testing of cement is done in accordance with the standard procedures in BS EN 196, which is published in different parts for the various physical and chemical tests. The British Standard - which now implements the European Standard - for cement testing covers a wide range of properties including chemical analysis, fineness, strength, setting time, soundness and, in special cases, heat of hydration.

Aggregates

For good quality control, it is important to ensure that the aggregate is clean and does not contain any organic impurities which might retard or prevent the setting of the cement, and that the proportions of the different sizes or particles within a graded material remain uniform.

Cleanness

Accurate tests for determining the proportion of fines (clay, silt and dust) in sand and coarse aggregates are given in Standards, but these tests are only suitable for the laboratory. On site, cleanness can be assessed visually, although for natural sands the 'field settling' test will give an approximate guide to the amount of fines; the test is not appropriate for coarse aggregates or for crushed-rock sand.

The test entails placing about 50 ml of a 1% solution of common salt in water (roughly two teaspoonsful per litre) in a 250 ml measuring cylinder. Sand is then added gradually until the level of the top of the sand is at the 100 ml mark, and more solution is added to bring the liquid level to the 150 ml mark. The cylinder is shaken vigorously, and the contents allowed to settle for three hours. The thickness of the layer of fines that settles above the sand (Figure 37) is then measured and expressed as a percentage of the height of the sand below the layer. The amount of fines in the sand is compared against previous test results to give a warning of changes in cleanness.

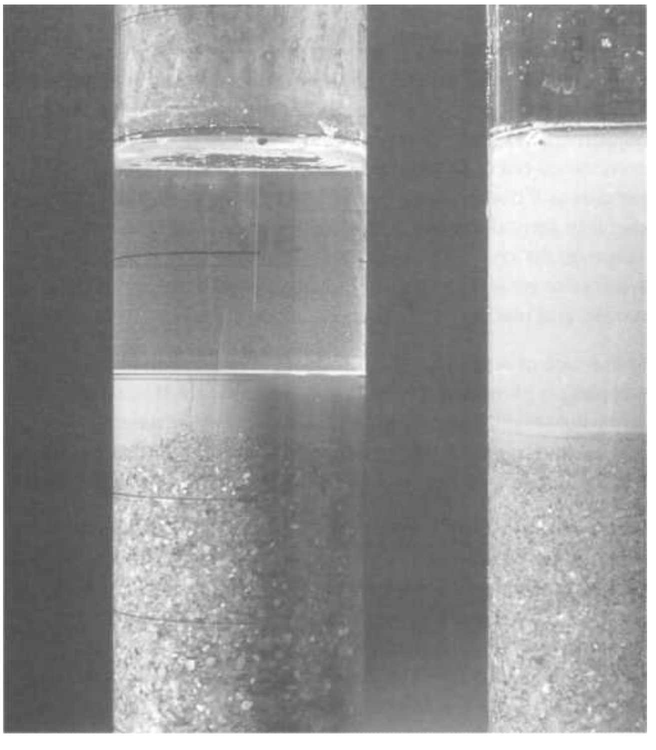


Figure 37: The field settling test for fines in sand.

If a measuring cylinder is not available, a jam jar or bottle filled to a depth of 50 mm with sand and to a total depth of 75 mm with the salt solution will give comparable results if the contents are allowed to settle for three hours.

The field settling test gives only an approximate guide. Sands apparently containing large amounts of fines cannot be regarded as having failed to comply with the specification, and further laboratory tests to assess their suitability must be carried out. It is, however, a useful and quick way of detecting changes in the cleanness of sand.

There is no suitable site test for the cleanness of coarse or all-in aggregates or of crushed-rock sand, and reliance is usually placed upon the grading analysis (see below) to show whether there is an excess of fine dust in the material. Problems arise, however, because of the tendency for fines to adhere to the rough surface of crushed coarse aggregate.

Similarly, there is no suitable site test for the cleanness of a gravel coarse aggregate. It is important to ensure that aggregate particles are not coated with clay and that lumps of clay are not mixed in the aggregate. The presence of clay indicates that the aggregate has not been washed adequately before delivery or that the aggregate has subsequently become contaminated.

Accurate determinations of the fines content in aggregates are made in laboratories using either sedimentation or (more usually) decantation or wet sieving methods in accordance with Standard procedures.

Organic and other impurities

Coarse aggregates from any source, and crushed-rock sands, are unlikely to contain organic impurities, though natural sands may do so. Current aggregate standards include tests for organic impurities. If there is reason to suspect the presence of organic impurities that could retard the hydration of the cement, the effects should be determined by performance tests on concrete made with the aggregate in question.

Where appearance is an essential feature of the concrete, aggregates should be selected from sources known to be free from materials such as iron pyrites or particles of coal that could mar the surface. The only guide is a knowledge of the source and of similar work that has been carried out with the aggregate in question.

Sieve analysis

The grading of an aggregate is found by passing a representative sample of dry aggregate through a series of sieves, starting with the largest mesh. If the sieving is carried out by hand, each sieve is shaken separately over a clean tray for not less than two minutes. For many routine purposes mechanical sieving is advantageous, but if this method is used care should be taken to ensure that sieving is complete.

The material retained on each sieve, together with any material cleaned from the mesh, is weighed and recorded. The amount passing each sieve is then calculated as a percentage by weight of the total. Table 20 gives an example of a method for recording a sieve analysis and calculating the percentage passing each sieve. Comparison with Table 6 on page 12 will show that this sample is a sand falling within grading limit M.

Table 20: Example of the method of recording sieve analysis of sand.

BS sieve size	Mass retained on each sieve (g)	Total mass passing each sieve (g)	Percentage passing each sieve
10 mm	0	275	100
5 mm	8	267	97
2.36 mm	36	231	84
1.18 mm	33	198	72
600 µm	38	160	58
300 µm	91	69	25
150 µm	47	22	8
Sieve pan	22	0	0
Total	275		

Sieving will not be accurate if there is too much material left on any mesh after shaking. The maximum weights of aggregate to be retained on a sieve to avoid overloading are given in BS 812.

The size of the sample tested depends upon the maximum size of the aggregate. For nominal 40 mm aggregate the sample should weigh at least 5 kg, for 20 mm at least 2 kg, for 10 mm at least 0.5 kg and for sand at least 0.2 kg.

The test results can be plotted on a chart similar to that shown in Figure 2 on page 11 so that the specified gradings and the sample gradings can be more easily compared. It should be noted that the points representing the percentage of material passing the various sieve sizes are joined by straight lines and not by curves. Although the BS 812 sieve test should be made on dried samples, an approximate grading, accurate enough for routine site testing, may be obtained by sieving coarse aggregates in a damp condition.

