Cement type/early age properties

The use of low CO_2 cements in concrete should not restrict the rate of construction

MATERIALS

There is a wide range of cement and cementitious materials available in the UK, available as either factory-made composite cements, or equivalent combinations of CEM I (Portland cement) and additional materials added at the concrete mixer.

There is a growing demand to use these cements and additions as they will help reduce the environmental impact of concrete, may reduce cost and can be used to enhance durability. The most commonly used additional materials, used either in factory-made or combination cements, are ground granulated blastfurnace slag (ggbs), fly ash, limestone and silica fume.

The reactivity of the additional materials depends on their chemical composition and their fineness. Simply stated, the greater the ratio of calcium and alumina to silica, and the finer the particle size material, the more reactive the material and so the more it can contribute to strength development. Table 1 shows a summary of the main physical characteristics of CEM I and the additional materials.

It should be noted that none of these additional materials are usefully cementitious without an activator. The normal activator is provided by Portland cement or the Portland cement clinker component of a factory-made composite cement.

Pozzolanic or latent hydraulic additional materials, such as fly ash, silica fume and ggbs, are those that either react with, or are activated by, alkali released by the hydration of the cement to form products that contribute to strength.

Limestone fines are not pozzolanic but act as additional nucleation points for cement hydration and so contribute a little to strength development.

The main components of these hydraulic, latent hydraulic and pozzolanic materials are calcium, alumina and silica, as shown in a simplified form on the ternary diagram of Figure 1. On this diagram, the more calcium a pozzolanic material has, the closer it will be to the calcium corner of the triangle, and similarly with alumina and silica.

CEM I is the most reactive material, as it is high in calcium, but ggbs is not far away and is part of the reason that combinations of CEM I with up to 50 per cent ggbs develop much the same 28-day concrete strength as CEM I alone.

Fly ash is somewhat further away and hence the more typical combination level is 30-35 per cent. Although chemically silica fume is furthest away from CEM I, its fineness, at nearly two orders of magnitude finer than the other materials, means it is very reactive, but the fine particles must be effectively dispersed.

In practice, this means it is essential that silica fume is used together with a superplasticising admixture such that a maximum

TABLE 1: SUMMARY OF THE MAIN PHYSICAL CHARACTERISTICS OF CEM I AND THE ADDITIONAL MATERIALS

Physical property	CEM I (Portland cement)	Fly ash	Ground granulated blastfurnace slag (ggbs)	Limestone fines	Silica fume
Fineness, m2/kg	350-450	450	350-550	660	15,000-35,000
Bulk density, kg/m^3	1400	1000	1200	1300	1350-1510
Relative density	3.15	2.2	2.9	2.7	2.2

FIGURE 1: TERNARY DIAGRAM SHOWING THE SIMPLIFIED CHEMISTRY OF CEMENTITIOUS MATERIALS

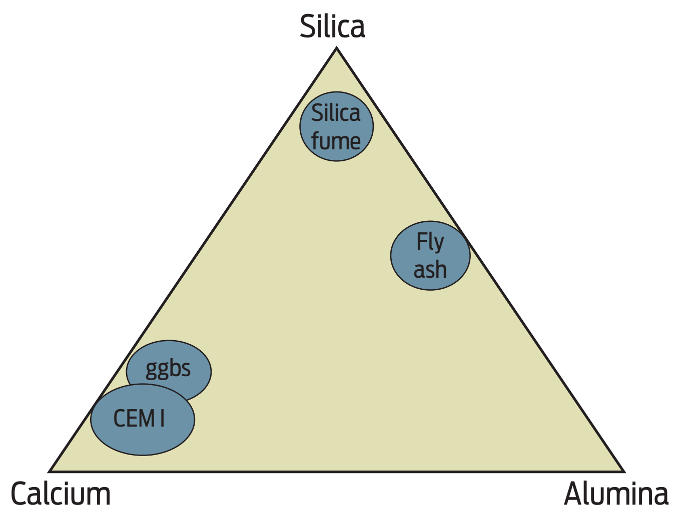


TABLE 2: CEMENT AND COMBINATION TYPES

Cement notation			Composition				
Cement type	Cement to EN 197-1 [1]	Combination to BS 8500 [2]	Clinker	fly ash	ggbs	limestone	silica fume
Portland	CEM I	–	95-100	–	–	–	–
Portland fly ash	CEM II/A-V	CIIA-V	80-94	6-20	–	–	–
	CEM II/B-V	CIIB-V	65-79	21-35	–	–	–
Portland slag	CEM II/A-S	CII-S	80-96	–	6-20	–	–
	CEM II/B-S		65-79	–	21-35	–	–
Portland limestone	CEM II/A-L or LL	CIIA-L or LL	80-94	–	–	6-20	–
Portland silica fume	CEM II/A-D	CIIA-D	90-94	–	–	–	6-10
Blast- furnace	CEM III/A	CIIIA	35-74	–	36-65	–	–
	CEM III/B	CIIIB	20-34	–	66-80	–	–
Pozzolanic	CEM IV/A	CIVA-V	–	11-35	–	–	–
	CEM IV/B	CIVB-V	–	36-55	–	–	–

TABLE 3: CEMENT STRENGTH CLASSES IN ACCORDANCE WITH EN 197-1 AND EN 197-4

Correction

Standard	Class	Compressive Strength, MPa			
		Early strength		Standard strength	
		2 day	7 day	28 day	
BS EN 197-1 (BS EN 197-4*)	32,5 L*	–	≥ 12,0	≥ 32,5	≤ 52,5
	32,5 N	–	≥ 16,0		
	32,5 R	≥ 10.0	–		
	42,5 L*	–	≥ 16,0	≥ 42,5	≤ 62,5
	42,5 N	≥ 10,0	–		
	42,5 R	≥ 20,0	–		
	52,5 L*	≥ 10,0	–	≥ 52,5	–
	52,5 N	≥ 20,0	–		
	52,5 R	≥ 30,0	–		

of surface area is available for reaction.

As silica fume is so reactive it uses up the alkali released by the cement, so the percentage used is generally quite low, that is around 10 per cent. Limestone is generally used in cement to improve the fresh concrete or mortar properties, where up to 15 per cent or so does not significantly reduce 28-day strength.

Table 2 shows the main cement and combination types, together with the standard nomenclature and the main constituents.

The pozzolanic cement with siliceous fly ash as the pozzolana at 11-35 per cent, CEM IV/A-V, is included for completeness, but this is not available as a factory-made composite cement and in practice the readily available CEM II/B-V is used.

In accordance with EN 197-1 and EN 197-4 [1], cement is also categorised by strength class as well as cement type, and these categories are shown in Table 3, where there are minimum limits to early-age strength and limits for 28-day strength.

Cement strength is based on testing a standard mortar, one part cement to three parts sand at a water/cement of 0.5, and so there will be no direct relationship between cement strength and concrete strength where the mix proportions will be very different.

It is also important to note that there is no unique relationship between cement type and cement strength class.

For example, in the UK:

- CEM I is available as 52,5 N and 52,5 R;
- CEM II/B-V is available as CEM II/B-V 42,5 N and CEM II/B-V 32,5 R;
- CEM II/A L or LL is available as 32,5R, 42,5 N, 42,5 R and 52,5 N;
- CEM III/A is available as CEM III/A 42,5 L but where CEM I is used in combination with higher percentages of ggbs then the appropriate equivalent strength class would be 32,5 L;
- CEM IV/B is available and where CEM I is used in combination with higher percentages of fly ash then the appropriate equivalent strength class would also be 32,5 L.

It should also be noted although these types and strength classes are available in the UK the local availability should be confirmed if a particular type and strength class is required at commercially viable rates.

Although the cement types with the lowest amount of clinker and of the lowest strength classes are likely to require more time to set, stiffen and develop strength, there is no unique relationship, as increasing the cementitious content and reducing the w/c ratio of the concrete may counter the effects of the lower reactivity materials.

Having said this, it is useful to compare some of the earlier age properties of concrete made with the range of cementitious materials using CEM I concrete as a reference, and this is shown in Table 4.

"The local availability should be confirmed if a particular type and strength class is required at commercially viable rates"

An oddity in Table 4 is that the early strength of CEM I is shown as 'High', whereas as the table generally takes CEM I as the reference perhaps the comparison should be 'Normal'.

The reason for this is that for a wide range of concrete applications the strength provided by using CEM I cement is more than what is actually required.

For some applications such as precast concrete elements, in-situ post-tensioned concrete or cold weather concreting, the early strength development of CEM I concrete is essential, but for more normal applications then the performance is rightly considered high.

"Combinations of CEM I with up to 50 per cent ggbs develop much the same 28-day concrete strength as CEM I alone"

TABLE 4: COMPARISON OF EARLY AGE PROPERTIES OF CONCRETE USING VARIOUS CEMENTITIOUS MATERIALS

Property	Cement (or equivalent combination)						
	Portland Cement CEM I	Silica fume cement CEM II/A-D (CIIA-D)	Portland Limestone Cement CEM II/A-LL or L	Portland fly ash cement CEM II/B-V (CIIB-V)	Blastfurnace Cements CEM III/A (CIIIA)	Blastfurnace Cements CEM III/B (CIIIB)	Pozzolanic cement CEM IV/B-V (CIVB-V)
Early Strength	High	High	High	Moderate	Moderate	Low	Low
28-day Strength	Normal	High	As CEM I	As CEM I	As CEM I	< CEM I	< CEM I
Long term Strength	Normal	High	As CEM I	High	High	High	High
Workability retention	Normal	< CEM I	Longer than CEM I	Longer than CEM I	Longer than CEM I	Longer than CEM I	Longer than CEM I
Bleeding/plastic settlement	Normal	Less likely than CEM I	Less likely than CEM I	Less likely than CEM I	More likely than CEM I	More likely than CEM I	More likely than CEM I
Plastic shrinkage	Normal	High	As CEM I	As CEM I	Less likely than CEM I	Less likely than CEM I	Less likely than CEM I
Setting finishing times	Normal	Normal/ Moderate	Normal/ Moderate	Normal/ Moderate	Moderate	Slow	Slow
Low heat	Poor	As CEM I	Modest	Moderate	Moderate	Very good	Very good

Similarly, the hydration of CEM I generates a significant amount of heat, which may be a problem in thicker sections, say greater than about 400 mm, where there is a requirement to minimise the risk of thermal cracking, and so it is correct to identify CEM I as having 'Poor' low heat properties.

For properties such as workability retention, bleeding/plastic settlement, plastic shrinkage and setting finishing times, the negative aspect can be ameliorated by the concrete mix design, and does not generally cause any difficulty.

However, the main drawback of using cements or combinations that incorporate ggbs, fly ash or limestone is that, although the 28-day strength will be similar to that achieved with CEM I alone, the early strength may be significantly reduced.

Figure 2 shows the comparative strength development of a range of concretes incorporating the various types of cementitious materials, on the basis of equal 28-day strength.

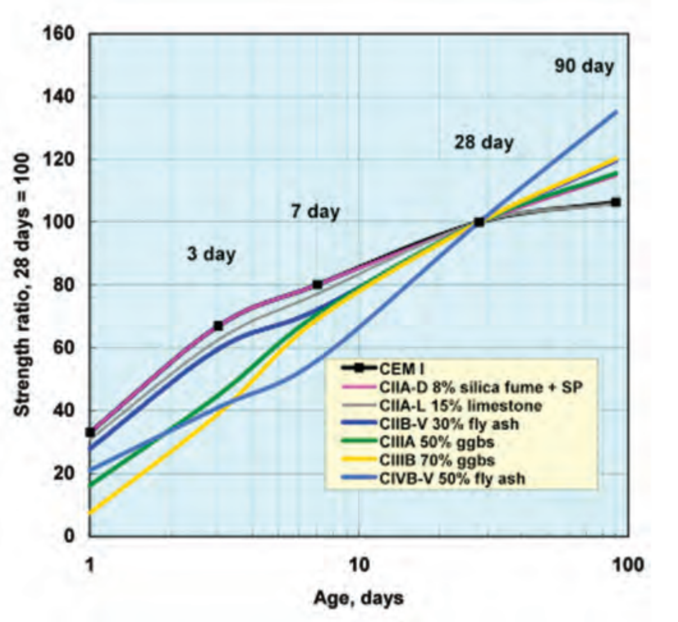
In overall terms, the pozzolanic reaction of ggbs and fly ash does not really start until after a day or so, and so their contribution to concrete strength at one day is not significant.

For example, in Figure 2 where 30 per cent fly ash is used, the one-day strength is only around 70 per cent of that achieved with CEM I, and similarly where 70 per cent ggbs is used the one-day strength is only around 30 per cent of that achieved with CEM I.

Early strength is particularly important as this will control the age at which formwork can be removed. The European Standard for the execution of concrete structures BS EN 13670 [3], where

"Early strength is particularly important as this will control the age at which formwork can be removed"

FIGURE 2: COMPARATIVE CONCRETE STRENGTH DEVELOPMENT AT STANDARD 20ºC WATER CURE FOR THE RANGE OF CEMENTS AND COMBINATIONS, AT EQUAL 28 DAY STRENGTH



'execution' is the European technical term for construction, requires that the concrete surface temperature shall not fall to 0 deg C until the concrete surface compressive strength has reached a minimum value of 5 MPa.

The UK complementary guidance, the National Structural Concrete Specification [4] (NSCS), recommends for formwork striking that in all cases a concrete strength of 2 MPa is required, but 5 MPa is recommended to minimise the risk of mechanical damage.

Unless the concrete curing temperature is particularly low, the 5 MPa requirement at one day is not an onerous requirement.

For example, if it is assumed that Figure 2 applied to a C40/50 concrete then 5 MPa represents 12.5 per cent of the 28-day strength, so all the cementitious materials show that this can be achieved by one day, except for the CEM IIIB at 70 per cent ggbs where the curing time required is only just over a day.

Where the concrete curing temperature is much below 20 deg C then the striking time will increase and greater consideration is required. In addition, where horizontal formwork is to be removed and the concrete structure has to support itself then higher strengths are required.

Guidance on early striking of slab soffits and back-propping is given in CS 140 *Guide to flat slab falsework and formwork*[5].

Eurocode 2 for the *Design of Concrete Structures* Part 1-1, sub-clause 3.1.2 gives an expression for estimating the early age compressive strength of concrete at 20 deg C, in terms of cement strength classes.

It is apparent that where available it is preferable to use more specific data, noting also that the Eurocode 2 expression does not cover the use of low early strength cements – the 'L' cements from Table 3.

For these reasons the expression is not particularly useful for application in the UK and reference to Figure 2 would be more useful.

In summary, the variation in early age properties of concrete containing a wide range of cementitious materials should not be a barrier to their use to reduce environmental impact, material cost or enhance long-term durability properties.

Where additional materials are used to replace significant proportions of CEM I, or the Portland Cement clinker component of factory-made composite cements, then the effect on early age properties may require some consideration to show that the required finishing or formwork striking times can be achieved.

"Where horizontal formwork is to be removed and the concrete structure has to support itself then higher strengths are required"

References

[1] British Standards Institution, BS EN 197-1 *Cement – Part 1: 2000 Specification, performance, production and conformity criteria for common cements*, BSI, London, February 2001, last amended 25 October 2004. *Part 4: 2004, Cement Composition, specifications and conformity criteria for low early strength blastfurnace cements*, BSI, London, July 2004.

[2] British Standards Institution, BS 8500 Concrete – Complementary British Standard to BS EN 206-1 – *Part 1: 2006 Method of specifying and guidance for the specifier. Part 2: 2006 Specification for constituent materials and concrete*, BSI, London, November 2006.

[3] British Standards Institution, BS EN 13670: *2009, Execution of concrete structures*, BSI, London, February 2010.

[4] Construct, *National Structural Concrete Specification for Building Construction*, CCIP 50, MPA The Concrete Centre, April 2010, Fourth Edition.

[5] Pallet, *P. F. Guide to flat slab falsework and formwork*, Construct CS 140, 2003.

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