Learning Text

Part 2

Cementitious Materials

Contents

Health and Safety

All mortar mixtures, both wet and dry, are abrasive and alkaline. When working with wet mortar, waterproof or other suitable protective clothing should be worn.

Guidance on the use of these materials can be found in Data Sheet No 20.

Introduction

This learning text considers the subject of cementitious material; the text discusses the manufacture and specification of the materials. A glossary of terminology and bibliography are included. The final section of this learning text is self-assessment questions and answers.

Cement is the adhesive or glue, which when set binds particles of fine aggregate (sand) together to produce mortar. When mixed with water the cement forms a paste, which is called the fine matrix. (When coarse aggregate is used as in concrete production the matrix is described as the fine and the coarse matrix). Cements are hydraulic materials, this means that they depend upon a reaction with water rather than air for strength development. When water is added to cement a chemical reaction called hydration commences immediately and continues while water is still present.

Lime mortars are believed to have been developed in ancient Egypt. These generally harden and gain strength by the evaporation of the water and the absorption of carbon dioxide from the atmosphere. This results in the gradual conversion of the lime into calcium carbonate (air limes).

It was the patenting of Portland cement by Joseph Aspin in 1824 that started the large-scale production of cements. There are a number of different types of cements, which may be used to produce mortar.

Portland Cement

Manufacture

Portland cement is made from limestone or chalk and shale or clay (i.e. calcium carbonate and siliceous material). There are two main methods of cement manufacture, the wet process and the more modern dry process.

In the wet process, soft raw materials are reduced to a water suspended slurry in washmills, hard oversized material being separated by screens and ground in a tube mill. The slurry has a creamy consistency and a water content of approximately 40%. The slurry is pumped to storage tanks, which are continuously agitated to prevent the solid particles from settling out. Because the raw materials can contain varying amounts of calcium and silica, it may be necessary to blend different slurries in order to obtain the desired chemical composition before feeding into the kiln.

In the dry process, the materials are crushed and fed through a tube mill, which reduces them to a fine meal. The meal is then stored in a silo from where it is transported to the kiln pre-heater. The material then cascades downwards while warm exhaust gas from the kiln passes through it.

The raw materials are fed through the kiln, which can be up to 250m long, and 6m in diameter, the length of the kiln depending on which process is used. In the kiln-firing zone, the material reaches a temperature of 1400^{o}C before leaving the kiln in the form of clinker. The clinker is rapidly cooled and stored until required for milling. Then it is fed into tube mills where about 3-7% gypsum is added to control the setting of the finished product and the materials are ground to the required fineness. Increasingly, other additives which impart water-reducing properties to the cement and aid grinding are incorporated at this stage. A reducing agent is also added during the grinding stage or just after the grinding stage this enables the cement to be used safely. The addition of a reducing agent is necessary to comply with the requirements of the European Union Directive 2003/53/EC Chromium VI) which requires that the hexavalent chromium content of cement or cement based preparation shall not exceed 2 parts per million. More details are given in the health and safety section of this text. After grinding the cement is fed to storage silos until required for bulk delivery or diverted to a bagging plant.

Properties

The proportions of the raw materials and the manufacturing process can be varied to produce different cements with a range of properties.

Portland cement contains four main compounds these are:

- *Tricalcium silicate* (C_3S) - this reacts rapidly with water producing relatively large amounts of heat to form calcium silicate hydrate. It has a high strength and is the main contributor to the early strength of cement hydrate. The cement chemist's shorthand notation for this compound is C_3S.

- *Dicalcium silicate* (C_2S) - this reacts slowly with water to form the same product as C_3S. Because of the slow reaction, the heat evolved is dissipated before significant temperature rises occur. It increasingly contributes to strength at later ages.

- *Tricalcium Aluminate* (C_3A) - this compound reacts very rapidly with water, evolving a relatively large amount of heat and with a very rapid set. This reaction is retarded by the addition of gypsum during the grinding stage.

- *Tetracalcium aluminoferrite* (C_4AF) - this compound reacts rapidly with water but does not produce much heat or strength. C_4AF must be absent in white cement because of its pronounced colour.

The symbols C_3S, C_2S, C_3A and C_4AF are the cement chemists' shorthand notation and are used internationally.

***Minor compounds* -** A number of minor compounds are present in cement, including free lime, alkalies and magnesia.

***Fineness* -** Since reaction with water is a surface one, increasing the fineness, which increases the surface area, speeds up the reaction.

British/European standards

The European Standard, BS EN 197-1 that is entitled "Cement - Part 1 Composition, specification and conformity criteria for common cements" was published in 2000 and replaced a number of former British Standards, it is the principal cement specification standard across the whole of the European Union and is also forming the basis of the ISO standard.

In the short term, BS 4027 (Specification for sulfate-resisting Portland cement) will continue in an unmodified form.

The European standard for Masonry cement BS EN 413 has been published in two parts and BS 5224, the former UK standard has been withdrawn.

Nomenclature for cements

Cements are described in a format that indicates the cement type, main constituents, strength class and rate of early strength development.

a) BS EN 197-1 categorises cements into five types based on their composition, these are:

CEM I — Portland cement; comprising Portland cement and up to 5% of minor additional constituents [Note 1].

CEM II — Portland composite cement; comprising Portland cement and up to 35% of certain other single constituents (the exception being Portland composite cement). [Note 2]

CEM III — Blastfurnace cement; comprising Portland cement and higher proportions of blastfurnace slag than in a CEM II cement.

CEM IV — Pozzolanic cement; comprising Portland cement and higher proportions of pozzolana than in a CEM II cement.

CEM V — Composite cement; comprising Portland cement and combinations of blastfurnace slag and pozzolana or fly ash.

Notes

[1] Minor additional constituents are inorganic materials, (limestone, fly ash or ground granulated blastfurnace slag), which because of their particle size can improve the physical properties of the cement, e.g. workability or water retention.

[2] Portland composite cement may incorporate a mixture of up to 35% of any of the materials listed as secondary main constituents (See c).

b) All the cement types apart from CEM I have a designatory letter immediately after the Roman numeral indicating the cement type, this indicates the range of Portland cement (PC) clinker proportions. Regrettably, for each of the cement types the same designatory letter indicates a different PC clinker range, this is a little confusing.

i) The cements described as CEM II which is a cement with a single secondary major constituent (the exception being Portland composite cement) have a designatory letter immediately after the CEM notation to indicate the level of Portland cement contained within the cement:

A = high level (PC clinker content 80-94%) - CEM II/A
B = medium level (PC clinker content 65-79%) - CEM II/B

ii) A similar system operates for CEM III cements which are cements containing a higher level of blastfurnace slag than permitted in a cement of type CEM II.

A = PC clinker content 35-64% - CEM III/A
B = PC clinker content 20-34% - CEM III/B
C = PC clinker content 5-19% - CEM III/C

iii) CEM IV cements contain a higher level of pozzolanic material than permitted in a cement of type CEM II, a designatory letter is used to indicate the PC content:

A = PC clinker content 65-89% - CEM IV/A
B = PC clinker content 45-64% - CEM IV/B

iv) CEM V cements are composite cements but contain a higher level of the secondary constituent than CEM II cements (it is also permitted to have more than one major secondary constituent). The range of Portland cement clinker content is also indicated by the use of a designatory letter:

A = 40-64% PC clinker content - CEM V/A
B = 20-39% PC clinker content - CEM V/B

c) CEM II cements also have an additional designatory letter after the letter indicating the Portland cement clinker level which indicates the second main constituent present in the cement. The letters are as follows:

S	=	blastfurnace slag	D	=	silica fume
P	=	natural pozzolana	Q	=	natural calcined pozzolana
V	=	siliceous fly ash	W	=	calcareous fly ash
T	=	burnt shale	L	=	limestone
M	=	a composite cement			

d) The standard strength class is the strength that will be achieved at twenty-eight days by a prism of cement, fine aggregate (sand) and water of a fixed composition tested in a prescribed manner. There are three strength classes 32.5, 42.5 and 52.5. The appropriate standard lists the exact requirements for determining the class and the permitted range of strengths within each class. Not all cements are available in each class. The strength class is expressed in MPa (Mega Pascals), these units are numerically equivalent to N/mm^2.

e) For example a cement with the description BS EN 197- CEM II/B-V 42.5N indicates a Portland fly ash cement with a Portland cement clinker content in the range 65-79%, a fly ash content in the range 21-35%, a standard strength class of 42.5 and a normal rate of strength development as shown in Figure 1.

BS EN 197 – CEM II/B-V 42.5N

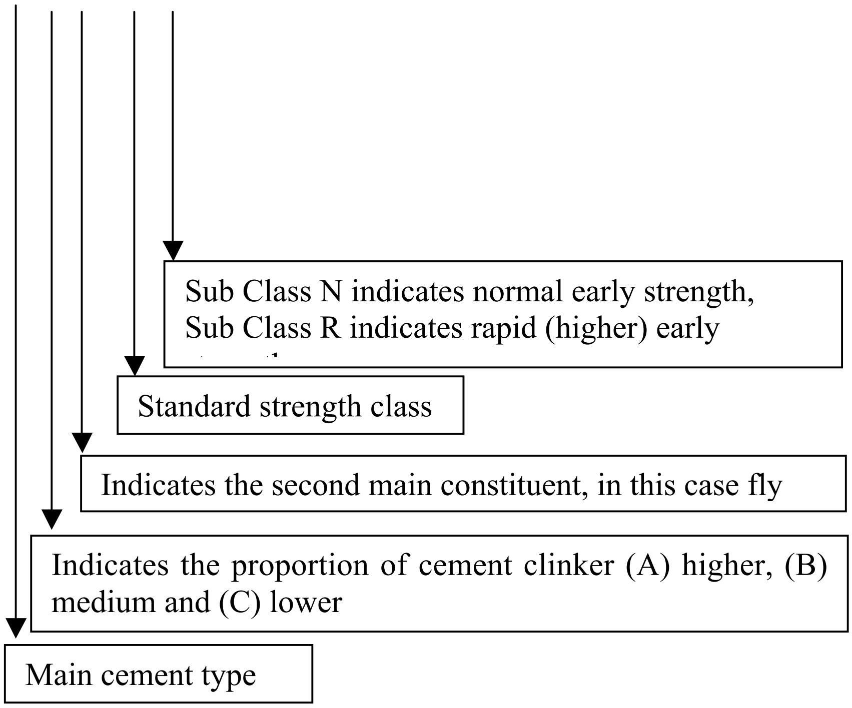

Figure I: BS EN 197-1 – description for Portland fly ash cement

f) Masonry cement has a different form of nomenclature. There are three strength classes 5, 12.5 and 22.5. For MC 5 the Portland cement clinker content is required to be a minimum of 25%, for the other classes it is required to be a minimum of 40%. The 12.5 class may be supplied without the incorporation of an air-entraining admixture; this is indicated by the letter "X" after the strength grade. The 22.5 strength class is not permitted to incorporate an air-entraining admixture. Masonry cements are only available in standard strength classes; no sub classes are permitted by the standard.

BS EN 413-1 prescribes requirements for the physical properties of the cement when assessed in a standard mortar. For MC 5 and MC 12.5 the air content is required to be in the range of 8-22% by volume and the water retention by mass greater than 80%. The requirements for MC 12.5X and 22.5X are the air content is required to be less than 6% by volume and the water retention greater than 75% by mass. Further strength and chemical requirements can be found in BS EN 413-1 clause 5.3.6 and clause 5.4.

Types of Cement

CEM I 42.5N (Portland Cement)

This is the basic cement and is commonly used for general construction work. This cement is frequently combined with ground granulated blastfurnace slag or fly ash (see the following sections).

CEM I 42.5R and 52.5N (Portland Cement)

This cement is normally made by grinding the same clinker as CEM I 42.5N to a greater fineness; in order to prevent a more rapid set occurring than for CEM I 42.5N, extra gypsum is usually added at the grinding stage. CEM I 42.5R or 52.5N is used where there is a requirement for early strength, for example precast applications.

Sulfate Resisting Portland Cement (BS 4027)

To produce this cement iron oxide is added to the raw feed to the kiln which results in the production of a material low in tricalcium aluminate (C_3A). This is the compound that reacts with sulfates to potentially result in sulfate attack which may lead to the disintegration of the hardened mortar. The increased iron oxide content gives sulfate resisting Portland cement a darker colour than plain Portland Cement. Sulfate resisting Portland cement is often ground finer than CEM I Class (42.5 N) in order to compensate for the reduced early strength caused by its low C_3A content.

Masonry Cement (BS EN 413)

Masonry cement was developed in the United States in the 1930's and is made by mixing Portland cement with up to approximately 60% of a filler such as ground chalk and incorporates a plasticiser/air entraining additive. This cement is lower in strength than normal Portland cement, but has improved plasticity and water retention.

CEM II/A-L (Portland Limestone Cement)

This cement is produced by blending or intergrinding 6-20% of ground limestone with Portland cement. It is also possible to produce this material in the plant mixer by mixing 6-20% of limestone fines, conforming to BS 7979, with Portland cement.

White Cement (CEM I)

This is cement made from especially pure non-iron containing raw materials (e.g. China clay and white limestone) in order that the tetracalcium aluminoferrite (C_4AF) content is very low. It is normally made in a separate kiln and is therefore more expensive than standard Portland cement. Currently, this cement is only available in the UK as strength class 52.5 N.

Ground Granulated Blastfurnace Slag (ggbs) - (BS EN 15167)

Ggbs is a by-product of the iron/steel manufacturing industry. The molten slag from the production of iron in a blastfurnace is rapidly cooled by high pressure water jets which subjects the slag to instantaneous solidification in the form of granules, these are then dried and ground to a similar fineness to CEM I Class (42.5N) in a tube mill. Ggbs is off-white in colour. It may be described as a latent hydraulic material which means it will gain strength on its own, but very slowly.

Pozzolanic Materials (including fly ash BS EN 450)

Pozzolanic materials may be divided into two categories, natural pozzolanas and artificial pozzolanas. Natural pozzolanas include volcanic ashes such as those found around Pozzouli near to Mount Vesuvius, hence the name. Artificial pozzolanas include fly ash, crushed burnt bricks and tiles. Traditionally in the UK fly ash was known as pulverized fuel ash (pfa), in common with the rest of Europe we have now adopted the term fly ash.

The Romans used to add volcanic ash to lime as they found that it created a stronger matrix. In some parts of Europe naturally occurring pozzolanas are still used. A pozzolana is mainly composed of compounds of silica, alumina and iron oxide, when mixed with a highly alkaline material, (such as cement) hydraulic properties are developed.

Fly ash is an artificial pozzolana which is the residue obtained from the combustion of pulverized coal collected from the flue gases in electrostatic precipitators at coal fired power stations. Normally, only the ash from base load power stations is of high enough quality for use in mortar or concrete, as a variable power generation cycle leads to unburnt carbon in the ash. The ash collected from the power stations may be further classified using air separators to remove certain size fractions. Fly ash particles are spherical in shape and are generally as fine or finer than CEM I Class (42.5N). Fly ash is similar in colour to plain Portland cement and the technical requirements it is required to conform to are listed in BS EN 450. Changes to the standard are being developed that will allow a percentage of co-combustion material to be included within the fly ash. Co-combustion materials that will be included are divided into 7 groups:

- Vegetable material like wood chips, straw, olive shells and other vegetable fibres,
- Green wood and cultivated biomass,
- Municipal sewage sludge,
- Bone meal,
- Paper sludge,
- Petroleum coke,
- Virtually ash free liquid fuels and gaseous fuels.

Lime

Introduction

The ancient Greeks and Romans produced mortar by burning limestone and slaking (mixing with water) the resultant product with water and, then mixing it with sand.

When limestone (calcium carbonate) is heated to a high temperature or calcined the resultant product is quicklime. (The correct technical name is calcium oxide):

$CaCO_3$	+	$\rightarrow$	CaO	+	CO_2
Limestone Chalk Marble	Heat 850°C		Quicklime		Carbon dioxide

The calcination process was traditionally undertaken in small mixed feed kilns and examples of the remains of these may still be seen around the country. Chemical analysis of historic mortars indicates that many of these contain inclusions of lime that have remained unmixed and unslaked during mortar production. Currently the calcination of limestone is generally undertaken in shaft or rotary kilns.

Lime was traditionally classified as hydraulic or non-hydraulic. Hydraulic limes possess the ability to set under water. The addition of water to quicklime, results in a great deal of heat being given off and the formation of calcium hydroxide.

CaO	+	H_2O	$\rightarrow$	$Ca(OH)_2$	+	Heat
Quicklime		Water		Calcium hydroxide		

Traditionally, an excess of water was added to quicklime and the material allowed to soak for several weeks or even months in pits (the process called slaking). As time progressed the process was refined and after the addition of water the mixture was passed over a screen to remove particles that were reacting slowly. The mixture was then left to mature for about a month prior to use. The inefficiency of this process could lead to the expansion of some of the unslaked particles resulting in popping and pitting of lime based plasters. Expansion of the mortar could also take place, a phenomenon known as blowing. The slaking of quicklime has largely been superseded by modern methods of producing hydrated lime.

Hydraulic limes

Manufacture

These are produced by burning limestone (calcium carbonate) containing quantities of impurities such as silica, alumina (active clay material) and iron. The carbon dioxide is driven off at a temperature in excess of 850° C and the resultant product is calcium oxide with calcium silicates (which gives this material its hydraulic properties).

Hydraulic limes made from limestones' containing quantities of silica, alumina and iron are called natural hydraulic limes. Artificial hydraulic limes are produced by blending powdered hydrated limes with pozzolanic material and/or cement.

Traditionally, hydraulic limes were classified as feebly hydraulic, moderately hydraulic and eminently hydraulic. Eminently hydraulic lime was sometimes called Roman lime. These terms are now no longer included in the new standards however for the sake of completeness they will be discussed briefly due to their appearance in many publications and existence in some heritage buildings.

Feebly hydraulic lime

Feebly hydraulic limes have less then 12% active clay material (alumina and silica). The great merit of feebly hydraulic lime is that it is often highly compatible with weakened, weathered stones and bricks, is able to accommodate minor building movement, tends to act sacrificially within the masonry face and is ideal in consistency for pointing, face repair and plastering. Non-hydraulic lime, as well as feebly hydraulic lime, can perform better than any other, in the right hands, for conservation, for many internal locations or for sheltered summer work.

Moderately and eminently hydraulic lime

Moderately hydraulic limes have between 12-18% active clay material and eminently hydraulic limes have 18-25% active clay material. These limes have great versatility and may be used on copings, chimneys, weatherings and pavings, as well as for bedding ashlars, rubble and for plastering. Their relatively quick-setting property and early hardness must not be confused with superficially similar properties in cement. These limes retain good water vapour permeability and the ability to accommodate movement. These limes are imported from abroad mainly France and Italy and may contain some minor additions such as cement or volcanic ash to give improved variety of use.

Non-hydraulic limes

These are materials with high calcium content and only minor amounts of silica, alumina and/or iron. Limestones that have a high content of magnesium may also be classified as non-hydraulic.

Hydrated lime

The addition of a carefully controlled quantity of water to quicklime produces a dry powder that is called hydrated lime, a process that is generally undertaken in a hydrating plant. When quicklime and water are combined, the product may be dry hydrate, lime putty or milk of lime, dependent on the increasing amount of water added.

To produce dry hydrate only the precise amount of water to complete the hydration reaction is required.

Lime putty is produced by the controlled addition of water to quicklime to produce a paste like consistency. Alternatively, milk of lime (which is not used in mortar production without further processing) can be allowed to settle out and the excess water removed. The properties of lime putties improve with age and they are frequently left to mature for some time.

Classification

The European Standard BS EN 459-1 (Building lime: Definitions, specifications and conformity criteria uses a classification (Table 1) for limes based on the calcium and magnesium oxide contents but also includes three categories of hydraulic lime.

Limes that contain $\geq$ 4 % magnesium oxide (MgO) are referred to as dolimitic Limes.

Designation	Notation
Calcium lime 90	CL 90
Calcium lime 80	CL 80
Calcium lime 70	CL 70
Dolomitic limes 85	DL 85
Dolomitic limes 80	DL 80
Hydraulic lime 2	HL 2
Hydraulic lime 3,5	HL 3,5
Hydraulic lime 5	HL 5
Natural hydraulic lime 2	NHL 2
Natural hydraulic lime 3,5	NHL 3,5
Natural hydraulic lime 5	NHL 5

Table 1: BS EN 459-1 Classification of building limes

Calcium and dolomitic limes are classified by the percentage of calcium oxide and magnesium oxide content. Hydraulic limes are classified by their compressive strength.

Cement, Lime and Combinations

There are a number of cements and combinations, which can be used in mortar, render, screed and concrete. While there are a considerable number of types of cement, many mortar plants have only limited silos and typically may stock:

CEM I Class (42.5 or 52.5), Ground granulated blastfurnace slag (ggbs) (BS EN 15167)

or

CEM I Class (42.5 or 52.5), Fly ash (BS EN 450) and lime

However for plants with several silos it may be possible to stock a combination of the above.

In some areas it is possible to purchase Portland slag cement (CEM II/A-S or CEM II/B-S), Blastfurnace cement (CEM III/A), Portland fly ash cement (CEM II/A-V or CEM II/ B-V) or Pozzolanic cement (CEM IV/B) direct from a manufacturer, but it is more usual to produce these cements in the plant mixer or truck mixer by batching the constituent materials from separate silos.

For example

CEM I (1) and ggbs are batched to give CIIA-S - 6-20% ggbs
CEM I (1) and ggbs are batched to give CIIB-S - 21-35% ggbs
CEM I (1) and ggbs are batched to give CIII/A - 36-65% ggbs
CEM I (1) and ggbs are batched to give CIIIB - 66-80% ggbs
CEM I (1) and fly ash are batched to give CIIA-V - 6-20% fly ash
CEM I (1) and fly ash are batched to give CIIB-V - 21-35% fly ash
CEM I (1) and fly ash are batched to give CIVB-V - 36-55% fly ash

Note[1]: CEM I Class 42.5 or greater is required.

The notation for mixer blended Portland limestone cement is CIIA-L or CIIA-L, the difference between the L or LL classification is related to the total organic content.

Applications

Sulfate resisting Portland cement may be used where there is a likelihood of sulfate attack, in some work where sufficient quantities of sulfates are present.

CIIA-S or CIIB-S are most commonly used for all types of construction work: CEM I may also be used.

Masonry cement may also be used for general masonry construction, but it has no particular sulfate resisting properties.

Safety

Precautions should be taken to avoid dry cement entering the eyes, mouth and nose when mixing mortar. If wet cement or lime enters the eye it should be immediately washed out thoroughly with clean water and medical treatment should be sought without delay. Wet mortar on the skin should be washed off immediately.

Cement contains an element known as tri-valent chromium. This form of chromium is relatively insoluble in water. Tri-valent chromium oxidizes when in contact with air to form Chromium VI. The latter form is very water soluble especially in alkaline conditions e.g. cement preparations, as explained earlier in this text a reducing agent is added to the cement.

When Chromium VI comes into repeat contact with skin it can lead to sensitisation, any further contact of Chromium VI then leads to an allergic reaction causing dermatitis. The abrasiveness of the particles of cement and fine aggregate in mortar can contribute to this effect.

Storage

Guidance on storage of cementitious materials can be sought from the manufacturer. The general rules are set out in BS EN 413-1 National annex NE.

To protect cementitious material from premature deterioration after delivery, bulk silos should be waterproof, clean and dry (internal condensation minimized).

Paper bags should be stored unopened, clear of the ground and in cool, dry conditions protected from excessive draught. Stacks of bags should be no more than eight-high and should be protected by a waterproof structure against water/moisture. Significant deterioration can begin after four to six weeks of storage in bags in normal conditions, and considerably sooner under adverse weather conditions or high humidity.

Glossary of Terms

The definitions in this learning text are based on those given in BS EN 459-1; BS EN 450-1 and BS 6100-9

Addition	Finely divided material used in concrete, mortar and screed to improve certain properties or to achieve special properties. There are two types of inorganic addition: - nearly inert additions (type I) - pozzolanic or latent hydraulic additions (type II)
Air limes	Limes mainly consisting of calcium oxide or hydroxide which slowly harden in air by reacting with atmospheric carbon dioxide. Generally they do not harden under water as they have no hydraulic properties. They may be either quicklimes or hydrated limes.
Ashlar	Surface appearance of a vertical construction of plain blocks of stone, finely dressed and jointed to given dimensions and laid in courses.
Binder	Material used for the purpose of holding solid particles together in a coherent mass.
Building limes	Limes used in building construction and civil engineering.
Calcium limes (CL)	Limes mainly consisting of calcium oxide or calcium hydroxide without any additions of hydraulic or pozzolanic materials.
Combination	Restricted range of Portland cements and additions which are combined in the mortar or screed mixer.
Dolomitic limes (DL)	Limes mainly consisting of calcium oxide and magnesium oxide or calcium hydroxide and magnesium hydroxide without any additions of hydraulic or pozzolanic materials.
Fly ash	Fly ash is a fine powder of mainly spherical, glassy particles, derived from burning pulverized coal, which has pozzolanic properties and consists essentially of SiO_2 and Al_2O_3, the content of reactive SiO_2 defined and determined as described in BS EN 197-1, being at least 25% by mass; fly ash is obtained by electrostatic or the mechanical precipitation of dust-like particles from flue gases or furnaces fired with pulverized anthracite or bituminous coal.
Fly ash obtained from co-combustion	Fly ash that is generated from firing pulverized coal, to which a certain amount of co-combustion material has been added.

Gypsum	Naturally occurring or chemically produced calcium sulfate dihydrate ($CaSO_4.2H_20$) from which binders are produced by various degrees of dehydration.
Hydrated limes	Air limes, calcium limes or dolomitic limes, resulting from the controlled slaking of quicklimes. They are produced in the form of a dry powder or putty or as a slurry (milk of lime).
Hydraulic binder	Binder that sets and hardens by chemical interaction with water and is capable of doing so under water.
Hydraulic limes (HL)	Limes mainly consisting of calcium hydroxide, calcium silicates and calcium aluminates produced by mixing of suitable materials. They have the property of setting and hardening under water. Atmospheric carbon dioxide contributes to the hardening process.
Latent hydraulic binder	Hydraulic binder that acts by the addition of an activator, usually cement/lime and water.
Lime	Material comprising any physical and chemical forms under which calcium and/or magnesium oxide (CaO and MgO) and/or hydroxide ($Ca(OH)_2$ and $Mg(OH)_2$) can appear.
Natural hydraulic limes (NHL)	Limes produced by the burning of more or less clay type or siliceous limestones with reduction to powder by slaking with or without grinding. All NHL have the property of setting and hardening under water. Atmospheric carbon dioxide contributes to the hardening process.
Pozzolana	Latent hydraulic binder, naturally occurring or manufactured that contains siliceous or siliceous and aluminous materials.
Quicklimes	Air limes mainly consisting of calcium oxide and magnesium oxide produced by calcination of limestone and/or dolomite rock. They have an exothermic reaction when in contact with water. They are available in varying sizes ranging from lumps to ground powder materials. They include calcium limes and dolomitic limes.
Reducing Agent	A substance that removes oxygen or add hydrogen to, another substance.

Bibliography

BS EN 197-1:2000	Cement - Part 1: Composition, specification and conformity criteria for common cements
BS EN 413-1:2004	Masonry cement- Part 1: Composition, specifications and conformity criteria
BS EN 450-1:2005	Fly ash for concrete- Part 1: Definitions, specifications and conformity criteria
BS EN 459-1:2002	Building lime-Part 1: Definitions, specifications and conformity criteria
BS 6100-9:2007	Building and civil engineering-Vocabulary-Part 9: Work with concrete and plaster.
BS EN 15167-1:2006	Ground granulated blast furnace slag for use in concrete, mortar and grout- Part 1: Definitions, specifications and conformity criteria
BS 4027:1996	Specification for Sulfate- resisting Portland cement
BS 5224:1995	Specification for Masonry cement (withdrawn)
BS 7979:2001	Specification for limestone fines for use with Portland cement
Directive 2003/53/EC	Restrictions on the marketing and use of certain dangerous substances and preparations nonylphenol, nonylphenol etoxylate and cement. (Directive of the European Parliament and Council)

Self-Assessment Questions

1	What are the basic raw materials from which Portland cement is manufactured?
2	What is added to Portland cement to produce masonry cement?
3	What compound is absent from white cement?
4	What process is ggbs a by-product from?
5	What is the difference between hydrated and hydraulic lime?
6	What are hydraulic materials?
7	How do lime based materials gain their strength?
8	What is the effect of grinding cement more finely?
9	How much gypsum is added to cement clinker at the grinding stage?
10	Who obtained a patent for the production of Portland cement in 1824?

Answers to Self-Assessment Questions

1	A source of calcium carbonate (chalk or limestone) and a source of Silica (clay or shale).
2	A filler such as ground chalk and a plasticiser / air entrainer.
3	Iron bearing materials (C_4AF).
4	The production of iron from iron ore.
5	Hydraulic lime sets by reaction with water, hydrated lime does not.
6	Materials that have the ability to set under water.
7	Lime based materials gain their strength by the absorption of carbon dioxide from the air and converting the calcium oxide to calcium carbonate.
8	The cement has the ability to gain strength more quickly.
9	3-7% gypsum is added to cement clinker at the grinding stage.
10	Joseph Aspin.