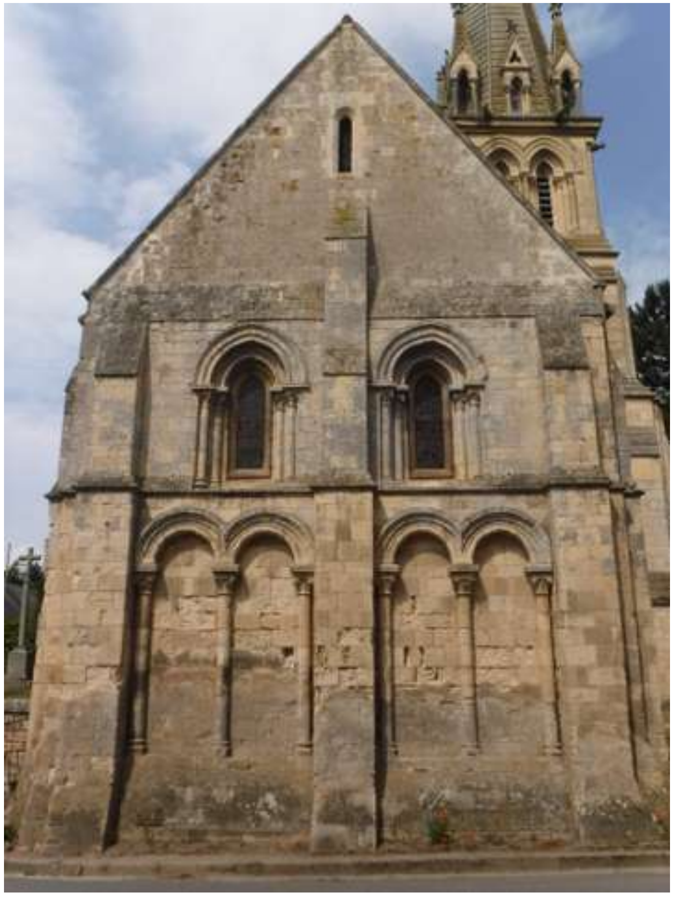
Earth-lime and Hot Mixed Lime Mortars



HES Symposium 30th August 2018 Stirling

Traditional mortars and their primary historic uses:

Earth mortars – clay-bearing sub-soil, improved or otherwise and well-tempered. Typically 12% clay, high volume of silt and of generally fine texture. Masonry construction, plastering, daubing, floors (with additives).

Earth-lime mortars, typically 10% lime (sometimes more) to a clay (and silt) bearing sub-soil as above; usually added as quicklime:

Masonry construction, especially of stone buildings across the UK and Europe until around 1800, though later in places; base-coat plasters. Usually pointed with lime rich mortar and finished internally with lime rich or pure lime, haired finish coat and limewash. Typically limewashed at the least.

Hot mixed air or feebly hydraulic lime mortars (the latter most particularly in the UK):

general building with stone and brick; repointing; plastering (except top coat); external renders. Feebly hydraulic in water works local to their sources, with and without pozzolanic addition.

Putty lime, slaked with minimum volumes of water and sieved:

Used on its own as a mortar for gauged brickwork, very fine stone ashlar, fine plaster finish coats. Very rarely as a binder before 20thC, when it was gauged with cement or gypsum to compensate for perceived weakness in binding properties.

Hot mixed moderately or eminently hydraulic lime mortars, either artificial (air quicklime and pozzolans) or NHL (typically blue lias in England and Wales, locally and then more widely after railways):

Underground or underwater works – docks, quays, sea-walls. Concrete footings.

Some above-ground construction late 19thC and early 20thC or where only locally available quicklime. Some gauging of hot mixed air lime mortars with NHL (eg Asturias). Immediately displaced by cement or cement-lime mortars for general use. And by Portland cement for concretes

Natural Cement (after 1796). Waterworks, cast mouldings, fortifications (mostly as a gauge for hot mixed common mortars), external renders, some repointing over earlier mortars. Often unsuccessful when used upon traditional fabric.

New Malton 1728, John Settrington. Vernacular and sustainable

York House, Malton, South, Garden Front. Hot Limewashed as per 17thC treatment. A rare survival of urban gentry house and garden of period. Earth and earth-lime mortars throughout. Earth-lime plasters have hay added.




Earth mortars, York House interior




Romanesque Tower of St John the Baptist, Whitton, North Lincolnshire, reputedly built on the site of a Roman Temple. Earth-lime mortars. Lime pointing mainly lost. STILL THERE, STILL PLUMB.



Cresswell Quay,
Pembrokeshire









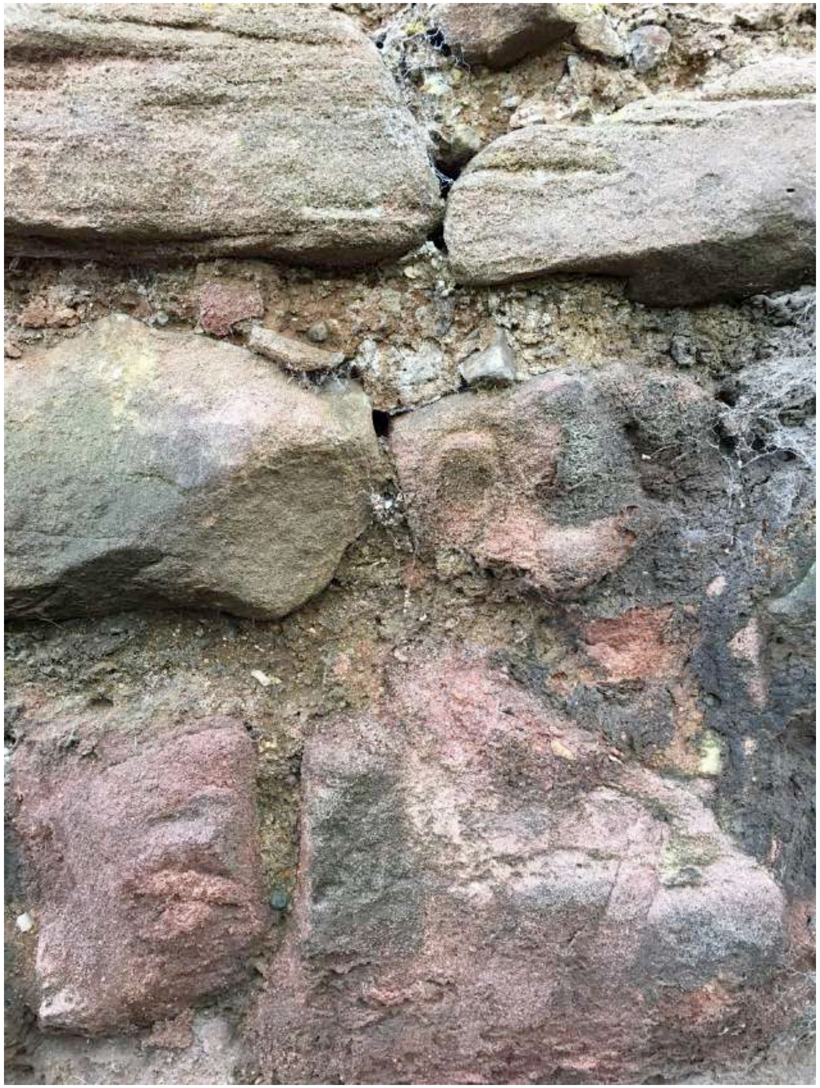

Asturias, NW Spain


Mileto, Vegas, Cristini, Garcia Soriano 2014

La tapia en la Península Ibérica

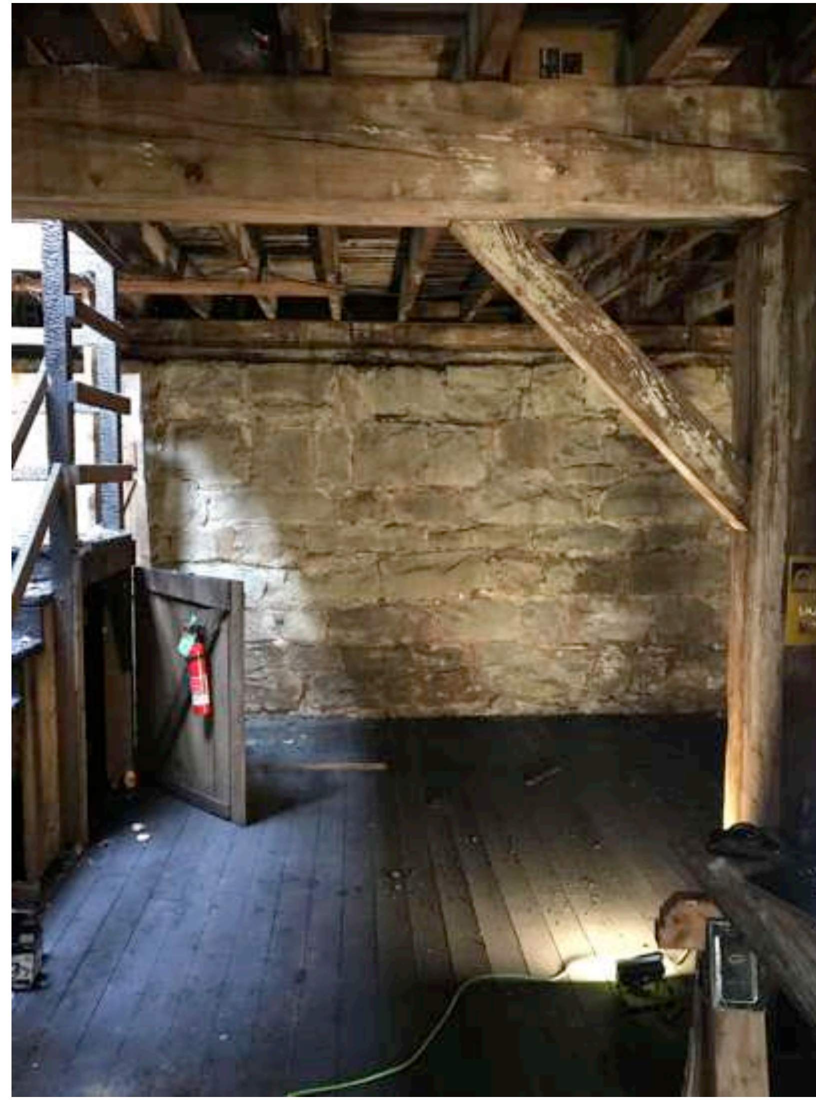
Tapia con cal en la masa

Log walls with earth chinking (with quicklime?) and renders,
Cold Lake, NE Alberta, Canada.
Original timber cladding lost.



