MPA Cement Fact Sheet 14b

# Modern cements (Bulk)

## What are modern cements?

'Cement' is the basic 'glue' that binds together all the components of concrete which, in turn, is the most widely used construction material on earth. But what is cement? And what are 'modern cements'?

Traditionally, 'cement' has meant 'ordinary Portland cement (OPC)' to most professional and occasional users in UK. Although re-named 'Portland cement CEM I' in 2000, it still dominates bulk supply from the factory for use, either as the sole 'glue' or in combination with other cementitious materials, in structures and civil engineering. Factory supply into the UK packed/bagged market (see Fact Sheet 14a) is, however, significantly different where major changes since 2006 have lead to a market which is now CEM II dominated; CEM II cements are types variously described as 'lower carbon' or 'factory-made composite' cements.

The expression 'modern cements' is used herein to describe all the major Portland-type cements (CEM I to CEM V) potentially available to the UK market, with those actually supplied by MPA Cement's four member companies specifically identified.

It should be mentioned that the UK ready mixed concrete industry has for many years produced combinations nominally equivalent to composite cements by blending CEM I with coal fly ash (pfa) or ground granulated blast furnace slag (ggbs) in the concrete mixer. The resulting combinations are designated CII or CIII, respectively, to distinguish them from CEM II and CEM III factory-made cements. Advice on the performance of such combinations should be sought from the UK Quality Ash Association (UKQAA - http://www.ukqaa.org.uk) or the Cementitious Slag Makers Association (CSMA - http://www.ukcsma.co.uk).

The introduction of even more 'new', or unfamiliar, cements is almost inevitable. Economic and regulatory changes together with an increasing commitment from all stakeholders to sustainable development are all drivers-for-change in cement process, composition and performance. In consequence, specifiers, concrete producers and construction workers alike are now encountering different types of cement with differing properties.

## Portland cement CEM I

To provide a reference point, we first need to know how Portland cements are made. The manufacture of the basic material, Portland cement CEM I, involves precise blending of limestone or chalk, with clay or shale (quarried and finely-ground) and heating the resultant mixture in a rotary kiln to 1450ºC. At that temperature, a chemical change takes place and the raw materials turn into a hard, nodular solid known as clinker. After cooling, the clinker is ground in a ball or roller mill to produce cement powder. Approximately five percent gypsum (calcium sulfate) is also inter-ground in order to control the setting time of the product. The overall process is energy-intensive and much $CO_2$ is emitted during the chemical changes in the kiln but the production of CEM I clinker or cement is essential because it is a basic constituent of all CEM II, CEM III, CEM IV and CEM V cements.

A library could be filled with the books and research material written about the manufacture, properties, uses and sustainability credentials of CEM I Portland cement; suffice it to say that it provides the multiple 'benchmarks' against which all other cements tend to be compared. Although patented almost 200 years ago, it is yet 'modern' in the sense that it has undergone continual development, has demonstrated remarkable adaptability/robust performance and its continued use in everyday concreting around the world means that it still forms the 'bedrock' of the built environment. Buildings constructed appropriately and imaginatively using this material can and do exhibit an impressive array of properties [1] especially those that have been designed to optimize the thermal mass of concrete [2].

The demands for 'sustainable development', however, have placed a responsibility on the construction sector to continuously improve existing processes, products and practices, and to innovate in order to reduce both energy used in service and embodied energy in products together with emission of greenhouse gases during manufacture. It is these societal drivers, coupled with the realities/logistics of a mature supply-chain together with the overarching requirement to provide products appropriately 'fit-for-purpose' into the wide range of end-use applications, that has led to the current market mix of modern CEM I and 'low carbon' factory-made composite cements. Whilst CEM I is readily available in bulk, the use of low carbon factory-made composite cements (particularly CEM II, CEM III and CEM IV) is becoming more widespread.

## Low carbon, CEM II, III, IV and V factory-made cements

Low carbon, factory-made cements have been available in the UK for over 90 years but until 2006 had been supplied into fairly localised markets. Now, however, a range of types is available across the UK which incorporate limestone, fly ash or blast furnace slag as secondary constituents. These factory-made cements are supplied variously by MPA Cement's Member Companies for use in bulk.