Moisture content

The purpose of measuring the moisture content of aggregate is to enable an estimate to be made of the quantity of water contained within it so that the water added at the mixer can be adjusted to control the required free water in the mix; as mentioned on page 1 3 (under *Storage of aggregates),* the moisture content of aggregates, especially the sand, can vary considerably from load to load or in the stockpile. Ideally, the weight of aggregate in each batch of concrete should be adjusted to allow for changes in the moisture content of the aggregate, but this is seldom practicable; adjustments to the batch weight of dry aggregate are therefore usually based on an average moisture content. There are various methods of determining the moisture content, which are fully described in BS 812 : Part 109 and outlined below.

Drying methods. Methods involving the drying of representative samples of aggregate are often used. On site the quickest and most direct way of measuring the moisture content of both coarse aggregate and sand is the 'frying pan' technique in which the aggregate is dried by heating it in an open pan. The sample of aggregate to be tested should weigh between 1.8 and 2.2 kg for coarse aggregate. The sample size for sand may be reduced to not less than 0.5 kg if an accurate balance is used for weighing.

The aggregate is first weighed (W_1), then dried and re-weighed (W_2). The moisture content is then calculated as:

$$\frac{W_1 - W_2}{W_2} \times 100\%$$

When the 'saturated surface-dry' (SSD) moisture content is measured, coarse aggregate should be dried until surface moisture has evaporated (this is often accompanied by a slight change in colour), but any further heating should be avoided. Sand should be dried until it just fails to adhere to a glass rod when stirred.

If an open source of heat is used it is important not to overheat the aggregate or heat it too rapidly, which could cause the particles to break up and spit out of the pan. A microwave oven may be more convenient.

This method gives the water content as a percentage of the SSD weight of the aggregate, which is the measure of moisture content generally used on site. It takes into account water on the surface of all particles of aggregate, but does not include water absorbed into the pores of the aggregate. The 'total' moisture content, which includes water absorbed into the pores of the aggregate particles, is sometimes used instead of the SSD moisture content. When the total moisture content is to be measured, the aggregate should be dried thoroughly; it is necessary to heat the aggregate at 105±5°C in an oven overnight. An important point to note is that the SSD moisture content must be used in conjunction with a specified saturated surface-dry water/cement ratio referred to as the 'free' water/cement ratio; similarly, the total moisture content must be used with a 'total' water/cement ratio.

Other methods. Most of the other methods of determining the moisture content of an aggregate are proprietary methods and instructions for carrying out the test are supplied with the apparatus.

In the calcium carbide method, using the 'Speedy' apparatus, a sample of aggregate is mixed with an excess of calcium carbide in a sealed metal flask.

The pressure produced by the acetylene liberated in the reaction between water and carbide is related to the moisture content, which can be read off a dial. This test is very quick, but the size of sample is small and two or three samples may be advisable to give a reliable measure of the moisture content in a stockpile of aggregate.

Care must be taken when releasing the pressure to avoid any possible source of flame as acetylene is flammable and can be explosive. There must be no smoking during this test.

Mechanical properties of aggregates

The facilities of a laboratory are needed for determining the mechanical properties of aggregates. The tests include crushing or abrading samples of an aggregate to give a measure of its strength or resistance to wear. The methods of test are described in BS 812.

Water

BS 3148 / BS EN 1008* describes the testing of water for concrete by comparing the properties of concrete made with any particular sample of water with those of an otherwise similar concrete made with distilled water.

The Standards specify acceptance limits for these tests, and guidance is given on the interpretation of the results. The tests will usually be performed in a laboratory.

*At the time of writing, BS EN 1008 is at draft stage.

Testing fresh concrete

The measurement of the consistence of fresh concrete is of importance in assessing the practicability of placing and compacting it and also in maintaining uniformity throughout the job. In addition, consistence tests can be used as an indirect check on the water content and, therefore on the free water/cement ratio of the concrete. In this instance, the relationship between water content and consistence is established in the laboratory or early in the site work. Then, by maintaining the correct proportions of cement, aggregate and any admixture, the free water/cement ratio is controlled by adding water to maintain the consistence. It is essential that all test results are based on representative samples of concrete. Tests on fresh concrete are described in BS 1881 and BS EN 12350.

Slump test

The slump test is suitable for normal cohesive concretes of low to high consistence and is the test most commonly used. Changes in the value of the slump may indicate changes in materials, in the water content or in the proportions of the mix, so it is useful in controlling the quality of the concrete as produced.

The apparatus consists of a truncated conical mould 100 mm diameter at the top, 200 mm diameter at the bottom and 300 mm high, with a steel tamping rod 16 mm diameter and 600 mm long with both ends hemispherical. The inside of the mould should be clean and damp before each test and it should be placed on a smooth, horizontal and rigid impervious surface. The mould is held down using the foot rests and filled with three layers of approximately equal depth. Each layer is tamped with 25 strokes of the tamping rod, the strokes being uniformly distributed over the cross-section of the layer. When tamping the first layer, the rod should be inclined slightly, and about half of the 25 strokes should spiral towards the centre. Each layer should be tamped to its full depth, allowing the rod to penetrate through into the layer below. The concrete should be heaped above the mould before the top layer is tamped.

After the top layer has been tamped the concrete should be struck off level with the top of the mould by a sawing and rolling motion of the tamping rod. Any spillage is cleaned away from around the base of the mould and, taking 5 to 10 seconds, the mould is then slowly lifted vertically from the concrete.

The slump is the difference between the height of the mould and of the highest point of the concrete being tested. If it collapses or shears off laterally, the test should be repeated with another sample of the same concrete and the type of slump noted. The slump should be recorded to the nearest 10 mm (Figure 38).

Figure 38: Measuring the slump of concrete.

After the slump measurement has been completed, if the side of the concrete is tapped gently with the tamping rod, a well-proportioned cohesive concrete will gradually slump further, but if it is a harsh or uncohesive it is likely to shear or collapse.

A formal certificate should be completed for every slump test. See Appendix 3.

Compactability

The compacting factor test of BS 1881: Part 103 has been replaced by a new test, described in BS EN 12350-4, which represents the way in which concrete may respond to vibration on site. A simple rectangular metal mould (Figure 39), is filled to the top using a special trowel, struck off with a straightedge and compacted using a small poker vibrator. The extent to which the concrete consolidates after complete vibration is measured and the compactability is calculated from the expression:

$$\text{Degree of compactability} = \frac{400}{400 - S}$$

where S is the distance (in millimetres) from the top of the mould to the surface of the concrete after vibration.

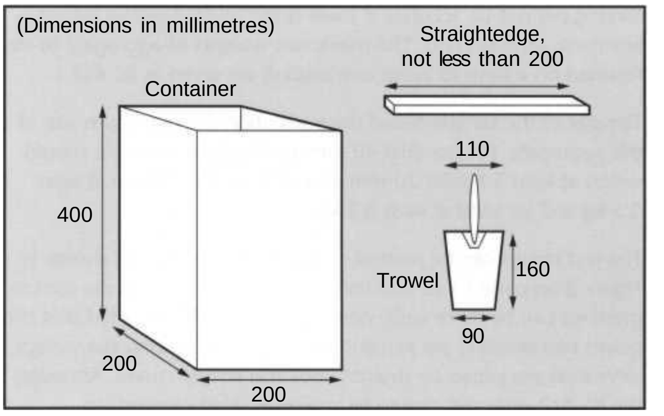


Figure 39: Compactability test apparatus.

Flow table test

The growing use of concrete that flows into place and is self-compacting calls for a test method that is more sensitive than the slump test. The slump test should not be used for any concrete whose slump could exceed 210 mm as the test results would simply be recorded as 'collapse' every time. The flow table test enables quite fine distinctions to be made between batches of concrete with differing degrees of very high consistence.

The main item of apparatus, shown in Figure 40, is a 700 mm square table that is attached by a hinge along one edge to a firm base. A handle is fixed to the edge opposite the hinge and the table is fitted with stops, which prevent it rising off the base by more than 40 mm. A truncated cone is used but it is quite different from the standard slump cone by being only 200 mm high. A wooden tamping bar 40 mm square completes the apparatus.

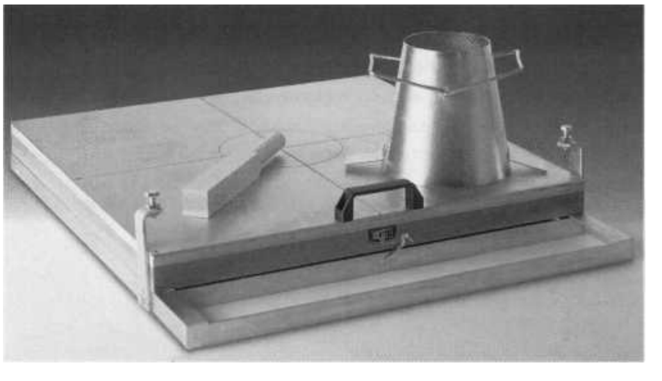


Figure 40: Flow table apparatus.

It is very important to set the base plate on a level surface to avoid the sample running off one side during the test.

Before starting the test, any dry surfaces of the table top, cone or tamping bar are moistened with a clean damp cloth. The person doing the test presses down on the footpieces of the cone so that no movement or leakage of concrete occurs.

A representative sample of fresh concrete is remixed and placed into the cone in two layers of equal depth, each layer being tamped exactly ten times. The tamping is rather different from that of other tests such as the slump test, because the bar should not penetrate far into the concrete and more of a levelling action is used for this fluid concrete. After the second layer has been tamped, the surface is ruled off with a suitable straightedge, and the surcharge removed from the table. Thirty seconds are allowed to pass between striking off the surface and starting to lift the cone, which is done in 3 to 6 seconds.

With one foot on the base plate and one hand on the handle fixed to the table top, the tester then raises the table top as far as the stops and then lets it drop onto the base. This is repeated every four seconds until the table has been given 15 drops. The concrete spreads across the table as a result and the maximum diameter is measured in two directions parallel to the table edges. The average of the two dimensions is calculated and reported as the flow of the concrete, recorded to the nearest 5 mm.

If any aggregate particles shake loose during the test or the final shape of the concrete is markedly asymmetrical, the fact should be reported because these are indications of possible problems with cohesion that could lead to segregation in the concrete. Also it is a good idea to leave the concrete on the table for a few minutes after the test is completed: any tendency to bleeding will become apparent. The test may, therefore, be regarded as a useful means of giving early warning of potential problems with placing and compacting concrete on site but it should be remembered that the flow table test is suitable only for mixes with very high and flowing consistence classes.

The normal tolerance for flow, according to BS 5328 : Part 4, is ±50 mm.

It is permissible, in the case of extreme consistence - where the concrete might be in danger of flowing off the table - to reduce the number of drops from 15 to a number determined by trials and agreed by all the interested parties.

Full details of the flow table test procedure are given in BS 1881 : Part 105 and BS EN 12350-5

Air content test

If an air-entrained concrete is used, the air content of the fresh concrete should be determined in accordance with either of the two methods given in BS 1881: Part 106 and BS EN 12350-7. Typical air meters as used for method A and method B are shown in Figure 41.

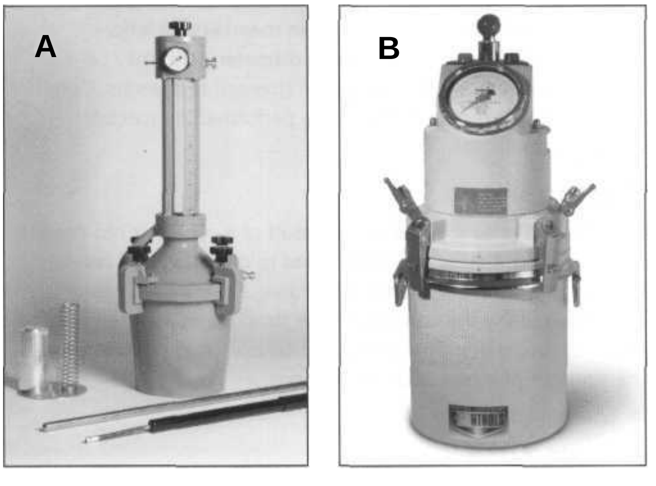


Figure 41: Air-entrainment meters - A, water column type, B, pressure gauge type.

The test involves measuring the reduction in volume of air resulting from an increase in the applied air pressure. The air meter should be of a type in which the air content is read off while the concrete is under an operating pressure of approximately 1 bar. The container of the meter should have a nominal capacity of at least 5 litres, and should be filled with concrete in three approximately equal layers. Each layer is compacted with at least 25 strokes of a steel tamping bar weighing 1.8 kg, and having a tamping face 25 mm square (as used for cube making). Alternatively, vibration may be used, provided the slump does not exceed 75 mm. The object of tamping or vibrating the concrete is to attain full compaction without removing an appreciable proportion of any deliberately entrained air.

The concrete should be compacted until it just makes good contact with the sides of the container; prolonged working should be avoided. After compacting each layer, the side of the apparatus is tapped using a 250 g soft mallet to remove any large air voids entrapped in the concrete. Provided that the air has been correctly entrained, the amount of air removed by excessive compaction is likely to be small.

The correct operating pressure (which is predetermined by calibration) is applied to the concrete and the volume of entrained air is read off the water column (method A) or the pressure gauge (method B).

An aggregate correction factor is necessary and will vary with different aggregates. This can be determined only by test, since it is not directly related to the water absorption of the particles. Ordinarily the factor will remain reasonably constant for a particular aggregate, but an occasional check is recommended.

Full details of the air meter test are given in the Standard and a proper certificate should be completed. See Appendix 4.

Testing hardened concrete

The strength of hardened concrete is usually measured on specimens that are tested in compression. Other tests are non-destructive, such as the rebound hammer, ultrasonic pulse, or various pull-off/break-off techniques, that can recognize variations in concrete strength and quality.

Manufacture of test cubes

Compressive strength tests for UK concretes with maximum aggregate sizes (D_{max}) of 10, 14 or 20 mm are usually made on 100 mm cubes. For aggregate with a D_{max} greater than 20 mm, 150 mm cubes are used. Details of the making and curing of test cubes are given in Parts 108 and 111 respectively of BS 1881, and BSEN 12390-2.

A summary of the procedure on site is given below. It should be emphasized, however, that cubes should always be made by personnel trained in the work and that it is preferable for the same personnel to make all the cubes throughout the job.

The moulds for test cubes are traditionally made of steel or cast iron, with very close tolerances for dimensions, flatness, squareness, parallelism, and surface texture and hardness. Each mould should have a removable steel base plate with a true surface to support the mould and prevent leakage. It is essential to keep the mould and base plate clean, and both should be thinly coated with release agent to prevent the concrete sticking to them. No undue force should be used during assembly.

Hard plastic cube moulds may be permitted where equal levels of precision can be assured and, if plastic moulds are deemed to be acceptable, hand tamping may be done with a slump rod to avoid the damage likely to be caused by the traditional square bar.

It is essential that the concrete in the cubes should be fully compacted. A 100 mm cube mould should be filled in two layers and a 150 mm mould in three layers. When compaction is by hand each layer should be tamped with at least 25 strokes for 100 mm cubes and at least 35 strokes for 150 mm cubes, with a steel bar, weighing 1.8 kg and having a tamping face 25 mm square. More strokes should be used if required to ensure full compaction. The tamping of the concrete should be carried out methodically, the strokes being evenly distributed over the surface of the concrete in a regular pattern and not concentrated in one particular spot.

Alternatively, the concrete can be compacted by vibration, again in layers, using either an electric or pneumatic hammer or a suitable table vibrator. In all cases the amount of compaction is recorded either as the number of strokes per layer or as the duration of vibration. After compaction, the surface of the concrete should be trowelled as smooth as practicable, level with the top of the mould.

Normal curing of test cubes

Immediately after making, cubes should be stored under damp matting or similar material in a place free from vibration, and wrapped completely with plastic sheeting to prevent loss of moisture. Cubes to be tested at an age of seven days or more should be kept at a temperature of 20 ±5°C; cubes to be tested at earlier age should be kept at a temperature of 20 ±2°C, during this initial moist-air curing period.

Cubes to be tested at 24 h should be demoulded just before testing; cubes for testing at greater ages should be demoulded within the period 16 - 28 h after the time of making. Each cube should be clearly and indelibly marked for later identification and immediately submerged in a tank of water maintained at a temperature of 20 ±2°C until the time of testing. Cubes that have to be transported to another location for testing should be removed from their moulds or from the curing tank and packed in such a way that they do not become damaged or dry. This can be done by enclosing them in plastic bags and transporting them in purpose-made boxes. Cubes can be transferred any time after demoulding, but they must arrive at the place of testing at least 24 hours before the time of testing, where they must be stored in water at 20 ±2°C.

A record should be kept of maximum and minimum temperatures, both for the initial moist-air curing period and for the subsequent water curing. A formal certificate should be completed for every set of test cubes made, see Appendices 5 and 6.

Testing cubes

Details of the testing of cubes are given in BS 1881 : Part 116 and BS EN 12390-3. Specimens will usually be sent to a laboratory for testing and it is recommended that the laboratory is one which is accredited for cube testing by the United Kingdom Accreditation Service (UKAS). For site testing, reference should be made to the Standard for full details of requirements for the testing procedure, but some of the more important points relating to testing procedure for cubes are as follows:

- The cube should be stored in water, as described above, and tested immediately on removal from the water. Surface water, grit and projecting fins should be removed and the dimensions and weight recorded, noting any unusual features, such as honeycombing. Cubes that are clearly misshapen should not be tested
- The bearing surfaces of the testing machine should be wiped clean and the cube should be placed in the machine in such a way that the load is applied to faces other than the top and bottom of the cube as cast. The cube must be carefully centred on the lower platen
- The load must be applied without shock and increased continuously at a rate within the range of 0.2 - 0.4 N/mm^2 per second until no greater load can be sustained. The maximum load applied to the cube is recorded. Any unusual features in the type of failure should be noted. The cube should be retained for a minimum period of one month
- The compressive strength is recorded to the nearest 0.5 N/mm^2
- It is important to maintain testing machines in good working condition ensuring, for example, that the spherical seating can move correctly. The seating must move freely as the slack in the machine is taken up but then must lock and remain rigid until the cube fails; otherwise low failure loads will be recorded, and the shape of the failure will be one-sided. The type of failure should always be noted, because an unusual shape of failure surface may indicate a defective machine. Compression testing machine requirements are specified in BS 1881: Part 115 and BS EN 12390-4. It is important that machines are regularly calibrated.

Test cores

Core tests are useful for assessing the quality of hardened concrete in situ. Not only can the compressive strength of the concrete be assessed, but a description of the aggregate, including maximum size, shape, surface texture and type, can be obtained and the degree of compaction noted. The results of the tests can be used to give the 'estimated in-situ cube strength' or to give an estimate of the potential strength of the standard test cube. While the relationship of core strength with in-situ cube strength is fairly straightforward, the relationship between core strength and standard cube strength is complex and will vary with particular conditions.

Before deciding to drill cores for compressive testing, full consideration must be given to the aims and value of the results that will be obtained. Reference should be made to specialist literature for the number of cores and the assessment of results - BS 6089, BS EN 13791, Concrete Society Digest No. 9 and Concrete Society Technical Report No. 11.

The usual diameter of a core (Figure 42) is 150 mm or 100 mm and the length/diameter ratio must be between 1 and 2, preferably between 1 and 1.2. In thin members, or where reinforcement is congested, smaller diameter cores may be necessary but these give less reliable strength test results. Core cutting is a skilled operation, usually performed by specialist subcontractors.

Testing cores

Core tests may be used when the result of a cube test has proved unsatisfactory. A cube may have failed to give a desired result because of a defect in the testing procedure, in which case it is usual to examine the concrete in the structure in an attempt to assess its properties. Core tests need careful interpretation because the strength of a core is dependent on:

- Quality of concrete
- Degree of compaction
- Location in the structure
- Curing
- Presence of reinforcement
- Method and direction of cutting
- Preparation of specimen
- Testing procedure
- Age at test

Figure 42: As well as providing a specimen for strength testing, the core gives a good indication of the distribution of the aggregate and the degree of compaction.

In contrast, the cube test, if properly performed, uses standardized preparation and testing procedures in an attempt to eliminate all variables except that of concrete quality. Concrete in a structure cannot be expected to have had the same treatment as a standard cube. Accordingly, cores give variable results and the equivalent cube strengths are usually lower than the standard cube strength of the concrete.

Because of the variability of the core test a number of cores are needed to form a reasonable estimate as to the acceptability of the concrete. If possible a set of cores should also be tested from comparable concrete that is known to be acceptable.

Cores must be prepared to give end surfaces that are plane, parallel and at right angles to the axis. The length and diameter of the core are accurately measured because they are necessary for the calculation of strength. Core tests should be carried out only in a UKAS accredited laboratory; details of the preparation and test procedure are given in BS 1881 : Part 120 and BS EN 12504-1.

The compressive strength of each core is calculated by dividing the maximum load by the cross-sectional area calculated from the average diameter. Correction factors dependent upon the length/diameter ratio of the specimen after preparation of the ends, the direction of drilling and the presence of reinforcement are applied to give the estimated in-situ cube strength. Other factors may then have to be applied if an estimate of the standard cube strength is required.

Non-destructive testing

Rebound hammer test

The rebound hammer or Schmidt hammer (Figure 43) gives a comparative measure of concrete quality as indicated by surface hardness, and can enable an approximate estimate to be made of concrete strength provided that users have prepared their own calibration charts by recording, as part of their quality control routine, the results of regular tests with the hammer on cubes and units made from the same concrete.

To standardize readings as far as possible it is recommended that they should be taken on cubes held in the testing machine under a stress of about 7 N/mm^2. Since readings taken on a trowelled face are often more variable than those on a moulded face, it is recommended that the hammer should be used on a vertical face of the cube as cast.

A rebound hammer may also be useful for indicating the variability of concrete in a structure as a guide to the significance of a core test. The use of rebound hammers is described in BS 1881: Part 202 and BS EN 12504-2.

Figure 43: Measuring the surface hardness of concrete with a Schmidt hammer.

Ultrasonic test

Ultrasonic tests give a comparative measure of concrete quality as indicated by the time taken by an ultrasonic pulse to travel through a section of concrete. Ultrasonic equipment, such as the Pundit (Figure 44) is portable and consistent in its behaviour. Its use is described in BS 1881: Part 203 and BS EN 12504-1.

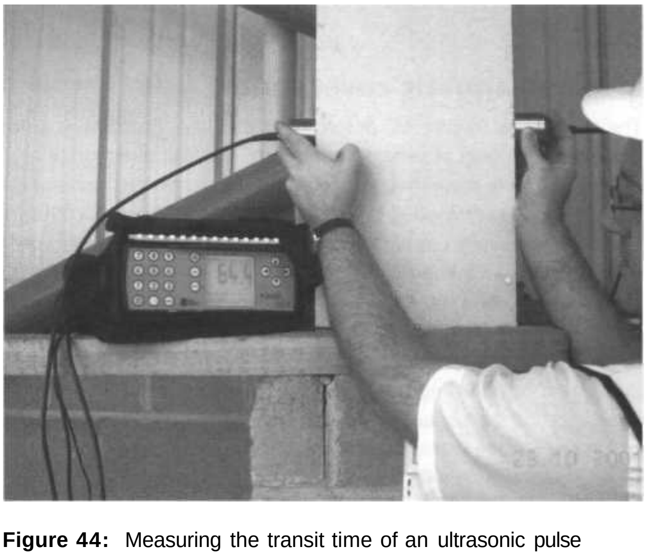


Figure 44: Measuring the transit time of an ultrasonic pulse though a concrete column.

The test consists of measuring the velocity of an ultrasonic pulse through the concrete. A transducer placed in close contact with the surface of the concrete transmits vibrations into the concrete that are picked up by another transducer on the opposite face of the specimen or member under test. The time taken by the pulse to travel through the concrete is accurately measured by the apparatus, and the velocity calculated knowing the distance between the transducers (thickness of member).

This method of test is essentially comparative and, because so many factors affect the pulse-velocity/strength relationship, it will not generally be possible to relate pulse-velocity values and strength without knowledge of the site conditions and constituents of the concrete under test. Interpretation of the results requires care and experience.

Pull-out test

This test can determine the strength of concrete that is less than three days old. It uses pull-out inserts that are cast into the slab or column, and the load is applied through a manually operated jack (Figure 45). The peak tensile force is recorded and correlated against the equivalent concrete cube strength. For more information see BCA publication *Early age strength assessment of concrete on site,* and CIRIA Report 1 36.

Figure 45: Measuring the force required to pull out an insert cast into a floor.

Electromagnetic covermeter

The covermeter (Figure 46) described in BS 1881: Part 204, is a non-destructive method of locating the depth, size and direction of reinforcement in hardened concrete. It is a portable electromagnetic instrument. Recent models have a working range of up to 100 mm cover and operate from rechargeable batteries. A typical instrument consists of a search head connected to the main unit containing the battery circuits and display panel. When the instrument is switched on, or switched from one scale to another, it is necessary to place the search head well away from any steel and to calibrate the instrument by adjusting the 'zero set'. The search head is then positioned on the surface of the concrete and, if any steel exists below the surface within a depth of 100 mm, the depth will be shown, usually by digital display.

The search head is rotated and moved methodically across the surface until the minimum reading is obtained: this reading indicates the depth of cover and the direction of the steel. Some covermeters also give a strong audible signal that assists in locating bars by rising when approaching steel.

Figure 46: Using the covermeter to estimate the depth and direction of the reinforcement in a structure.

The accuracy likely to be obtained on the average site can be within about ±10% or ±2 mm, whichever is the greater, when used to detect normal reinforcement. Calibration by breaking out some concrete to reveal the reinforcement is recommended in all cases and is essential when very small bars or stainless steel are being detected. Calibration methods are given in the standard.

Analysis of fresh concrete

The Rapid Analysis Machine (RAM) (Figure 47) is a floor-mounted unit which enables the cement content of a sample of fresh concrete to be easily and rapidly determined in accordance with BS 1881: Part 128. It provides a practical and accurate method of analysing a concrete for cement content in the short time available after mixing and before placing the concrete. The total time for carrying out a test from loading the RAM to reading off the cement content from a calibration graph is less than ten minutes.

The operating cycle of the RAM is fully automatic, and is controlled by an electronic timer that is started after the machine has been loaded with an 8 kg sample of fresh concrete. Water is pumped through the sample at a carefully controlled rate to separate the cement size particles and wash them up and over the top of the elutriation column. Three sampling channels at the top of the column remove 10% of the cement slurry, with the remainder going to waste.

The 10% sample passes through a 150 µm vibrating sieve, which removes all the small particles greater than cement size from the slurry. After these particles have been removed, the slurry passes into a conditioning vessel where chemical agents are stirred into the slurry causing the cement particles to cling together and drop out of suspension to the bottom of the vessel. Excess water is removed by siphons until a constant volume is obtained in the removable pot at the bottom of the conditioning vessel. After all the cement particles have settled, this vessel is removed from the RAM and weighed on a balance (to an accuracy of 1 g), and the cement content of the concrete sample is determined from a calibration graph.

Modules are available for determining the water/cement ratio of the concrete and for determining the quantities of any mineral additions.

TESTING CONCRETE & CONCRETING MATERIALS

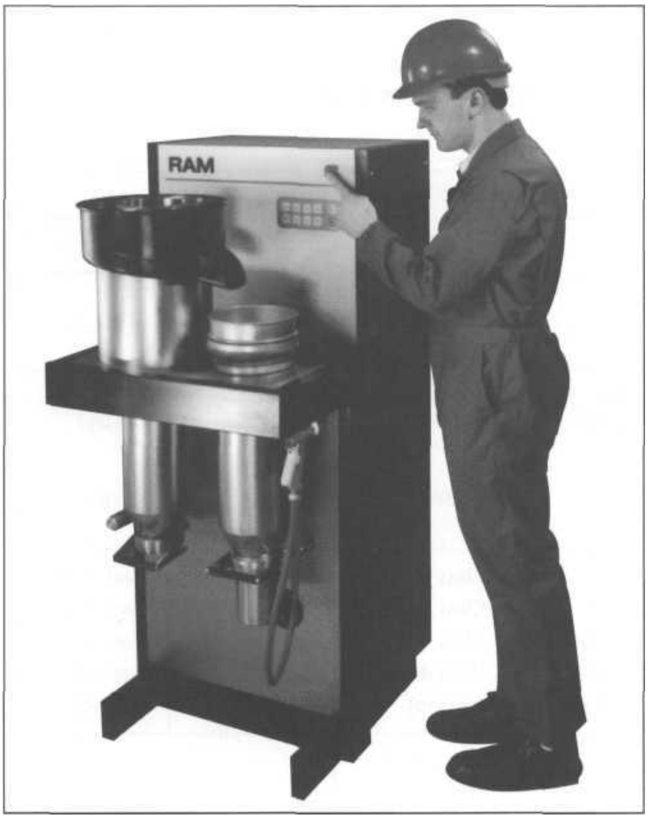


Figure 47: Measuring the cement content of fresh concrete with the RAM.

References/further reading

BS 812, *Testing aggregates.* British Standards Institution, London.

Part 102: 1989, *Methods for sampling.*

Part 103: 1985, *Methods for determination of particle size distribution.*

Part 109: 1990, *Methods for determination of moisture content.*

BS 1881 *Testing concrete.* British Standards Institution, London. To be replaced by BS EN 12350 : 2000 *Testing fresh concrete;* BS EN 12390 : 2000 *Testing hardened concrete;* BS EN 12504: 2000, *Testing concrete in structures;* and BS EN 13791, Assessment of *concrete compressive strength in structures or in precast concrete products,* as indicated.

Part 101:1983, *Method of sampling fresh concrete on site.* (BSEN 12350-1, *Sampling)*

Part 102: 1983, *Method for determination of slump.* (BSEN 12350-2, Slump test)

Part 103: 1983, *Method for determination of compacting factor.*

Part 104: 1983, *Method for determination of Vebe time.* (BS EN 12350-3, *Vebe test)*

Part 105: 1984, *Method for determination of flow.* (BS EN 12350-5, *Flow table test).*

Part 106: 1983, *Method for determination of air content of fresh concrete.* (BS EN 12350-7, *Air content of fresh concrete - Pressure methods).*

Part 108: 1983, *Method for making test cubes from fresh concrete.* (BS EN 12390-2, *Making and curing specimens for strength tests).*

Part 111:1983, *Method of normal curing of test specimens* (20°C method.) (BS EN 12390-2, *Making and curing specimens for strength tests).*

Part 115:1986, *Specification for compression testing machines for concrete* (BS EN 12390-4, *Compressive strength - Specification of compression testing machines).*

Part 116: 1983, *Method for determination of compressive strength of concrete cubes.* (BS EN 12390-3, *Compressive strength of test specimens).*

Part 118: 1983, *Method for determination of flexural strength.*

Part 120: 1983, *Method for determination of compressive strength of concrete cores.* (BS EN 12504-1, *Cored specimens - Taking, examining and testing in compression).*

Part 128: 1997, *Methods for analysis of fresh concrete.*

Part 130:1996, *Method for temperature-matched curing of concrete specimens.*

Part 201: 1986, *Guide to the use of non-destructive methods of test for hardened concrete* (BS EN 13791, *Assessment of concrete compressive strength in structures or in structural elements).*

Part 202: 1986, *Recommendations for surface hardness testing by rebound hammer* (BS EN 12504-2, *Non-destructive testing - Determination of rebound number).*

Part 203: 1986, *Recommendations for measurement of velocity of ultrasonic pulses in concrete* (BS EN 12504-4, *Determination of ultrasonic pulse velocity).*

Part 204: 1988, *Recommendations on the use of electromagnetic covermeters.*

BS 3148 : 1980, *Methods of test for water for making concrete (including notes on the suitability of the water)* (to be superseded by BS EN 1008, currently prEN 1008 : 1997 *Mixing water for concrete - specifications for sampling, testing and assesing the suitability of water, including waste water from recycling installations in the concrete industry as mixing water for concrete).* British Standards Institution, London.

BS 6089 : 1981, *Guide to the assessment of concrete strength in existing structures.* British Standards Institution, London.

BS EN 196 : Parts 1 - 7, *Methods of testing cement.* British Standards Institution, London.

BS EN 932 : 1997, *Tests for general properties of aggregates.* Part 1: *Methods for sampling.* British Standards Institution, London.

BS EN 12350, *Testing fresh concrete.* Part 4 : 2000, *Degree of compactability.* British Standards Institution, London.

BS EN 12390, *Testing hardened concrete.* British Standards Institution, London.

Part 1 : 2000, *Shape, dimensions and other requirements for test specimens and moulds.*

Part 3 : 2002, *Compressive strength of test specimens.*

Part 5 : 2000, *Flexural strength of test specimens,* (currently BS1881 : Part 118: 1983).

BS EN 12504, *Testing concrete in structures.* British Standards Institution, London.

Part 1 : 2000, *Cored specimens. Taking, examining and testing in compression.*

Part 2 : 2000, *Non-destructive testing. Determination of rebound number.*

Part 3 : *Determination of pull-out force* (not yet published).

Part 4 : *Determination of ultrasonic pulse velocity* (not yet published).

CIRIA Report 136. *Formwork striking times - criteria, prediction and methods of assessment.* 1995, Construction Industry Research and Information Association, London.

CSTR 11, *Core testing for strength.* 1987, The Concrete Society, Crowthorne. 44 pp.

CS020, Digest No. 9, *Concrete core testing for strength.* 1988, The Concrete Society, Crowthorne. 8 pp.

Early age strength assessment of concrete on site. 2000, RCC/The British Cement Association. Ref. 97.503. 4 pp. For free download visit www.rcc-info.org.uk

APPENDICES

1- SCHEDULES FOR SPECIFYING CONCRETE (TAKEN FROM BS5328)

Appendix 1a

Form A. Schedule for the specification requirements of designed mixes required for use on contract ....

....

The mixes below shall be supplied as designed mixes in accordance with the relevant clauses of BS 5328 Parts 2, 3 and 4

1. Mix reference				
2. Strength grade				
3. Nominal maximum size of aggregate (mm)				
4. Types of aggregate — Coarse, Other [Ring those permitted]	BS 882 BS 1047	BS 882 BS 1047	BS 882 BS1047	BS 882 BS 1047
Fine, Other	BS 882	BS 882	BS 882	BS 882
5. Sulfate classes (see Note 1) (ring if applicable)	Class 2 Class 3 Class 4A Class 4B	Class 2 Class 3 Class 4A Class 4B	Class 2 Class 3 Class 4A Class 4B	Class 2 Class 3 Class 4A Class 4B
Includes adjustment for acidity (yes/no) (see Note 1)	(yes/no)	(yes/no)	(yes/no)	(yes/no)
6. Cement type(s) or combinations conforming to BS 12 BS 146 BS 6588 BS 4027 BS 7583 (see Note 2) Others [Ring those permitted]	PC PBFC PPFAC SRPC PLC	PC PBFC PPFAC SRPC PLC	PC PBFC PPFAC SRPC PLC	PC PBFC PPFAC SRPC PLC
7. Minimum cement content (see Note 3) (kg/m^3)				
8. Maximum free water/cement ratio (see Note 3)				
9. Quality assurance requirements				
10. Rate of sampling intended by the purchaser for strength testing (for information only)				
11. Other requirements (e.g. maximum chloride, alkali, etc.)				

The following section to be completed by purchaser of fresh concrete only

12. Workability — Slump (mm), Compacting factor, Vebe(s), Flow (mm) [Ring method and give target]				
13 Method of placing (for information only)				
14. Other requirements by purchaser of fresh concrete (if appropriate)				

NOTES

1. The purchaser should ensure that the sulfate class specified accounts for the modifications required in tables 7c and 7d of BS 5328 : Part 1: 1997 where appropriate. If the classification includes an adjustment for acidity (see table 7d of BS 5328 : Part 1 : 1997), this should be specified in item 5
2. Reference should be made to 4.2.4 of BS 5328 : Part 1 : 1997 before specifying this cement
3. Where a sulfate class is ringed and no preference for a cement type is indicated, the minimum cement content and maximum free water/cement ratio for the cement type to be used should be in accordance with table 7a of BS 5328 : Part 1: 1997

Readers should be aware that this is a representation of the form from BS 5328, where the following terminology is still used:

'Mix' is used instead of 'concrete'
'Workability' instead of 'consistence'
'Fine aggregate' instead of 'sand'
'Grade' instead of 'strength class'

'PC instead of CEM I
'PBFC instead of CEM III A or CIIIA
'PPFAC instead of CEM II/B-V or CIIB-V
'PLC instead of CEM II/A-L and CEM II/A-LL

APPENDICES

1 - SCHEDULES FOR SPECIFYING CONCRETE (TAKEN FROM BS 5328)

Appendix 1b

Form B. Schedule for the specification requirements of prescribed mixes required for use on contract.....................................
....

The mixes below shall be supplied as prescribed mixes in accordance with the relevant clauses of BS 5328 : Parts 2, 3 and 4

1. Mix reference				
2. Type(s) and standard strength class(es) of the cement(s) or combination(s)				
3. Nominal maximum size of aggregate (mm)				
4. Types of aggregate Coarse Fine				
5. Mix proportions Cement (kg) Fine aggregate (kg) Coarse aggregate (kg) Admixtures Other				
6. Workability Slump (mm) Compacting factor Vebe(s) Flow (mm) Ring method and give target				
7. Quality assurance requirements				
8. Method of compliance and rate of sampling (for information only)				
9. Other requirements (e.g. maximum chloride, etc., if appropriate)				

Readers should be aware that this is a representation of the form from BS 5328, where the following terminology is still used:
'Mix' is used instead of 'concrete'
'Workability' instead of 'consistence'
'Fine aggregate' instead of 'sand'

APPENDICES

1-SCHEDULES FOR SPECIFYING CONCRETE (TAKEN FROM BS 5328)

Appendix 1c

Form C. Schedule for the specification requirements of standard mixes required for use on contract............

(This form also applies to standardized prescribed concretes)

The mixes below shall be supplied as standard mixes in accordance with the relevant clauses of BS 5328 : Parts *2,* 3 and 4 Designated mixes agreed as equivalent will be acceptable/unacceptable (delete one) as alternative mixes to those below.

1. Standard mix [Ring those required]	ST1	ST2	ST3	ST4	ST5
2. Class of concrete (for information only) [Ring the appropriate]	Unreinforced	Unreinforced Reinforced	Unreinforced Reinforced	Unreinforced Reinforced	Unreinforced Reinforced
3. Cement type(s) or combinations conforming to BS 12 BS 146 BS 6588 BS 4027 (see Note 1) BS 4027 (see Note 1) BS 7583 (see Note 2) [Ring as permitted]	PC PBFC PPFAC PLC	PC PBFC PPFAC PLC	PC PBFC PPFAC PLC	PC PBFC PPFAC SRPC LASRPC PLC	PC PBFC PPFAC SRPC LASRPC PLC
4. Nominal maximum size of aggregate (mm) [Ring as appropriate]	40 20	40 20	40 20	40 20	40 20
5.Types of aggregate Coarse Fine All in ST1, ST2, S [Ring those permitted]	BS 882 BS 1047 BS 882 BS 882	BS 882 BS 1047 BS 882 BS 882	BS 882 BS 1047 BS 882 BS 882	BS 882 BS 1047 BS 882	BS 882 BS 1047 BS 882
6. Workability Slump [Ring as appropriate]	Very low 75 mm 125 mm	 75 mm 125 mm	 75 mm 125 mm	 75 mm 125 mm	 75 mm 125 mm

The following section to be completed by purchaser of fresh concrete only

7.	Quality assurance requirements
8.	Other requirements (if appropriate)

NOTE
1. Reference should be made to 8.2.4 of BS 5328 : Part 1: 1997 before specifying these cements
2. Reference should be made to 4.2.4 of BS 5328 : Part 1 : 1997 before specifying this cement

Readers should be aware that this is a representation of the form from BS 5328, where the following terminology is still used:

'Mix' is used instead of 'concrete'	'PC instead of CEM I
'Workability' instead of 'consistence'	'PBFC instead of CEM III A or CII1A
'Fine aggregate' instead of 'sand'	'PPFAC instead of CEM II/B-V or CIIB-V
	'PLC instead of CEM II/A-L and CEM II/A-LL

APPENDICES

1 - SCHEDULES FOR SPECIFYING CONCRETE (TAKEN FROM BS 5328)

Appendix 1d

Form D. Schedule for the specification requirements for designated mixes required for use on contract.................................

..

The mixes below shall be supplied as designated mixes in accordance with the relevant clauses of BS 5328 : Parts 2, 3 and 4\. Standard mixes agreed as equivalent will be acceptable/unacceptable (delete as appropriate) as alternative mixes to those below.

1. Mix designation If the FND mix includes an adjustment for acidity (y/n)	(yes/no)	(yes/no)	(yes/no)	(yes/no)
2. Use of concrete For unreinforced concrete [Ring one only] For reinforced concrete For reinforced concrete that will be heat cured For prestressed concrete	U R HR PS	U R HR PS	U R HR PS	U R HR PS
3. Environment (see table 5 of BS 5328 : Part 1 : 1997) Chloride bearing Non-chloride bearing [Ring as appropriate] Severe freeze/thaw	CB NCB F/T	CB NCB F/T	CB NCB F/T	CB NCB F/T
4. Nominal maximum size of aggregate (mm) (enter 10 or 40, or leave blank for 20 mm				
5. Other requirements (if appropriate)				
6. Workability [Ring one or give value] Slump (mm) Other (to be completed by the purchserlaser of the fresh concrete)	50 75 125	50 75 125	50 75 125	50 75 125
7. Method of placing (for information only)				
8. Method of finishing (for information only)				

NOTE
The purchaser should ensure that when specifying FND mixes, the mix indicated includes the modifications recommended in tables 7c and 7d of BS 5328 : Part 1 : 1997 if appropriate. If the FND mix has included an adjustment for acidity (see table 7d of BS 5328 : Part 1 : 1997), this should be specified.

Readers should be aware that this is a representation of the form from BS 5328, where the following terminology is still used:
'Mix' is used instead of 'concrete'
'Workability' instead of 'consistence'

APPENDICES

APPENDIX 2-CERTIFICATE OF SAMPLING FRESH CONCRETE

Sample taken in accordance with: Please indicate

- ☐ **BS 1881: Part 101** *(General method)*
- ☐ **BS 1881: Part 102, Clause 4.2** *(Alternative method from truck-mixer for slump test only)* **(BS EN 12350-1,** *Spot sample)*
- ☐ **BS EN 12350-1,** *(Incremental sample)*

Date of sampling
Time
Name of works
Location in works of the concrete which the sample represents
Location of sampling (e.g. discharge from truck or from a heap of concrete)
Delivery note number or other means of identifying batch
Sample identity number
Ambient temperature
Weather conditions
Name of sampler

Affirmation that the sampling was done in accordance with: BS 1881: Part 101 or Part 102, Clause 4.2 or BS EN 12350-1 as indicated above Signature of person responsible for sampling

APPENDICES

APPENDIX 3-CERTIFICATION OF SLUMP TEST

For test in accordance with:

Please indicate

- ☐ **BS 1881: Part 102**
- ☐ **BS EN 12350-2**

Essential information

Date of test
Sampling: Time Place
Sampling method: General - BS 1881: Part 101 Or alternative - BS 1881: Part 102, Clause 4.2
Sample identity number
Sampling certificate available (copy attached)
Slump: Time of test Place
Time from sampling to beginning of test
Form of slump: true / shear / collapse
Measured true slump
Name of tester

Optional information to be supplied if requested

Name of project
Part of works where concrete used
Name of supplier
Source of concrete
Time of production or delivery to site
Specification of concrete mix (e.g. strength class)

Affirmation that the test was made in accordance with BS 1881: Part 102 or BS EN 12350-2 as indicated above   Signature of person responsible for test

APPENDICES

APPENDIX 4 - CERTIFICATE OF AIR CONTENT TEST

For test made in accordance with:

☐ BS 1881: Part 106

☐ BS EN 12350-7

Please indicate

Essential information

Date of test
Sampling: Time Place
Sample identity number
Sampling certificate available (copy attached)
Air content: Time of test Place
Type of apparatus (A or B)
Aggregate correction factor
Method of compaction (hand or vibration)
Type of vibration equipment
Number of strokes of bar or duration of vibration
Measured air content
Name of tester

Optional information to be supplied if requested

Name of project
Part of works where concrete used
Name of supplier
Source of concrete
Time of production or delivery to site
Specification of concrete mix (e.g. strength class)
Temperature of concrete at time of sampling
Density of concrete
Consistence class of concrete
Calculated air content of mortar fraction

Affirmation that the test was made in accordance with BS 1881: Part 106 or BS EN 12350-7 as indicated above Signature of person responsible for test

APPENDICES

APPENDIX 5-CERTIFICATE OF CUBE MAKING

For concrete test cubes made in accordance with:

Please indicate

- ☐ **BS 1881: Part 108**
- ☐ **BS EN 12390-2**

Essential information

Sample identity number
Date and time of sampling
Place of sampling
Time of making the cubes
Place where cubes were made
Number of cubes made in the set
Size of cubes
Method of compaction (hand/vibration)
For hand tamping: number of strokes used
For vibration: type of equipment and duration of vibration
Identification number or codes of the cubes
Age(s) at which cubes are to be tested
Name of person making cubes

Optional information to be supplied if requested

Name of project
Location of concrete represented by the cubes
Name of supplier and source of the concrete
Time of production
Time of delivery to site
Specification of the concrete
Measured consistence
Air content of concrete (if air-entrained)

Affirmation that the cubes were made in accordance with BS 1881 : Part 108 or BS EN 12390-2 as indicated above Signature of person making cubes.

APPENDICES

APPENDIX 6-CERTIFICATE OF STANDARD CURING OF TEST CUBES

For concrete test cubes cured in accordance with:
☐ **BS 1881: Part 111**
☐ **BS EN 12390-2**

Please indicate

Essential information

Sample identity number
Identification number or codes of the cubes
Location of moist air curing
Method of moist air curing
Period of moist air curing
Maximum and minimum moist air curing temperatures
Maximum and minimum water curing temperatures
Name of person responsible for curing cubes

Optional information to be supplied if requested

Time of adding water to the concrete
Time of making the specimens
Time of immersion of specimens in curing tank
Time of removal of specimens from curing tank
Temperature record during moist air curing
Temperature record during water curing
Age(s) at which cubes are to be tested

Affirmation that the cubes were cured in accordance with BS 1881 : Part 111 or BS EN 12390-2 as indicated above

Signature of person responsible for curing cubes

ACKNOWLEDGEMENTS

Our appreciation goes to the following for permission to use their photographs

Alstom Transport - Figure 24

Building Research Establishment - Figure 16

Controls Testing Equipment - Figures 36, 40, 41

Dow Construction Products - Figure 23

Germann Instruments - Figure 45

Protovale Oxford - Figure 46

Wexham Developments - Figure 47

Concrete practice

G F Blackledge and R A Binns

BRITISH CEMENT ASSOCIATION PUBLICATION 48.037

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BETTER BUILT IN concrete