Roman Lighthouse, Dover, England.

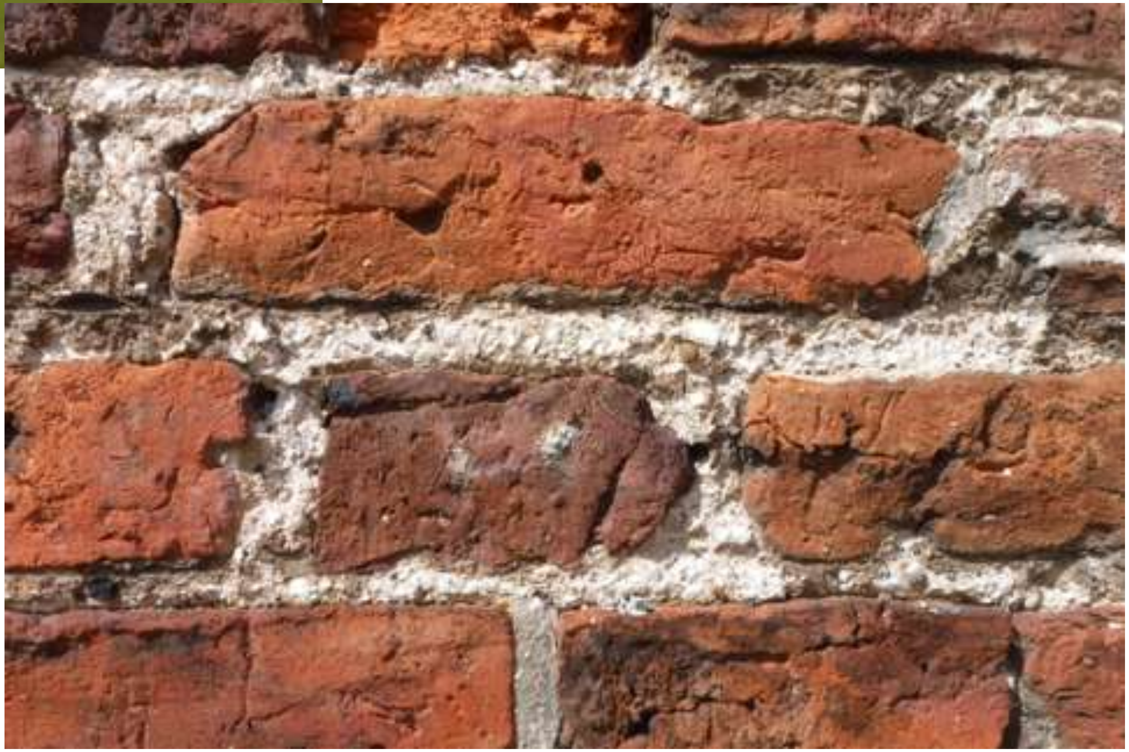
Hot mixed mortars with pozzolan



Butte Creek Corn Mill, Oregon, 1873

Boynton Hall, East Yorkshire.
16th, 17th and 18th Centuries.

Hot mixed chalk lime mortars used hot. Pointed with same, but with added wood ash.

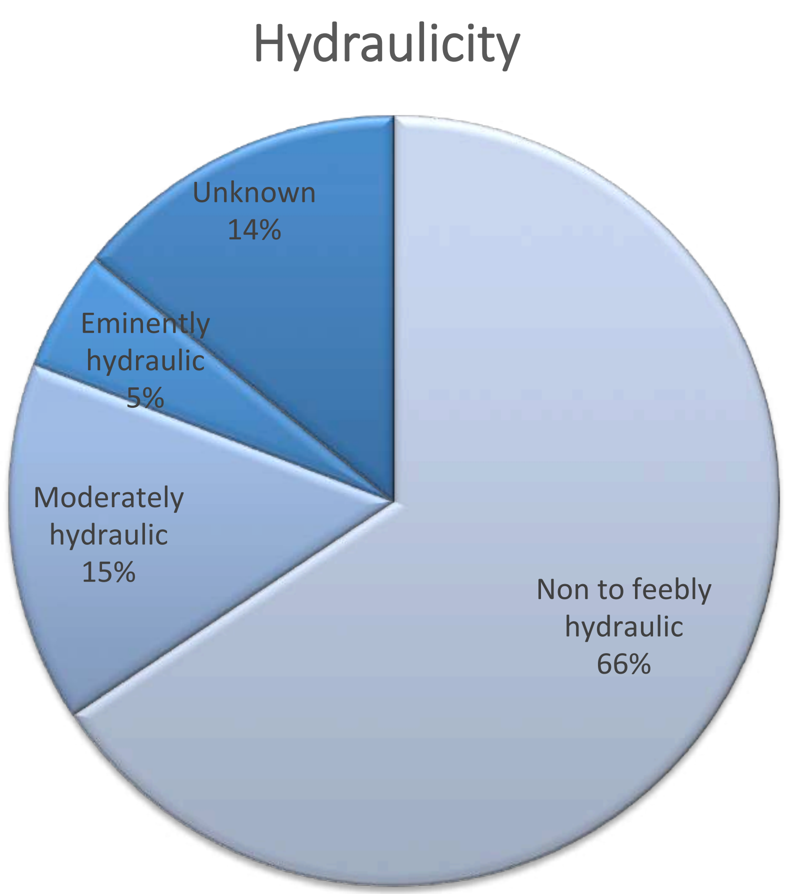


Late medieval brick and hot mixed lime mortar, Hull, UK; brick and mortar from Frank Lloyd Wright building, Chicago

These mortars were fit for purpose and durable

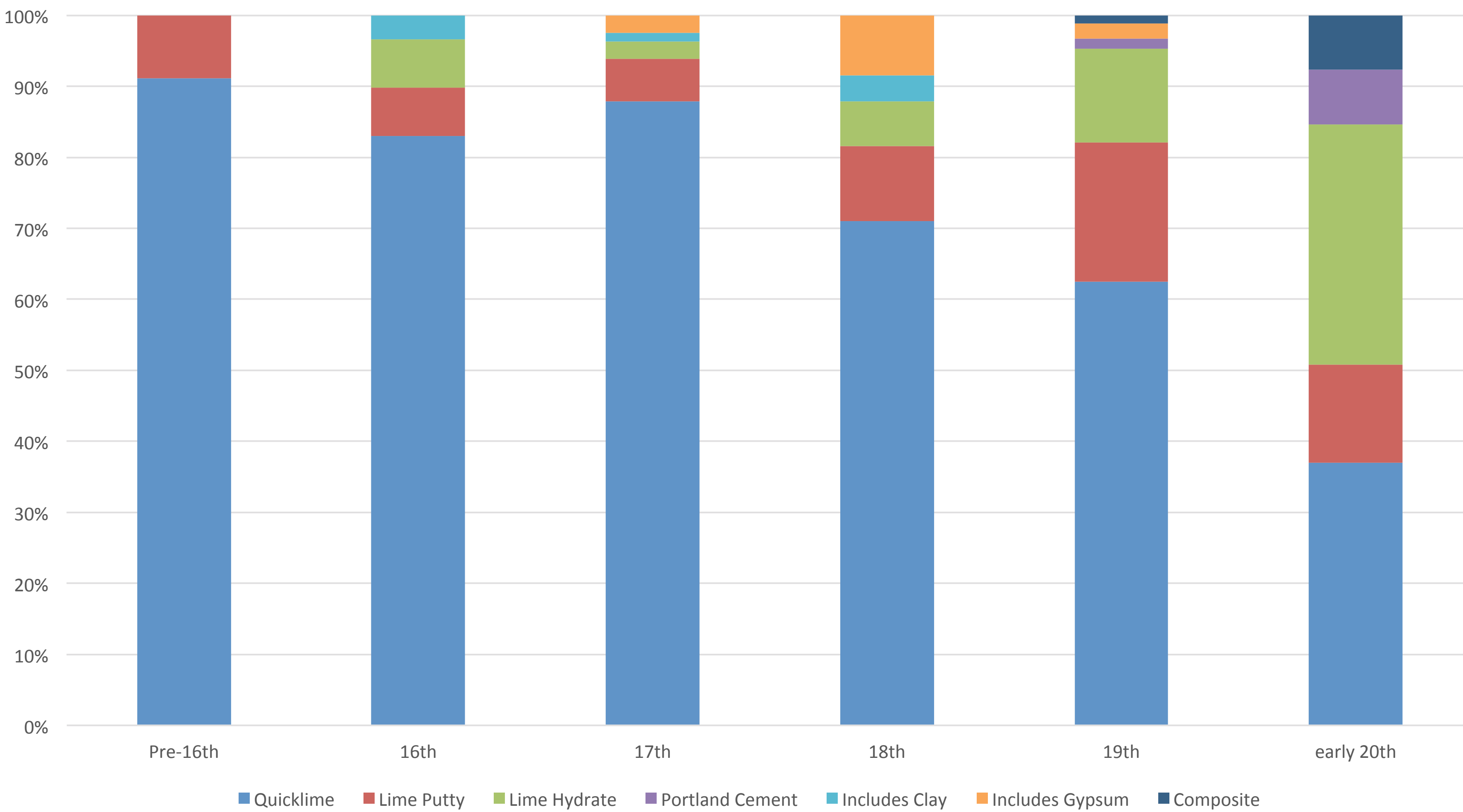
Carnegie Library, Calgary, Alberta. 1909-10. Hot mixed air lime with small (primitive) portland cement addition.

The Scottish Experience



Information from 962 Scottish mortar samples from the Scottish Lime Centre's Historic Mortars Database
Adapted by Craig Frew from a presentation by Anne Schmidt, HES Hot-Mixed Mortars Seminar, February 2017, Edinburgh.

Binder type use per century



Research Anne Schmidt courtesy Jessica Snow, Historic Environment Scotland

In the ordinary constructions, we prefer to employ fat limes and sand to gather stones and to build walls because this mortar is abundant and cheaper. In humid places, in particular underwater, wherever we wish to stop the action and infiltration of water we use a mortar that hardens underwater or we use some 'béton'. Hassenfratz 1825

We differentiate mortars thus: fat lime, used for raising walls, hydraulic lime for foundations, substructures, basement and works meant to be immersed. Slow or prompt cement for underwater works or in very humid places. Champly 1910

“ I can confidently recommend our lime for harling, as it is used for this purpose all over the country and it is preferred to any other lime in Scotland for building Wet Docks, bridges and any other buildings exposed to water, and for making concrete drain tiles…” (letter from Charlestown lime works to James Gregg Esq 1843) - SLCT 2006

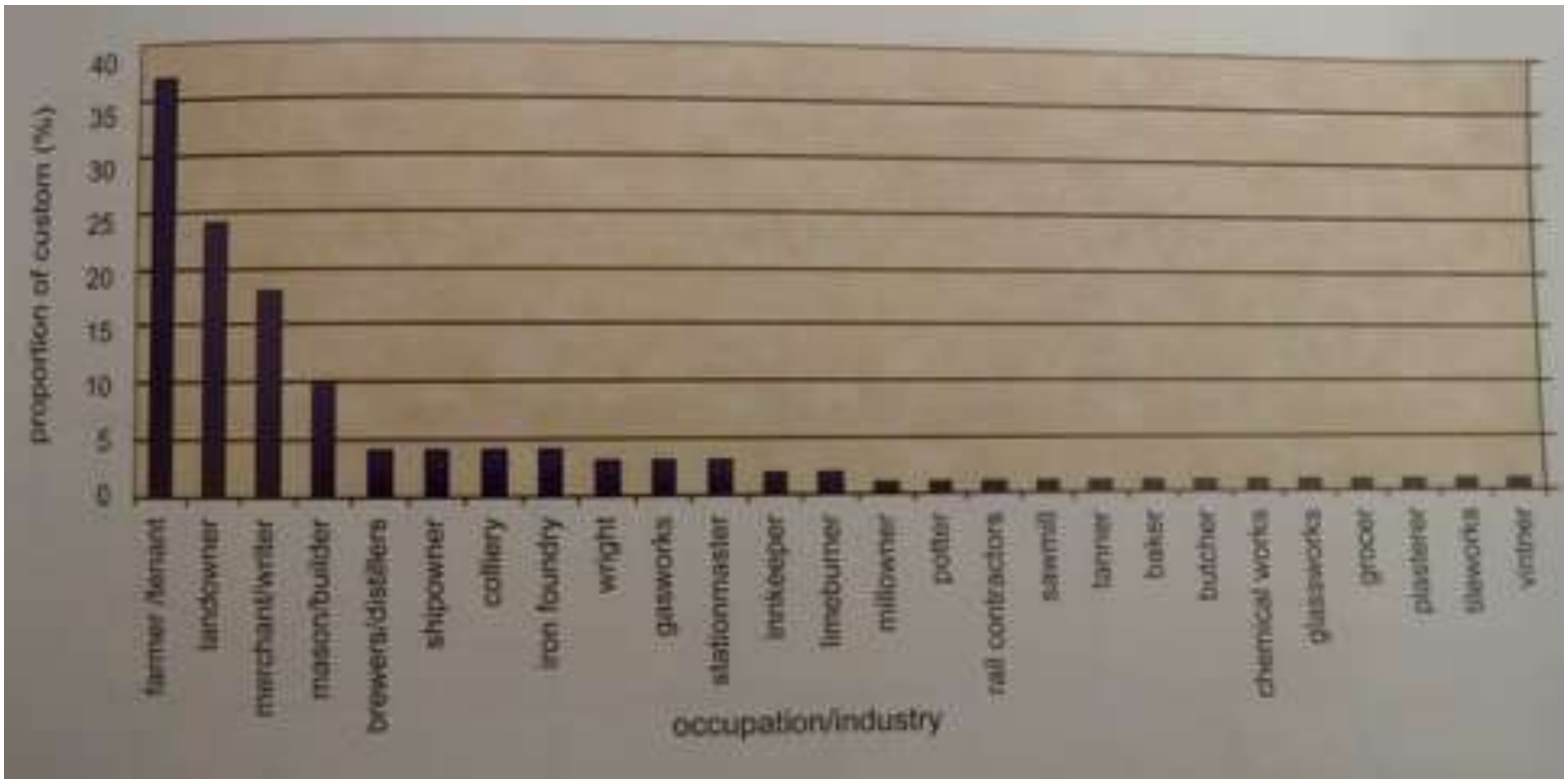


Figure 8.1 The Distribution of known occupations amongst customers for shell lime (1773-1863)

Smeaton long since explained**, " It is not to be wondered at that workmen generally prefer the more pure limes for building in the air, because being unmixed with any uncalcareous matter, they fall into the finest powder, and make the finest paste, which will of course receive the greatest quantity of sand (generally the cheaper material) into its composition, without losing its toughness beyond a certain degree, and requires the least labour to bring it to the desired consistence; hence mortar made of such lime is the least expensive; and in dry work the difference of hardness, compared with others, is less apparent."…** The workman, however, preserves his empire…

It is a difficult matter to alter the practice of those who have grown grey in exalting " practical experience," and in the comfortable persuasion that the bricklayer knows best how to make good mortar, and can be trusted to make it….

I look confidently forward to the day in which we shall feel quite independent, as respects mortar making, of the workman's traditions.

Scott Royal Engineer 1862

Lime. This being derived from an almost pure carbonate of lime, slacks with great energy and the evolution of heat; forms a fine paste with water; **admits the addition of a great deal of sand; is more easily laid on by the mason; and therefore, is the most economical for common purposes. On all these accounts it is regarded as the best kind of lime; and sought after the most**. For it is not generally known in this country, that it does not form so hard and durable a mortar as the next variety.
Hitchcock 1842 Geology of Massachusetts

Magnesian Limes – limes containing over 5% (usually 30% or over) of magnesia. These limes are all slower slaking and cooler than the high calcium limes…and they appear to make a stronger mortar. **They are, however, less plastic or 'smooth', and in consequence are disliked by workmen. Kidder/Nolan 1920**

Sometimes, the workers reject….types of lime which would be preferable to the ones they are accustomed to using. Thus, in the region of Calvados, **half of the limekilns produce hydraulic lime for the consumption of farmers to enrich their fields whereas this same lime is not at all used by the masons,** because it does not expand as much as the others and because it hardens quickly, therefore the workers would have to change how they work…. Biston 1828

Chemical purity is not inauthentic – it is the optimal, predictable base from which a multitude of different mortars with different characteristics may be made quickly, efficiently and in a controlled manner.

The St Albans Lime, manufactured by C H Fonda, St Albans Vt
Is absolutely the PUREST LIME IN THE UNITED STATES…
99 ½ per cent Pure Lime.

It is particularly adapted to Paper Makers’ and Bleachers’ use, as it is unequalled in pureness, and strength…**For Masons’ use it is the best and cheapest, as it takes more sand than other lime** and makes **A STRONG WHITE PLASTER.**

Put up in 200lb and 300lb barrels… the barrels are well coopered and nailed, are made of spruce and will not fall to pieces by handling.
(Rolando 1992)

For the production of ordinary mortar for general use by builders, either a fat lime, a lean lime, or a hydraulic lime (Lias lime) may be used. **Fat limes are preferred**, but lean limes can be employed if they do not slake too slowly; they are regarded less favourably by some builders, because they have a much smaller sand carrying capacity, and-the resulting mortar does not "work" very smoothly. Hydraulic limes are stronger in cementing power, and **behave like a mixture of fat lime and Portland cement.**
Searle (1935) *Limestone and its Products.*

Binders routinely used at Chatham Dockyard:

Most building above ground with chalk lime at 1:3; subsequently repointed as necessary with feebly hydraulic (Dorking or Halling) lime or with natural cement (Sheppey or Harwich).

Water limes: Previously fat lime within wharf walls, faced up with fat lime plus pozzalan (from Italy) or trass from Holland. Now (1838), natural cement throughout.

Blue Lias (‘the strongest water limes of this country’), necessarily mixed at 1:2; Dorking or Halling lime - Halling from near Rochester.

‘Three cubic feet of sand to one of Dorking or Halling lime, will be a good proportion for making mortar with those limes, **which approach very nearly to pure lime’** (Pasley 1838 p15).

The typical lime:aggregate proportion of most traditional lime mortars is 2:3 or 1:2. if not richer in lime than this.

‘Customary’ for specified mortar: aggregate proportions to be expressed in lump lime (before slaking): aggregate, unless otherwise stated (Pasley 1826). In fat and feebly hydraulic limes this will give 2:3 after slaking.

Vicat indicates 1 part of slaked lime to 2 parts aggregate. This might be just slaked hydrate or stiff, dough-like putty made by adding just enough water to the lump lime plus a little more– not putty as we know it – ‘drowned’ in a surplus of water, which all authors says delivers a weak material with less bond.

Hydraulic, **‘WATER’ limes were NEVER mixed at 1:3 – typically at 1 part quicklime: 2 aggregate**, hydraulic limes expanding much less than fat limes on slaking, or not much at all. 1:1 was also commonly specified, particularly for eminently hydraulic natural cements.

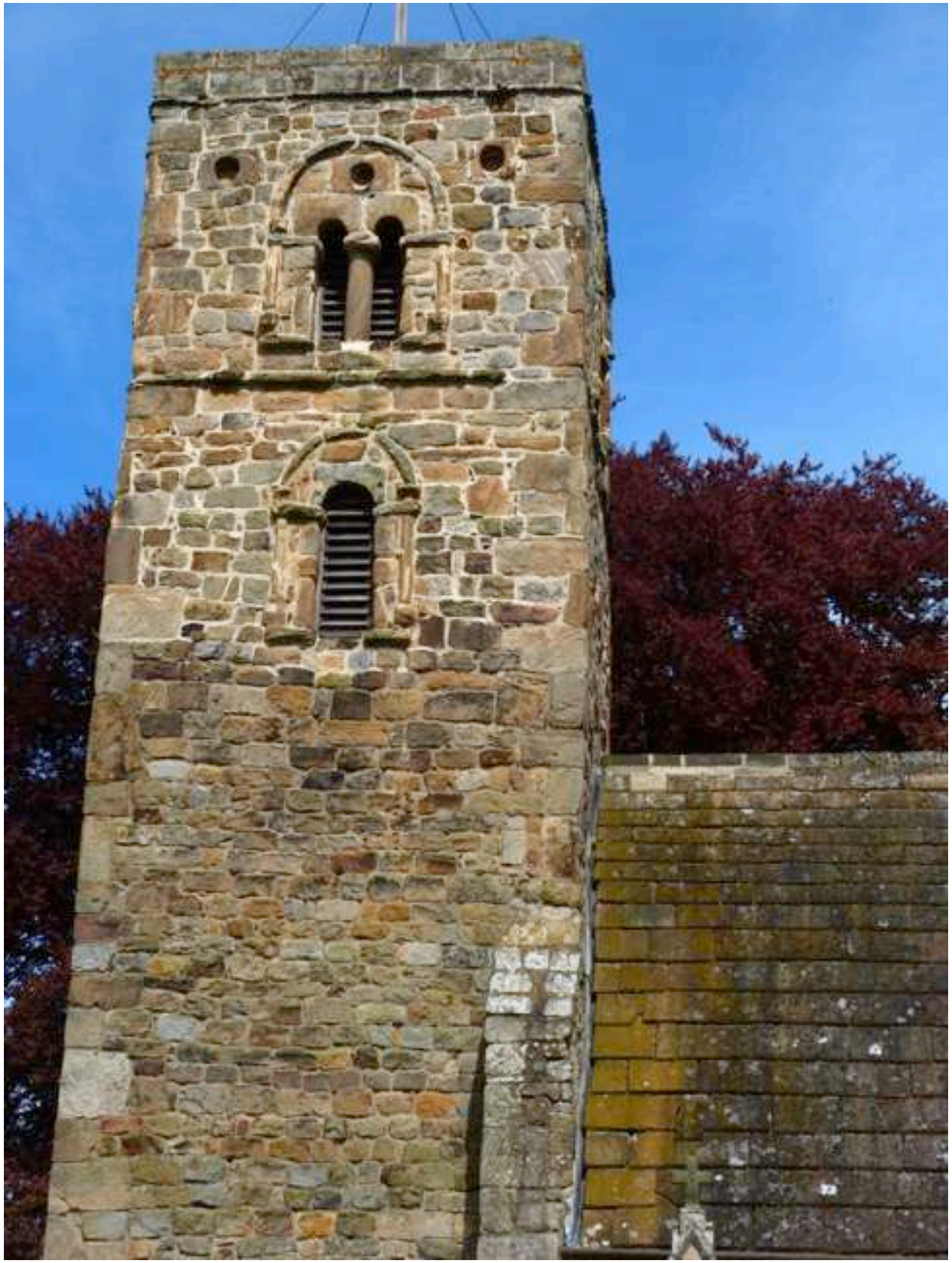
The objective was to get as much sand into the mortar without compromising workability and performance. WHAT MASONS LIKED TO USE AND DID WHAT THEY WANTED BEST WAS THE STANDARD.

1:3 slaked lime to aggregate never found or specified historically. Became the norm with cement-lime mortars, the cement compensating for the reduced lime content. Even so, 1:2:9 weaker than a 2:3 or 1:2 fat lime: aggregate mortar (but gains initial set much faster) and considerably less strong than a 1:3 modern NHL:sand mortar.

Until quite recently, opinions **among engineers** were divided as to the effect of time upon the quality of paste of fat lime, preserved with suitable precautions for future consumption. General Treussart entertained the opinion that they **should be made into mortar and used soon after their extinction.** This idea finds few advocates at the present day**,**

<u>although the practice in this country conforms to it with</u> singular <u>unanimity</u>.

[which is to say that, in practice, and <u>craft practice</u> in the US, hot mixing was generally by the first method and taken directly to a mortar and used soon after being made]. Gillmore 1886



The plaisterers, who use a finer kind of mortar made of sand and lime, observe that their plaster or stucco blisters, when it contains small bits of unslaked lime; and as their purpose is to work their stucco to a smooth surface, and to secure it from cracking, or any such roughness…**and as the hardness of the stucco is not their chief object, they very properly <u>keep their MORTAR a considerable time before they use it,</u>** to the end that the bits of imperfect lime, which passed through the screen, may have time to slake thoroughly.
Higgins 1780

Now, while all this precaution is taken in regard to plastering, in making mortar for building the lime is slaked and made up at once, and it is frequently used within a day or two. But this is not all**. Limes which are unsuitable for plasterwork, known as hot limes**, and which, when plasterers are obliged to use them, must be slaked for a period of - not three weeks, but more - nearly three months before using, and are then not quite safe from blistering, ***<u>are the limes mostly used for building purposes.</u>*** Millar Plastering Plain an Decorative 1898

Slingsby N Yorks 2009; Fylingdales 2011-12

In all the regions of France and Italy I have traveled to study the way of building, I questioned workers, the ones who seemed the smartest. I found that their knowledge came, from a practical side, from use and experience. There are many differences in materials; it is not possible to prescribe specific methods, because every rule requires uniform qualities and properties in the materials, which does not happen. **A worker of long experience knows how to judge if the mortar is fat enough, beaten enough, if it has the right consistency - he almost never makes a mistake; he crushes and mixes the different materials until it feels right**. This is why it is not enough to propose methods, we need to train workers to understand and modify them on account of the materials and buildings intended to be built. There is an infinity of things that cannot be said nor prescribed in advance. **We can only indicate the general precautions to take for the most important operations, which are the methods of slaking lime and the methods of mixing it with sand and cement** ***(pozzolan)*** **to make a good mortar.** **Rondelet 1803**

Moxon 1703

First: That the Morter be made of well-burnt, good Lime and sharp Sand, and that it have a good proportion...to wit, **to one Bushel of Quicklime, a Bushel and a half of sand**

Secondly**: when you slack the Lime, take care to wet it everywhere a little, but do not over-wet it, and cover with sand every laying, or bed of lime...so that the steam or Spirit of the Lime, may be kept in, and not flee away, but mix itself with the Sand, which will make the Morter much stronger than if you slack all your lime first, and throw on your sand altogether at last, as some use do....**

Thirdly, that you beat all your Morter with a beater three or four times over before you use it, **for thereby you break all the knots of lime that go through the sieve** and incorporate the sand and lime well together, and the air which the beater forces into the mortar at every stroke conduces very much to the strength thereof

Mechanick Exercises; or the Doctrine of Handy-works applied to the Arts of Smithing, Joinery, Carpentry, Turning, Bricklayery

The several kinds of Mortar used in Buildings are Eight, viz

*Inside and Outside mortar made of Lime and Sand
*Terrace Mortar, made of Lime and Terrace
*Brick-Dust Mortar, made of red Stock Brick dust and Lime
*Bastard Terrace, made of a Smith's Forge Ashes and Lime
*Pargetting Mortar, made of Lime and Horse-dung
*Furnace Mortar, for Furnaces, Ovens, Kilns, etc made of Woolwich Loam or Windsor Loam only
*Plaister Mortar, made of calcined Alabaster
*Fine Mortar, called PUTTY, **for rubbed and gaged Works,** made of Lime only.

Langley 1750

Inside Mortar: 1 Load of Sand put 1 ½ Hundred of Lime, **which mix up together <u>as the Lime is slacked</u> in small Quantities.**

Out-Side Mortar: (sharpest, cleanest sand) The Proportion that the Lime should have to the Sand, is as 2 is to1, viz. **2 heaped Bushels of <u>unslacked</u> Lime to 1 ditto of Sand**
Terrace Mortar is **chiefly used in Walls exposed to Water, as to Rivers, Ponds, Cisterns, Bog-Houses, Cold Baths &c…**The best Terrace Mortar is made with two Bushels, &c**<u>. of hot Lime</u>**, and one Bushel &c. of Terrace **.**
Brick-dust mortar: To two heap'd Bushels of <u>hot Lime</u> put one heap'd Bushel of Brick-dust made from red Stock Bricks, which mix, beat, and work up, as before directed for Terrace.
Likewise**, sea coal/forge scale** mortars.

These pozzolanic 'water limes' would leave little free lime available if all silica and alumina combined with the lime.



“The vaulting of St. Paul's is a rendering as hard as Stone; it is composed of Cockle-shell-lime well beaten with Sand; the more Labour in the beating, the better and stronger the Mortar.” (Wren 1708)

The due beating of the mortar is, however, of *great* consequence…a degree of beating sufficient to give it all *possible* consistence and toughness before it is used, is in reality *indispensible*…The customary allowance for tarras mortar beating, first and last, **is a day’s work of a man for every bushel of tarras, that is, for two bushels of lime powder with one bushel of tarras….(108 kilograms or a wheelbarrow-full)…” (Smeaton 1791)**

“To form mortar, **fresh slaked lime** is mixed up with a sufficient quantity of proper sand, water enough being added to make it into a tough paste. In mixing the lime and sand together, considerable labour should be used; as it is found that the beating the mortar well, so as to incorporate the materials thoroughly, is essential to make it of good quality, and fit for the mason or bricklayer.” (Webster 1844)

“To half a Bushel of slaked lime mix a Bushel of clean sharp road or wash(ed) sand which will be quantity sufficient for a Days use, this must be beaten in small quantities by two Labourers for three hours at Least & they must keep on beating it…”(Wilkins 1799).

To slake lime by the ordinary method, put it upon a dry horizontal surface, and form a ring (enclosure) around it, with the intention of afterwards mixing with it the materials which will constitute the mortar. These 'basins' are commonly made with the same sand with which it will be mixed. It is better to form a shallow pit with sides of stonework, when the works will be of long duration, the same is also more convenient when slaking hydraulic limes.

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Espinosa, 1859. Spain.

When we mix powdered quicklime and sand in the proportions of one part of lime to 2 of sand and we moderately wet the mix while kneading it, we obtain a mortar which sets quicker than the first one and hardens better. But we should avoid letting it dry too quickly.

Martin 1825

If we mix two parts of sand freshly extracted from the river with one part of powdered quicklime, it will create a very fatty and adherent mortar. De la Faye 1777.

Pozzolanic additives identified by John Smeaton in Narrative of the Building of the Edystone Lighthouse (1756).

pumice stone (volcanic ash);
terra puzzolana (ash from Mount Vesuvius);
trass (volcanic ash)
minions - calcined ironstone
coal cinders (coal ash);
brick and tile dust
wood ash.

Others: smith's forge ashes; iron filings.

Modern pozzolans: slate dust/micro-silica; calcined china clay (metastar/argical); pfa.

Smeaton concluded the minimum pozzolan for a water lime was one third part of the aggregate so 1 part fat quicklime: 2 parts sharp sand: 1 part pozzolan.

Some feeble hydraulic activity may be achieved with hot mixing of iron-bearing limestone or sandstone aggregates or clay-bearing sands.

For work in the air, less than 5% <u>**of the slaked lime is required. More than 5% is usually unnecessary and no more than 10% should be used.**</u>

BRICKLAYER. The bricks to be sound, hard, well burned square stocks, equal to a sample to be approved by the Architect and deposited with the Clerk of the Works ; the whole of the brickwork to be laid English bond, and no four courses to exceed 11 ½ inches., and every course flushed up solid in mortar. **The mortar to be composed of stone lime and sharp river sand, in the proportion of three measures of sand to one of lime, the whole well mixed in a pug-mill.** The lime to be kept in an inclosed shed, and no more mixed at one time than is sufficient for the day's consumption.

Signed Charles Barry (Architect), Henry and John Lee 08.11.1837

All the mortar for **rubble masonry** to be composed of **2 measures of fresh, well-burnt lime to 5 measures of sand.** All the mortar used in **the brickwork** to be of the best fresh burnt brown (Hull) lime, **1 part lime and 3 of clean, sharp pit sand.**

The whole to be properly mixed together dry and a sufficient quantity of water added, the whole to be ground under edge runners or in pug mills.

The mortar to be used as hot as possible and no more mortar to be mixed in one day than can be used on the same.

The pointing mortar – 1 part best brown lime, 1 part sharp forge ashes, 1 part iron scales.

Mixed and ground under the edge runner to a fine paste as required **for immediate use.**

Contract and Specifications for the Parliament Buildings Ottawa Fuller & Jones Architects 1859. (Toronto Public Library)

The Bath freestone is of the pure calcareous kind, and it is remarked that when it is walled with this kind of mortar(blue lias), which is *frequently,* if not generally, used for the purpose, **the joints are more permanent, and resist the weather better, than the stone itself…** Smeaton, account of Edystone etc p115 1791

Repointing(left) and rebuilding (right) of hard Pennine sandstone, NHL 3.5 1990s

Archbald Moffat House, Moffat, Dumfries & Galloway.

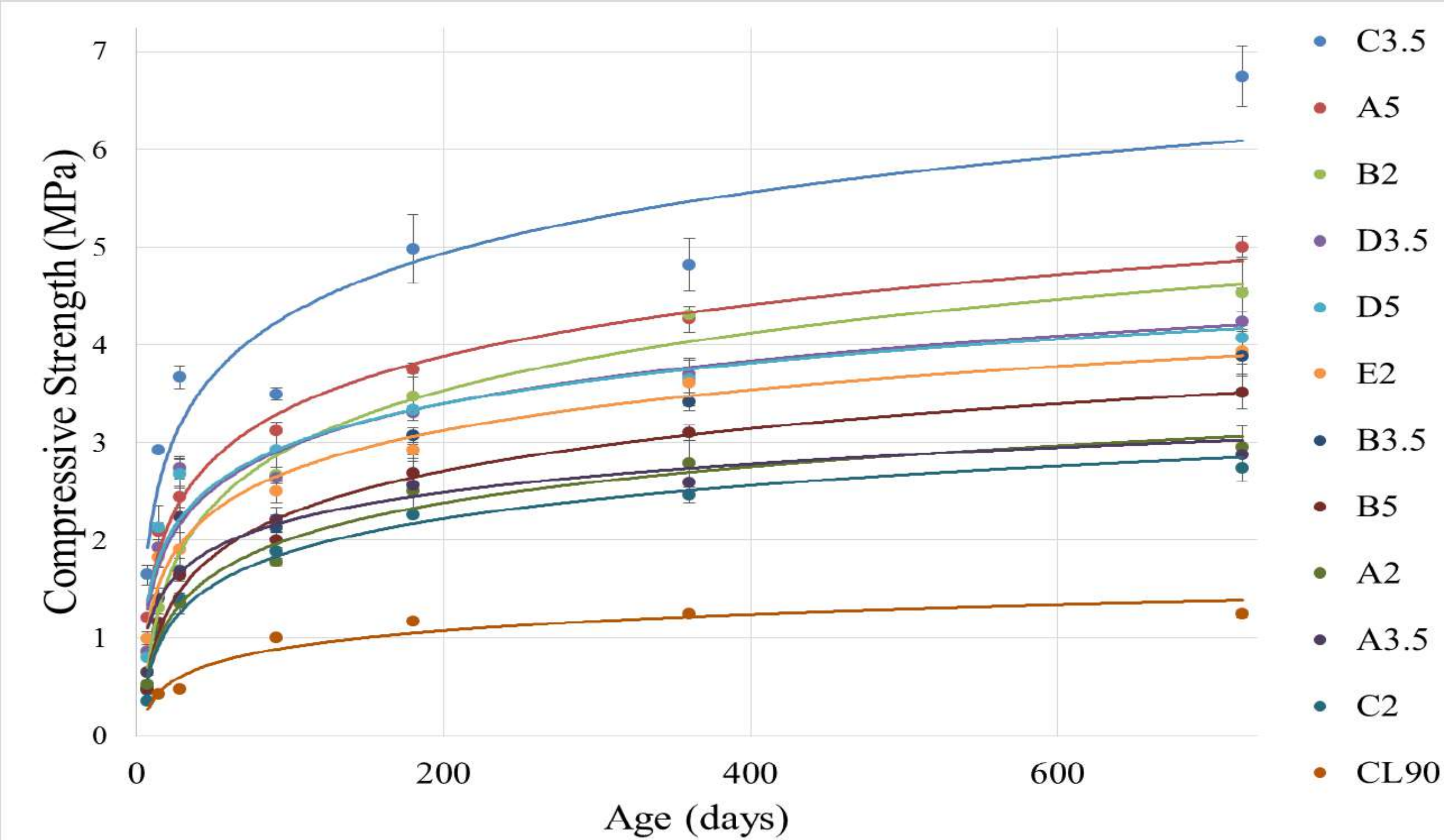
NHL 5.0 (left); hot mixed air lime (below)

Bleeding of calcium carbonate from NHL 5 used to bed ridge stones in late September. None from hot-lime mortars emplaced at same time. Fuller and more rapid carbonation. Straw Builders for Natural England.

Chalk lump wall collapse after rendering with NHL 3.5.

Image Henry/Stubbs

720 day compressive strengths. Mixed by volume.

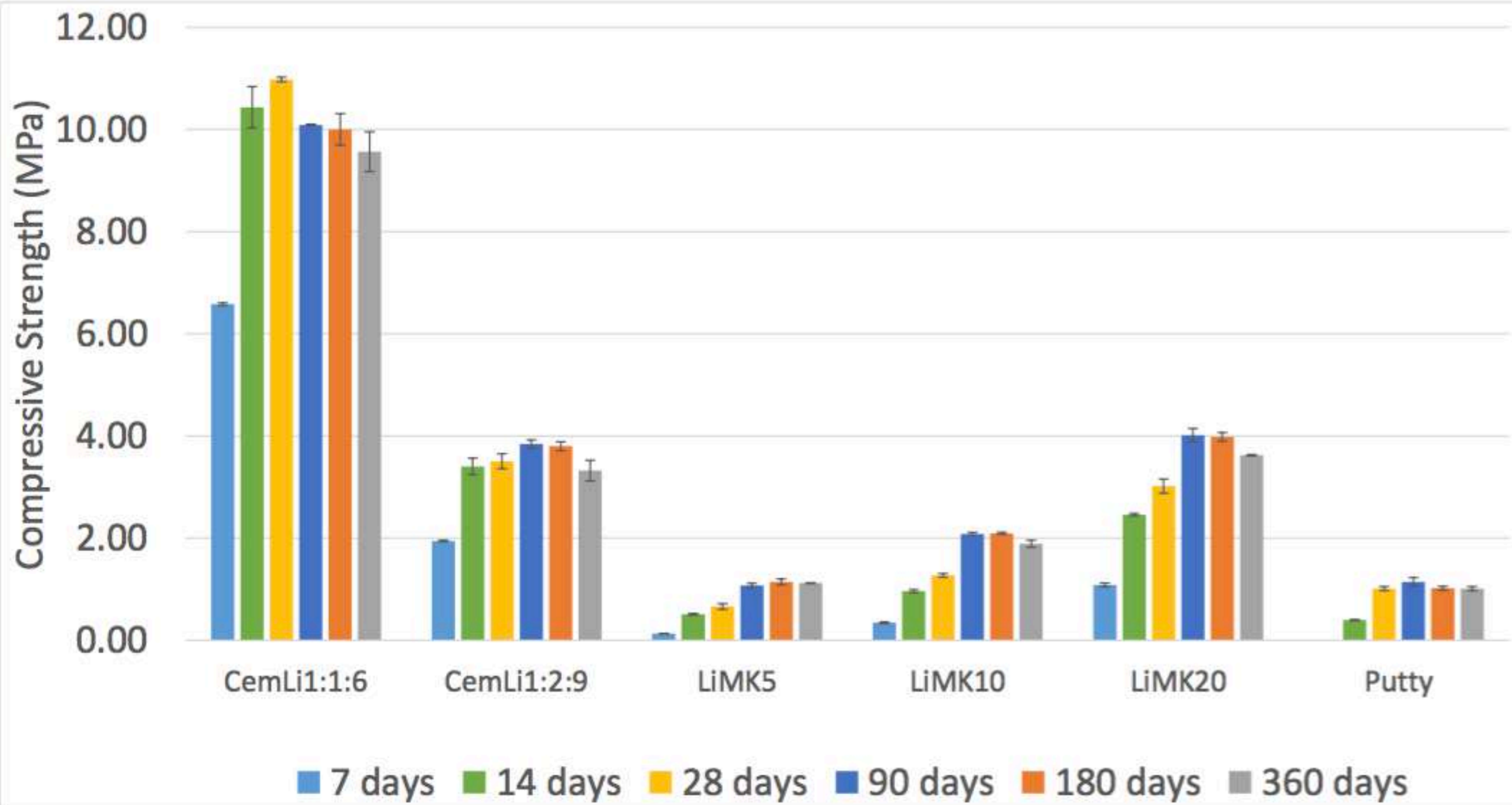


Historic England

Weymouth College, March 2017

Alternatives to NHL mortars

Formulated mortars



Historic England

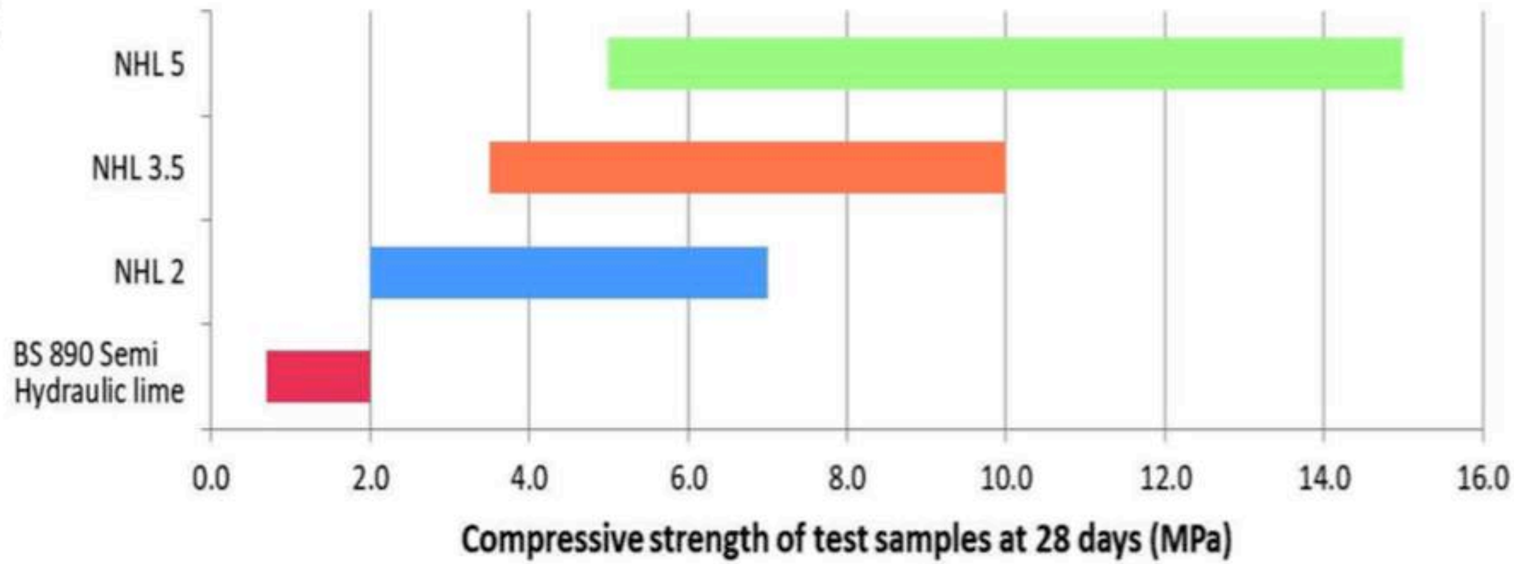
SPAB: November 2017

BS 890 (1966)

- Semi-hydraulic lime (grey lime)

BS EN 459 classification (1995)

- NHL 2
- NHL 3.5
- NHL 5



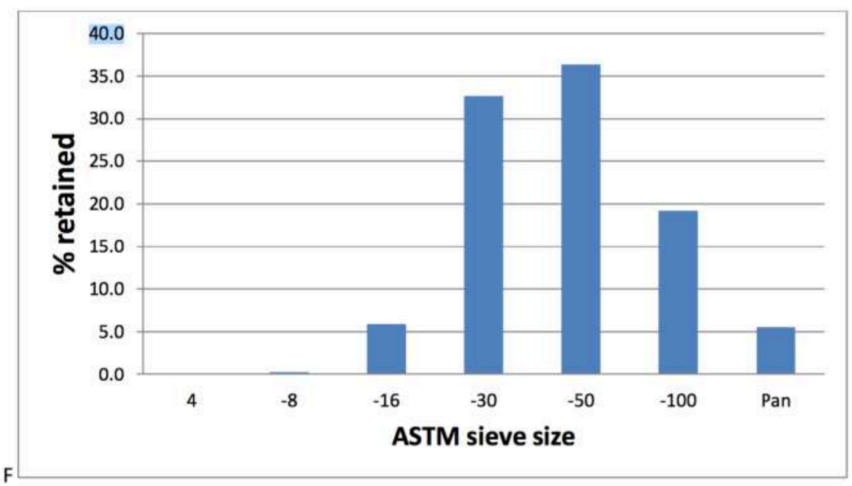
APT Mortar Workshop – October 2017

Table 2 Compressive Strength Development

Mortar Mix	Vicat Cone (mm)	Air (%)	Compressive Strength(MPa)			
			28d	56d	90d	6 months
P1	32	3.5	-	0.75	1.01	1.55
P2	22	3.75	-	0.80	1.20	1.94
W1	12	-	0.90	1.28	2.02	-
W2	24	4	0.82	1.53	1.98	-
W3	18	5.25	0.80	1.48	2.05	-
W4-X	19	7.5	0.22	1.22	1.27	-
W4	31	5.5	-	1.21	1.21	-

Note: 1MPa = 145 psi

W1 1:3 Graymont kibbled quicklime from Quebec: Nesbitt sand
W2 1:3 Graymont powdered quicklime ditto; Nesbitt sand
W3 1:3 Indiana limestone fired on site: Nesbitt sand.



Mortar ought to serve at least three purposes: it ought to form **a soft but gradually hardening bed to receive the various building-materials, so that these shall obtain an uniform bearing notwithstanding the irregularity of their surfaces**; in the second place, it ought to prevent the passage of wind and rain through the joint of the walling; and, lastly, it ought to have adhesive and cohesive strength enough to bind the component parts of the wall into one solid mass. Sutcliffe 1899

Mortar strength…is often greatly over-emphasised to the detriment of other **essential mortar properties**, such as **workability, water retentivity, and bond-strength**…and those builders who strive for high or maximum mortar strengths usually obtain inferior mortar for normal, above-grade masonry construction. Boyton & Gutschick 1964

Where walls of greater thickness are used or where 8-inch walls are used for a one-story building and where reasonable care is taken to prevent undue loads, the use of straight lime mortar should be made optional.

Recommended minimum Standards for Small Dwelling Construction. Report of the Building Code Committee. 1923. Government Printing Office, Washington.

Construction industry globally contributes towards 54% of global warming.

Cement production contributes 8%.

Optimum effective porosity will only come from carbonated free lime
Only free lime may take back CO_2 emitted during firing.

Free lime in an air lime: 90 – 96%
Free lime after 5% pozzolanic addition: 80 – 86%
Free lime in historic Blue Lias NHL: 60 - 72%
Free lime in a 1:3:12 mortar: 75%
Free lime in a 1:2:9 mortar: 66%
Free lime in a typical NHL 2.0: 35%
Free lime in a typical NHL 3.5: 25%
Free lime in a typical NHL 5: 15%
Free lime in typical new build mortar of 1 part cement: 5 parts sand: ZERO.
Addition of air entrainers compromises bond.
Addition of water repellents destroys effective porosity.

Typical compressive strength of an air lime mortar after 3 months: 0.7 – 1.3 Mpa, but up to 2 Mpa with a hot mixed air lime and sometimes more than this.

Hot mixes made to historic lime: sand proportions are economic to produce; they offer mortars of eminent workability, **encouraging good and efficient workmanship;** they offer optimal water retentivity and excellent bond strength as well as consistent extent of bond. They demand much less after-care than other forms of lime. They are tenacious. They offer appropriate durability so long as traditional building details are respected and maintained. The addition of small volumes of pozzolan enhances strength, durabilty and speed of set **without compromising workability** or other essential characteristics. They offer high effective porosity, keeping building fabric dry and thermally efficient and reducing the need for repair or replacement of building elements.

In pursuit of carbon reduction, lime rich, hot mixed mortars are not only the most appropriate like-for-like and compatible mortars for the conservation and repair of traditional buildings, but for sustainable, mainstream new build as well.

Marine Guardhouse, Cole Island,
Victoria BC. Royal Engineers, 1864




Chicago - rebuilt with hot mixed air lime mortars; These buildings repaired with the same in recent years





Quality
watch
repairs
Carphone


Carphone Warehouse
O LET

Old (1862) and new (2014) hot-mixed lime mortars; 1 **local** quicklime: 3 sharp, granitic silver sand. Nearest NHL 3,000 miles away, having already crossed the Atlantic.

SOME TECHNICAL APPENDICES

Traditional (and universal) slaking methods:

the ‘ordinary’ or ‘common’ method - lump lime slaked in a mortar box, pit or basin of sand to reduce to a size that may be readily mixed with aggregate. Just enough water added (to slake to a hydrate), or just enough and a little more (to slake to a thick, dough-like paste). Mixed with sand as soon as slake is substantially complete. Can be screened, along with the (dried) sand, if dry-slaked. Both guarantee necessary temperature of the slake and avoid both ‘burning’ (and subsequent chilling) or ‘drowning’ of the lime.

Direct mixing of pulverised or powdered quicklime with sand. Generally considered to give the ‘best’ and strongest mortar. Incremental addition of water or immediate addition of 1 to 2 ½ volumes of water for dry-slaked or ‘wet-slaked’ mortar.

Aspersion or immersion - lump lime sprinkled or held under water and tipped out to form a dry hydrate, which can be sieved before mixing with sand, whilst still hot (best case), or after cooling. May be stored in humid environment, or transported longer distances. Aspersion common for hydraulic limes.

Air slaking - uncommon, but used for some more hydraulic limes (Blue Lias, around Bath, e.g.).

Sand-slaking - as above for dry-slaking. Allowed to cool before mixing - common for more hydraulic limes, just enough water added to slake the free lime, but not enough to activate hydraulic set. Covered, usually with sand and left to allow for late-slaking (less likely with fat limes) and may be stored up to 10 days before making up to a mortar.

Putty - a slight excess of water added in first instance to guarantee necessary slaking temperature; subsequently diluted to allow passage through a grill or a sieve, removing unslaked lumps. Later, lump lime added to 2 volumes of water (BS Code of Conduct 1951). Mixed hot, gives very adhesive and cohesive mortar, but typically used on its own for specific purposes – often whilst still hot. Rarely as a binder. Romans preferred to leave in a pit to remove lumps – though 3 months, not 3 years, the norm – mainly for fine stucco finish coats.

Mixing any (except sand-slaked) of these mortars whilst lime still hot delivers eminently workable, adhesive and cohesive mortar with excellent water retentivity. If lime is left to cool before mixing, mortars tend to be shorter, requiring much beating to bring to good workability.

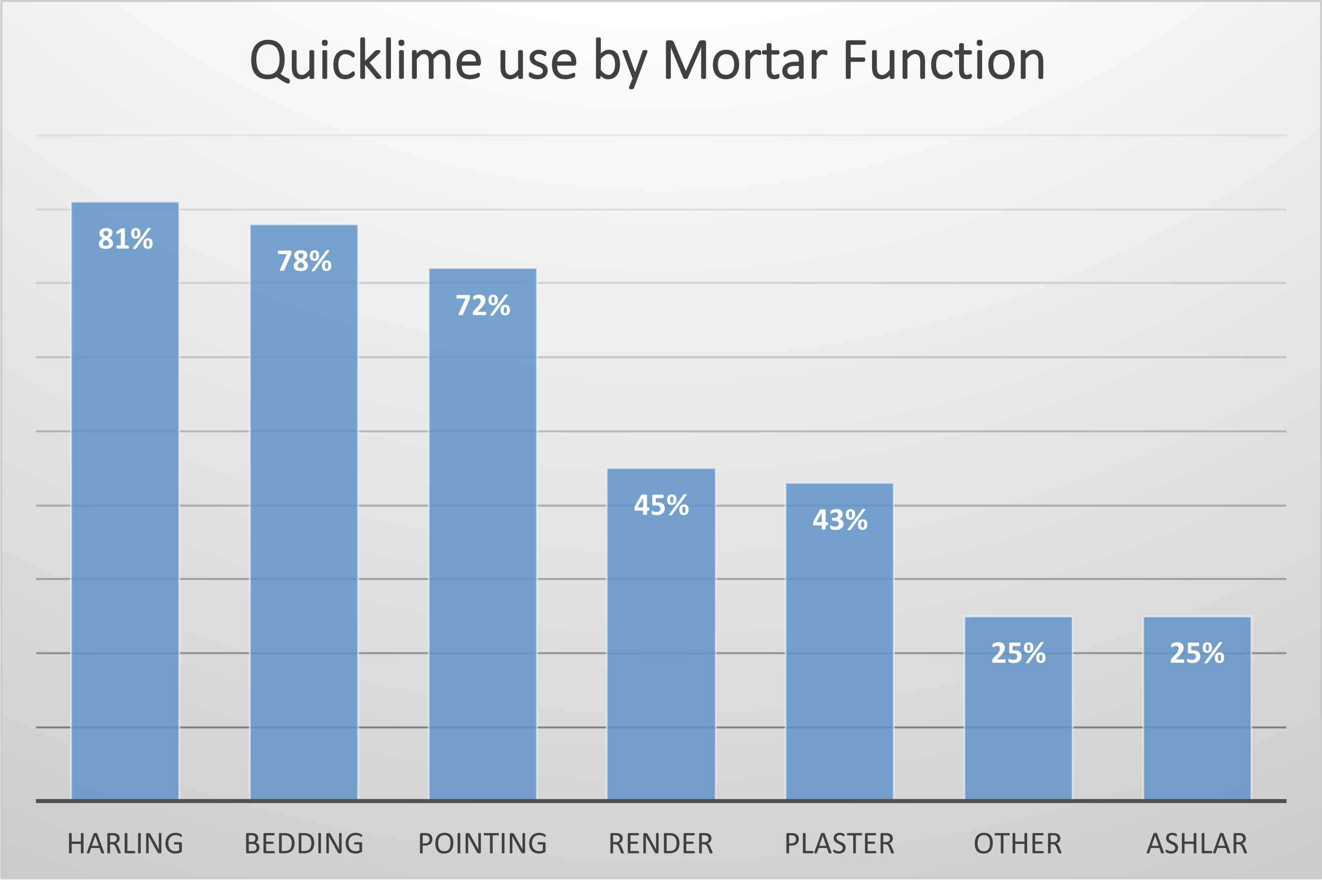
Yemen. Putty lime, slaked with a slight excess of water to a dough-like consistency. Traditionally beaten for 3 days; these days more like one. The lime is used ONLY for lime-wash upon interior and exterior earth plasters

“The term putty, better known as the cement for fixing glass in windows, is applied in brickwork to a very different substance, which is nearly the same **as hot lime grout**, It is made by **dissolving in a small quantity of water, as much hot lime as, when slaked,** and continually stirred up with a stick**, will assume the consistency of mud**…It is then sifted, in order to remove the unburnt parts of the lime, and **should be used without delay.**

It is only proper for gauged brickwork, or for the ornamental outside work of brick walls….” (9). Pasley 1826)

"Decreasing water to binder ratio reduced the shrinkage of mortar, consequently reducing shrinkage cracks during mortar drying. In addition, decreasing the water-to-binder ratio increased the strength of the lime mortar, especially the compressive strength…**decreasing the water-to-binder ratio also tends to reduce the porosity of the mortar in the range of pores greater in size than one micrometer *(reducing proportion of ineffective pores)*…**an excessive amount of mixing water lessens the density of the mortar, decreases the strength of mortar and retards the carbonation process….high-calcium lime and lime mortars are thixotropic materials and…an intensive or long period of mixing improves the lime-putty and lime mortar consistency and workability…a long time spent mixing a small amount of mortar using a mixing paddle (chopping and beating) or using a roller pan…can convert stiff coarse stuff into a smooth and workable mortar with a very low water-to-binder ratio" (Michoinova D & Rovnanikova P 2008).

The Scottish Experience



Information from 3,407 mortar samples from the Scottish Lime Centre's Historic Mortars Database

Adapted by Craig Frew from a presentation by Anne Schmidt, HES Hot-Mixed Mortars Seminar, February 2017, Edinburgh.

1. The Plasticity Index (or degree of plasticity of the soil) decreases sharply – as much as three- or more fold.
2. The Plastic Limit generally increases and the Liquid Limit decreases. (The difference between these two values is the Plasticity Index).
3. The soil binder (clay and fine silt sizes) content decreases substantially because of the agglomerating effect of lime.
4. The lineal shrinkage and swell drop markedly. Fine-grained clays without lime have greatest volume change in wetting and drying cycles as evidence of their instability.
5.Lime and water accelerate the disintegration (breaking up) of clay clods during the pulverisation construction step, resulting in coarser, more friable soils that can be manipulated more readily, thereby expediting construction.
6. Unconfined compressive strength increases considerably – in varying amounts, but as much as forty-fold.
7. Load-bearing values, as measured by California Bearing Ratio (CBR) and triaxial tests, increase substantially from two to ten times
8. In swampy areas or with soils exceeding optimum moisture content, lime facilitates drying the soil by increasing both the plastic limit and optimum moisture content of the soil. This expedites construction under wet conditions.
9.A lime-stabilized subbase or base forms a water-resistant barrier by impeding the penetration of both surface and capillary moisture. Exposed but compacted lime-stabilized clay layers shed water readily during rains, thereby minimizing construction delays. This factor also provides some degree of protection against disruptive frost heaving.
BOYNTON 1980 THE EFFECTS OF LIME ADDITION IN CONTEXT OF SOIL STABILISATION

…….Walls consisting of ‘shell’ – as I prefer to call it…- should be constructed of seasoned wickerwork and reed matting; this is not a work of any distinction, but was often used by the plebians of ancient Rome. The wickerwork is smeared with a mixture of **mud and straw** which has been **kneaded for three days. It is then dressed…with either lime or gypsum**, and finally adorned with pictures or reliefs. If you mix your gypsum two to one with crushed tiles, it will have less to fear from being splashed. If mixed with lime, its strength will be enhanced. In the damp, frost or cold, **gypsum will be entirely useless. Vitruvius**

…There are other kinds of masonry construction – some where **mud, not lime,** is used in the joints, and still others where the stones are fitted together without the support of any mortar….

Any stone to be smeared with a **mortar of clay** should be cut square, but **most importantly it must be dry;** the bricks most suited to this are fired ones, or even better, unfired ones that have been well dried out. **A wall of unfired brick is very healthy for those who live within,** completely impervious to fire and little disturbed by earthquakes; on the other hand, unless it is reasonably thick, it will not be capable of of bearing the weight of the flooring. For this reason, Cato recommends that we incorporate masonry pillars in the structure to support the beams.

…Some assert that mud, if it is to be used as mortar, should be **like bitumen, and they consider the best mud to be that which dissolves slowly in water, is difficult to wash off the hands, and contracts markedly on drying. Others prefer it to be sandy, being easier to mould. This sort of work ought to be coated on the outside with lime, and on the inside, if you wish, with gypsum, or even silver clay.**

Alberti 1460

In summer-time wee usually fetch clottes out of the field to make morter on, but in winter wee eyther shoole up some dirte togeather, in some such place as is free from gravle and stones, or otherwise wee digge downe some olde clay or mudde-wall that is of noe use, or else grave up some earth, and water it, and tewe it. Morter neaver doeth well unlesse it bee well wrought in, viz.; except it bee well watered and tewed; and it is accounted soe much the better if it bee watered over night, and have nights time to steepe in. In makinge of morter, yow are first to breake the earth very small, and with your spade to throwe out all the stones yow can finde, and then to water it and tewe it well, till it bee soe soft that it will allmost runne; then lette it stande a while till the water sattle somethinge from it, and it will bee very good morter….(Best 1641).

When they are to make a new barne floore, they grave it all over, and then rake it all over with hey rakes or iron waine rakes till the mowles be indifferent small; then they bringe water in seas and in greate tubes or hogsheads on sleddes and water it till it bee as soft as morter, or almost as a puddle; then lette it lye a fortnight, till the water bee settled in that it beginner to waxe harde again, and then beate it downe smooth with broad flatte peeces of wood. When a floore is decayed , that there are holes worne, they usually leade as many coupe loades of red clay, or else clottes from the faugh field, as will serve, but they must not leade theire clottes from such places where the clay is not mixed with sands; and then when it commeth, theire manner is for one to stand will a mell and breake the clottes small, another hath a showle and showleth the mowles into the hole, the third and all the rest have rammers for ramming and beating the earth down into the hole….then they water it, and lette it lye three or foure dayes to mawme, for if they shoulde ram it presently it would cleam to the beater: we use to digge and leade clay for our barne from John Bonwickes hill.

Henry Best, East Yorkshire 1641

But though burning of Bricks be necessary for building of Houses, &c. yet a Wall or House may be made with un-burned Bricks; for which end, 1. Let your Earth be high and well temper'd, smooth and well moulded, as already hinted, and this done in the hottest Season; then dry'd and turn'd after the manner of Brick-making; only it must be longer exposed to the Sun and Elements, till they become hard and tough, and then use them after this manner: **Take Loam or a Brick-earth, and mixing therewith some good Lime, temper them very high till they become tough, smooth and glewy**; let the Wall of your House be one Brick or one and an half thick, and your unburnt Bricks being laid in this well-temper'd Mortar, they will cement and become one hard and solid Body, as if the whole were but one entire Brick or Stone:

When you have raised your Wall 4 or 5 Foot high from the Foundation, let it dry 2 or 3 Days before you proceed further; then build thereon 4 or 5 Foot more, making the like Pause as before, and so proceeding till the Wall is finished: Afterwards temper **some of the same Earth the Wall was made of,** with a little more Lime that was used for the Wall, which you must be sure to temper very well, and with this Mortar plaister all your Wall well on the other side, which will keep off the Weather; and if you would have it more beautiful, it's only putting more Lime to it and less Loam; and when this is dry, you may colour and paint it, with Red, Blue, or any other colour that you like best. Worlidge & Bailey 1726

“An array of mud plasters…are concocted with various grades of laterite and supplemented with quantities of chopped straw, dry rice husks, and cow manure; less commonly used are tiny pebbles, ash, earth from termite mounds, powdered baobab fruit, or karite butter. The added ingredients improve the mud’s durability and water resistance. Most plasters are prepared and used immediately, but others are fermented in pits or piles for several days or weeks and command high prices. The breakdown of organic matter liberates colloid particles, and the fermentation strengthens the mud’s cohesion and repellent properties. In the process, the mud typically changes colour from shades of ochre and red to dark grey. The smell of fermented mud…is especially putrid, and this plaster is reserved as a final coat for interior and exterior surfaces.”

Marchand T ