Learning Text

Part 1

Introduction to Mortar

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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.

Scope

This learning text is primarily concerned with those mortars that use Portland cement as a binder, although to a lesser extent those using a blend of cement and lime or even lime only are considered. A glossary of terminology and bibliography are included. The final section of this learning text is self-assessment questions and answers.

Many other cements and binders may theoretically be used to produce mortar, but these are generally very specialist. For example, phosphate cements, magnesium oxychloride cements, calcium aluminates and a variety of materials are used for very special applications but will not be considered further.

However, gypsum based mortars, although only used for restricted applications, will be briefly discussed as they have a long history of use.

The Historical Background and Development of Building Mortars

Ancient mortar

The most ancient mortar discovered to date is in Galilee, Israel near Yiftah'el and is reputed to be 10,000 years old.

Some of the oldest examples of our built environment dating back about 5,000 years to the time of Mesopotamia, still survive today in the form of masonry ruins. Much of the mortar in those ruins remains durable today, a testament to the long lasting nature of masonry!

Gypsum mortar

The Egyptians used gypsum mortars in the construction of the pyramids. More recently, this type of mortar was used to rebuild much of the city of Paris, which gave its name to the Gypsum, sometimes called Plaster of Paris, as a result of the natural gypsum deposits found under the district of Monmartre.

Some of this gypsum-bonded masonry still exists in the older parts of Paris. More recently, an external render, based on Gypsum, originally developed in France, was imported into the United Kingdom. However, after a short period of time and a bad history of failures this was withdrawn from the market.

In addition to this recent problem, it is known that many of the existing historic dwellings in Paris, that were originally built with gypsum mortar and have not been restored, suffer badly from damp and deterioration. Partly as a result of these adverse experiences, and partly arising from the theoretical view that they do not form hydrates that are stable in the presence of water, gypsum mortars are not used today and are certainly not recommended for external work.

Gypsum mortars will not form a further part of this series of learning texts, although in very dry climates, or where there is protection from the elements they could almost certainly be used without problems. In these situations, or in an internal environment without excessive damp they have the potential to perform quite satisfactorily, as demonstrated by the widespread use internally of gypsum based internal building blocks in continental Europe.

Lime Mortars

The Egyptians used lime mortars, with literature on this subject dating backover 2000 years.

Lime mortars are believed to harden and gain strength by the evaporation of water and the absorption of carbon dioxide from the atmosphere. This results in the gradual conversion of lime into calcium carbonate.

This mechanism is theoretically correct, but takes a very long time to produce any meaningful strength.

There are different compounds that are known loosely as lime, and these are described in more detail in the learning text on cementitious materials which is Part 2 two in this series. They are described briefly below.

Quicklime

When lime is produced, it is generally by burning mineral raw materials; usually those based on calcium although magnesium based limes also exist. Magnesium based limes are not however used for mortar in the United Kingdom or Ireland and will not be considered further in this text.

In the United Kingdom and Ireland the most common raw materials that are burnt in the kiln to produce lime are chalk or limestone, but in theory any calcareous feedstock could be used. In some countries, shells, corals and other sources of calcium are used satisfactorily.

When the raw material, which is basically calcium carbonate whatever its actual form, is heated to about 850^{o}C, the combined carbon dioxide is driven off in the form of gas, to result in calcium oxide or quicklime remaining.

Hydrated lime

Quicklime is not used directly in mortar, but is first reacted further with water to produce calcium hydroxide, known as “slaked” or “hydrated” lime, which in this form it is ready to be incorporated in a mortar mix. However, it must be noted though that pure calcium hydroxide mortars, although in theory being capable of hardening and strength development, in reality only react extremely slowly. Typically, it would take a period of perhaps 100 years for a mortar joint to carbonate or harden to a depth of perhaps 6 to 10 mm (carbonation is the conversion of calcium hydroxide to calcium carbonate).

The ancient craftsmen realised this, and knew that a very pure lime was actually inferior to one that had some impurities.

Hydraulic lime

When cement is manufactured, limestone is burnt in a kiln with clay, to provide a cementing compound that reacts with water to produce a hardened hydrate. It can be seen therefore, that the presence of clay impurities produces what is effectively weak cement and it is this mechanism that is behind the strength development and hardening of many lime mortars, both historical and modern.

Unfortunately, this is very often misunderstood and a large number of people fail to realise that without the inclusion of at least some clay during the burning of lime, lime mortars will not harden at a meaningful rate.

This lack of understanding also leads to an erroneous interpretation of the properties of lime mortars. Some modern builders and specifiers ascribe a whole plethora of beneficial properties to "lime" mortars, based primarily on their observations of the long life of historic structures, without realising exactly what type of lime mortars they are basing their views on. Many, probably the vast majority of the successful and long lasting structures that they believe to contain lime mortars are based on hydraulic lime. In reality this is a weak and crude cement, when compared to the purer hydrated limes that are produced today. It will be seen that use of the latter material will not produce a mortar with a great deal of strength or durability, as the carbonation process proceeds so slowly and produces relatively low strength development.

Due to the evident long lasting nature of hydraulic lime based mortars, in recent years some specifiers have again been stipulating them, unaware of the way in which they were produced originally, and in the belief that similar materials are readily available today.

Unfortunately, it is not the case that hydraulic limes are readily available in the United Kingdom today as only one small works in Dorset produces commercial quantities. Some hydraulic limes are imported from Italy and France but whilst these may be genuine, a number are formulated using mixtures of Portland cement, lime and air entraining admixture and are thus not hydraulic limes at all, but rather masonry cements.

It will be seen therefore that in almost every situation where historic limes are referred to these are hydraulic lime in reality and not hydrated lime, which constitutes a common misapprehension.

Turning now to the consideration of those historic mortars, many examples of Roman mortar survive; many within the United Kingdom. For example Hadrian's wall still has massive unrestored areas of original materials.

More recently, the Tower of London, some 900 years old, provides further evidence of the durability of masonry materials and historic lime mortar.

Ash Lime Mortar

The potential pozzolanic properties of ash or other material containing reactive silica have been known since Pre-Roman times, perhaps earlier and there are many historical references to the use of ground brick dust as a source of silica, to mix with lime and thus generate a false set.

Unfortunately, there are also misconceptions surrounding the use of brick dust and there have been examples recently of the inappropriate specification of this material. Early bricks were fired at low temperatures and the resultant product was quite highly reactive in the presence of free lime. In contrast modern bricks are fired at a much higher temperature and are not nearly as reactive, indeed sometimes not at all reactive, compared to these historic examples.

It is clear therefore that this is another area where a great deal of confusion exists, with the specification of materials that are thought to mirror favourable historic characteristics being a potential source of failure. This means that any specification for a lime mortar to be used in conjunction with ground brick dust should be critically questioned.

In contrast to the situation with brick dust, the relatively recent use of ash in ash lime mortars has been both more widespread and more successful, although that is not to say that these mixes should really be specified today, without adequate research.

From the time of the industrial revolution though, with the widespread availability of furnace ashes, ash lime or black ash mortars became more widely used.

These materials are often criticised today, primarily because of their impurities, which in theory may lead to durability problems. It has been said that their use in cavity work built around the beginning and middle of the twentieth century caused corrosion of the wall ties, but it is unclear whether or not many of these ties would have corroded in any event regardless of the type of mortar used.

Indeed, many structures exist where old ash lime mortars are still durable. Ash lime mortars were still used well into the middle of the twentieth century in those parts of the country where ash was widely available.

The Development of Modern Cement Mortars

One of the first references to the manufacture of a calcareous cement compound was from Bryan Higgins who patented a cement for use in external rendering in 1779 and published a paper on the manufacture of cement in 1780.

John Smeaton an engineer from Yorkshire developed a rapid setting cement which he used to join blocks of granite for the construction of the fourth Eddystone lighthouse in the period 1756-1759. This structure served for 127 years and was then taken down stone by stone and reassembled on Plymouth Hoe, the base stump being left on the Eddystone rock. The structure on Plymouth Hoe was refurbished in 2002. Smeaton heated limestone, with clay to produce a material that reacted with and hardened in the presence of water.

Joseph Aspin a Leeds bricklayer patented Portland cement in 1824, which was so called because of the resemblance to Portland stone. The material was first produced commercially in Wakefield in the late 1920s.

In France, Vicat was working on the production of cements and hydraulic limes and this work culminated in his comprehensive book on the subject (published in 1837, later edition 1997).

At about the same time, many other people were working on patented cements and a host of proprietary formulations were developed. Interestingly, one of these was for "Roman" cement, not literally Roman, but patented in the eighteenth century and so called because of it's distinctive brown colour. It was said to resemble that of the original Roman cement that contained some of the ground Roman brick or tile dusts.

Cement : Lime : Sand Mortars

Following from the development of "modern" Portland cements, the potential for masonry construction greatly increased. This was attributed to the reliable strength development and much increased rate of strength gain, which enabled construction to be planned and executed far more rapidly.

The early limes previously used, produced acceptable working properties for the masons however, the rate of strength gain was low, especially in cold weather conditions. This meant that even a high quality lime, with a good ultimate strength, could prove very problematic for winter usage. Indeed it is probable that the majority of masonry construction proceed little, if at all, during the winter months.

The availability of the new Portland cements changed this situation and enabled construction to carry on throughout the year, with the obvious exception of periods of very severe winter weather with heavy precipitations or freezing temperatures.

However, a problem arose with these new materials. With the original limes, mix proportions of between one part binder to two or two and a half parts sand (1:2 and 1:2 _): were used by the masons. These mix proportions produced a mix with acceptable working properties, but unfortunately, the use of such high binder contents with cements resulted in a mortar that was too strong for the masonry units to which it was being applied. This caused particular difficulties for restoration works.

One solution was to use a combination of lime and cement as the binder, with the lime and cement together forming the proportions of one part of binder to two and a half or three of sand. At present mortars based on this principle are widely used in most continents.

Masonry Cement Mortars

Masonry cement is produced in a cement works and is an alternative concept to that of mixing together cement and lime on site or in a mixer to obtain a blend or mix of the properties of each, with a resultant mortar that is neither too strong nor too weak. These materials may be obtained in a pre-blended form within the United Kingdom, this material is known as masonry cement, which has traditionally used an inert material instead of lime, either ground limestone or fine silica being utilised. In practice, ground limestone was the usual material as this was often available at a cement works, which meant that haulage was not a factor causing increased materials cost.

Recent research work has shown that limestone may also provide an enhanced strength development in the medium and long term as it may contribute, albeit in a minor way, to a slow continuation of the cement hydration/strength development process.

In addition to the mixture of cement and other material, masonry cement mortars also include an air- entraining admixture.

Whilst United Kingdom masonry cement has utilised mixtures of Portland cement and crushed or ground stone, in North America, the tradition has been to use mixtures of Portland cement and hydrated lime, together with air entrainment.

This concept has been adopted at one United Kingdom cement works and has now been incorporated into the Code of Practice BS 5628.

Current Practice

Site made mortars are less common today partly due to an increased emphasis on accurate gauging and mixing. This has meant that factory produced mortars are now taking an increasing share of the market to the extent that on large sites today it is rare to find site mixing taking place. Factory made mortar may be one of the following types:

- Wet ready to use
- Dry ready to use (delivered in silos or bags)
- Lime sand for mortar

These different types of factory made mortars are discussed in greater detail in subsequent learning texts and they are briefly described below.

Wet ready to use

This is cement and fine aggregate (sand), sometimes with the addition of lime and contains a cement set retarder. It is gauged with water ready to use at the time of mixing in the factory, and remains workable for a specified period of time, generally up to 48 hours. It is normally delivered in bulk, using agitators or specialist vehicles and discharged into designated containers on site ready for use.

Dry ready to use

This is cement and dried fine aggregate (sand), sometimes with the addition of lime and/or admixtures. It is stored on site in bulk silos or bags generally the former in the United Kingdom and Ireland. The silos incorporate their own integral mixer, with provision for the connection of water and power. This means that only the desired amount is mixed at any one time.

Lime sand for mortar

This is pre-batched fine aggregate (sand) and lime, sometimes containing admixtures that require the addition of cement and water on site. The material is usually delivered to site in tippers, skips or jumbo bags.

Factory produced mortars manufactured under controlled conditions have advantages in both quality and consistency when compared to site mixed materials.

Glossary of Terms

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

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.
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.
Carbonation	-	Chemical reaction that occurs between the calcium hydroxide or the mortar matrix and atmospheric carbon dioxide.
False set	-	Premature stiffening of a binder in a mortar immediately after mixing that can be corrected.
Gypsum	-	Naturally occurring or chemically produced calcium sulfate dihydrate ($CaSO_4.2H_20$) from which binders are produced by various degrees of dehydration.
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.
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 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.

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 offered in varying sizes ranging from lumps to ground powder materials. They include calcium limes and dolomitic limes.

Bibliography

BS 5628-1:2005	Code of practice for the use of masonry- Part 1: Structural use of unreinforced masonry.
BS 5628-2:2005	Code of practice for the use of masonry- Part 2: Structural use of reinforced and prestressed masonry.
BS 5628-3:2005	Code of practice for the use of masonry- Part 3: Materials and components, design and workmanship.
BS 6100-9:2007	Building and civil engineering-Vocabulary-Part 9: Work with concrete and plaster.
BS EN 459-1:2001	Building lime- Part 1: Definitions, specifications and conformity criteria.
Mortar Industry Association	Data Sheet 20: Health and Safety Guidelines- Factory Produced Mortar for Masonry and Render.

Higgins, Bryan; *Experiments and Observations Made with the View of improving the Art of Composing and Applying Calcerous Cements and of Preparing Quick-Lime: Theory of These Arts; and Specifications of the Author's Cheap and Durable Cement, for Building Incrustation or Stuccoing, and Artificial Stone*, London: T. Cadell, 1780.

Smeaton, John; *A Narrative of the Building and Description of the Construction of the Edystone [sic] Lighthouse with Stone*, 2nd edition, printed by T. Davison for Longman, Hurst, Rees, Orme, and Brown, London, 1813.

Vicat, L.J; *A Practical and Scientific Treatise on Calcareous Mortars and Cements, Artificial and Natural*, translated by J.T. Smith [from the French edition of 1828], John Weale, Architectural Library, London, 1837.

Self-Assessment Questions

1	Where may gypsum mortars be used satisfactorily?
2	What problems arise where gypsum mortars are used in the incorrect location?
3	What are the basic raw materials from which hydraulic lime is manufactured?
4	What is plaster of Paris?
5	What is Quicklime?
6	How do quicklime and hydraulic lime differ?
7	What are masonry cements?
8	What is ash lime mortar?
9	What is Roman cement?
10	What are the three types of factory produced mortar?

Answers to Self-Assessment Questions

1	Gypsum mortars may only be used satisfactorily internally.
2	If gypsum mortars are used externally they will fail.
3	Hydraulic lime is manufactured from chalk or limestone and clay.
4	Plaster of Paris is calcium sulfate dihydrate.
5	Quicklime is calcium oxide.
6	Hydraulic lime contains siliceous components, quicklime does not.
7	Masonry cements are mixtures of Portland cement, filler or binder and an air entraining admixture.
8	Ash lime mortar is a mixture of lime and furnace ash.
9	Roman cement is a patented 18th century cement, made to look like historic lime mortar.
10	Wet ready to use Dry ready to use Lime sand for mortar