Used here the expression 'low carbon factory-made cement' means any cement type that conforms to BS EN 197-1 [3] other than CEM I. They comprise Portland cement clinker combined (inter-ground or blended) with one or more additional inorganic constituents plus an optimized amount of set-regulator ('gypsum'). They are 'low carbon' because they contain lower proportions of cement clinker; they are collectively, types CEM II, CEM III, CEM IV and CEM V and are identified generically, along with CEM I, by standard name in Table 1.

| Table 1. Types of modern cement including low carbon, factory-made composite cements standardized in BS EN 197-1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Type** | | **Standard name** | | | | | | |
| **CEM I** | | Portland cement | | | | | | |
| Low carbon, factory-made composite cements | **CEM II** | Portland-slag cement (S) | Portland-silica fume cement (D) | Portland-pozzolana cement (P, Q) | Portland-fly ash cement (V, W) | Portland-burnt shale cement (T) | Portland-limestone cement (L, LL) | Portland-composite cement (M) |
| | **CEM III** | Blast furnace cement | | | | | | |
| | **CEM IV** | Pozzolanic cement | | | | | | |
| | **CEM V** | Composite cement | | | | | | |

NOTE 1. Note that types CEM II/M and CEM V include the word 'composite' in their names but the expression 'factory-made composite cements', as used here, is not restricted to these two types.

NOTE 2 The capital letters in brackets denote the specific type of secondary constituent permitted in the cement; their meaning is defined in BS EN 197-1 for common cements.

Low carbon, factory-made composite cements are the manufactured alternatives to the additions/mixer combinations used in concrete and are available across the full range of standardized strength classes. They are appropriately formulated to cover the full scope of possible applications.

## Which low carbon, bulk cements do MPA Cement's Member Companies market?

### MPA Member Company low carbon cements identified by 'standard designations'

MPA Cement's Member Companies market their low carbon cements under a variety of brand names. However, even within a given company, brand names often differ for the same cement where supplied both in bulk and packed in bags. Nevertheless, the 'standard designations' (generic descriptions in product standards) are always included on delivery documents and those that are currently manufactured (2014) by MPA Cement's members are identified in Table 2.

| Table 2. MPA Cement's Member Company low carbon, bulk cements (2014) | | | |
|---|---|---|---|
| **Types** | **Standard designation** | | |
| | **Notation (types of cement)** | | **Strength classes of current production** |
| CEM II | Portland-limestone cement | CEM II/A-L and II/A-LL | 32,5 R, 42,5 N and 52,5 N |
| | Portland-fly ash cement | CEM II/A-V | 32,5 R and 42,5 N |
| | | CEM II/B-V | 32,5 N, 32,5 R and 42,5 N |

| | | | |
|---|---|---|---|
| CEM III | Blast furnace cement | CEM III/A | 42,5 L |
| | | | 42,5 N |
| CEM IV | Pozzolanic cement | CEM IV/B-V | 32,5N |

NOTE 1. The letters 'A' and 'B' in notations for CEM II cements indicate the range of proportions of the secondary constituent. 'A' indicates from 6% to 20%, whereas 'B' indicates from 21% to 35%, all by mass.

NOTE 2. The letter 'A' [and 'B' and 'C', if used] in notations for CEM III cements indicates the range of proportions of the secondary constituent. 'A' indicates from 36% to 65% by mass [whereas 'B' would indicate from 66% to 80% and 'C' would indicate from 81% to 95%].

NOTE 3. The letter 'A' [and 'B' and 'C', if used] in notations for CEM IV cements indicates the range of proportions of the secondary constituent. 'A' indicates from 11% to 35% by mass [whereas 'B' would indicate from 36% to 55%].

NOTE 4. In strength classes, the letter N denotes ordinary early strength, the letter R denotes high early strength and the letter L denotes low early strength.

MPA Cement members will be pleased to provide samples of cement and/or technical advice as appropriate; see Table 3 for contact names:

**Table 3. Contact names in MPA Cement's Member Companies (2014)**

| Company | Contact | E-mail | Tel |
|---|---|---|---|
| CEMEX Cement | Richard Boult | richardguy.boult@cemex.com | 01788 517252 |
| Hanson Cement | Simon Chudley | simon.chudley@hanson.biz | 01724 282211 |
| Hope Cement | Jo Cantwell | joanne.cantwell@hopeconstruction materials.com | 0845 520 1888 |
| Lafarge Tarmac Cement | Bill Price | bill.price@uk.lafarge.com | 0845 812 6296 |

## Properties/performance of low carbon, factory-made composite cements

### Performance

Portland cement CEM I has an enviable record of successful performance as 'the' global binder. Its properties are understood and it is robustly fit-for-purpose in concretes, mortars and grouts in all but the most demanding environments. However, in general, the appropriate specification/use of factory-made composite cements can deliver performance equal to that of concrete containing CEM I cement and under certain conditions, can improve on the durability performance achieved.

When using modern low carbon bulk cement, users should be aware that the rate of strength gain with time varies with cement type. In general CEM II/CEM III/CEM IV cements have a lower early strength than Portland cement CEM I but tend to gain a higher strength over a longer period. There is, however, an important caveat in that the quality of workmanship is paramount in determining adequate strength and durability of the end-use product, irrespective of the cement type.

**Importance of workmanship**

There really is no substitute for good practice and workmanship in ensuring a durable cement-based building product. It is essential to use the correct materials, proportion and mix the materials properly, add the correct amount of water, compact, cure and protect as appropriate. When using low carbon, factory-made composite cements (CEM II etc), it is particularly important to ensure that effective curing (days rather than hours) is applied. Precautions should be taken to avoid loss of water to the surroundings and to prevent premature drying whether the end-use is: concrete, mortar, screed or render.

**Sustainability**

As a consequence of continual improvement in process and composition, modern Portland type cements are more sustainable than previously. There is, however, a gradation amongst 'standalone' factory-made cements with the least sustainable type being CEM I given that it incorporates the highest proportion of cement clinker. Put simply, as clinker content decreases, a Portland cement's contribution to sustainability increases. Clinker production is very energy, and carbon, intensive and even though specific energy consumption and $CO_2$ emissions are being reduced year-on-year future reductions will become more difficult to achieve until, eventually, irreducible minima are reached. In consequence, the means for satisfying societal demands for cement, fulfilling environmental obligations and responding to economic imperatives have had to be reconsidered. This has led, where appropriate to the end-use, to two separate but technically-related solutions:

- the increasing use of inorganic 'additions' added, at the mixer, to factory-made CEM I cements in order to reduce 'clinker intensiveness' in the end-use 'combination'/product;

- the direct reduction of 'clinker intensiveness' in factory-made cements by the manufacturer using increased quantities of these same inorganic materials, inter-ground or blended, to produce low carbon CEM II and CEM III cements.

The effects of the above procedures on the embodied $CO_2$ ($CO_2e$) of modern cements can be seen in the indicative values for Portland cement CEM I and the range of additions used in UK as constituents of concrete, as reported in MPA Cement Fact Sheet 18 [4]. In addition, $CO_2e$ figures for a range of factory made composite cements and their equivalent combinations are given in MPA Cement Fact Sheet 18. These values are 'year-specific' and therefore subject to change by way of periodic improvement; progress is reported by updating Fact Sheet 18 from time-to-time.

**Benefits in use**

Some particular benefits of improved properties/performance of use of low carbon, bulk cements in concrete are described in Table 4.

**Table 4. Improved properties/performance of UK low carbon, factory-made bulk cements in concrete (in comparison with use of CEM I)**

| Property /performance | Benefit | Notation (type of cement) | |
|---|---|---|---|
| **Workability** | Improved workability | Factory-made low carbon cements in general | |
| **Bleeding** | Reduced bleeding | Portland-fly ash cement | CEM II/B-V |
| | | Portland-limestone cement | CEM II/A-L(LL) |
| **Heat of hydration** | Reduced heat of hydration leading to a reduced risk of early thermal cracking | Portland-fly ash cement | CEM II/B-V |
| | | Blast furnace cement | CEM III/A |
| | | Pozzolanic cement | CEM IV/B-V |
| **Sulfate-resistance** | Increased resistance to both the conventional (ettringite) and the thaumasite (TSA) forms of sulfate attack | Portland-fly ash cement | CEM II/B-V (+SR)* |
| | | Pozzolanic cement | CEM IV/B-V |
| | | Blast furnace cement | CEM III/A (+SR)** |
| **Chloride ingress** | Decreased rate of chloride ingress leading to a reduced risk of corrosion of reinforcement | Portland-fly ash cement | CEM II/B-V |
| | | Blast furnace cement | CEM III/A |
| | | Pozzolanic cement | CEM IV/B-V |
| **Alkali silica reaction** | Reduced risk of damaging ASR | Portland-fly ash cement | CEM II/B-V |
| | | Blast furnace cement | CEM III/A |
| | | Pozzolanic cement | CEM IV/B-V |

* (+SR) means 'sulfate-resisting' and that the CEM II/B-V cement contains at least 25% by mass of fly ash.

** (+SR) means ‘sulfate resisting’ and that the CEM III/A cement contains slag with <14% $Al_2O_3$ and or clinker with <10% $C_3A$

## Implications of low carbon, factory-made composite cements for the specifier and concrete producer

Factory-made composite cements can be manufactured either by inter-grinding or blending. These operations are, as are all others, under factory production control. In particular, the proportioning of the constituents is under the responsibility of the cement maker and is subject to factory production control procedures and audit testing leading to CE marking under a system of 'Assessment and Verification of Constancy of Performance' (AVCP) of 1+, the highest level of involvement of a 3rd party. This gives a specifier confidence, in a transparent and easily traceable manner, that the correct composition has been achieved.

In addition, the cement maker has a range of measures at his disposal with which to optimize the properties and performance of his cements in the fresh wet and hardened states. These measures include:

- optimizing the gypsum/sulfate content to regulate setting without compromising strength development;
- using additives to reduce water demand or to improve early strength;
- ensuring compatibility at source between the individual constituents;
- and, if necessary, modifying clinker composition to optimize performance.

Potential benefits for the concrete producer in using a factory-made composite cement, include:

- factory production control of proportions and CE marking;
- ensured homogeneity of constituents;
- reduced batching time;
- single point ordering;
- possible reductions in required storage capacity.

It must be acknowledged, though, that the fixed proportions of factory-made composite cements may lead to some reduction in a concrete producer's overall flexibility. However, it would be possible for a cement maker to adopt a 'winter' and 'summer' formulation, within the compositional limits of a particular factory-made composite cement.

## Structures in which low carbon, factory-made composite cements have been used

Although by no means exhaustive, a few examples of where factory-made composite cements have already been used in the UK are given in Table 5.

**Table 5. Examples of the use of low carbon, factory-made composite cements in the UK**

| Type of cement | Name/types of structure or application | Location in UK |
|---|---|---|
| Portland-fly ash cement | Falkirk Wheel | Falkirk |
| | Channel Tunnel Rail Link | Kent |
| | Thames Crossing tunnel segments | Woolwich |
| | Wind farms | [Several locations] |
| | Water infrastructure | [Several locations] |
| | Industrial floors | [Several locations] |
| | Ready-mixed concrete | [Several locations] |

| | | |
|---|---|---|
| Portland-limestone cement | Falmouth College of Arts | Cornwall |
| | Ready-mixed concrete | S W England |
| Low early strength blast furnace cement | Ready-mixed concrete, precast concrete blocks and precast concrete pavers | [Several locations] |

## How will modern cements develop in the future?

Although it is the operational impacts of a building that are the most significant in terms of the overall sustainability of construction, the embodied environmental impacts of materials/construction units are also subject to comparative rating. This means that manufacturers need to constantly innovate in order to minimise such impacts. In the case of cements, the effect is almost certain to be that the proportion of low carbon, factory-made composite cements (particularly CEM II and CEM III), as a fraction of total production of modern cements, will continue to increase.

MPA Cement's Members are committed to improving the sustainability credentials of all their cements and to supplying them in both bulk and packed.

## Where can I find out more?

Contact: C McCague, Tel: +44(0)20 7963 8000, colum.mccague@mineralproducts.org

## References


[1] Eco concrete, The contribution of cement and concrete to a more sustainable built environment, British Cement Association, 97.381, ISBN 0 7210 1577 8, 2001

[2] Thermal mass, The Concrete Centre, 2005, TCC/05/05, ISBN 1-904818-13-7

[3] British Standards Institution. BS EN 197–1, *Cement-Part 1: Composition, specifications and conformity criteria for common cements*

[4] MPA Cement (plus CSMA and UKQAA), Fact Sheet 18 *Embodied* $CO_{2e}$ *of UK cement, additions and cementitious material*



**MPA Cement**

**Mineral Products Association**

Gillingham House

38 – 44 Gillingham Street

London SW1V 1HU

Tel +44(0)20 7963 8000

Fax +44(0)20 7963 8001

http://cement.mineralproducts.org


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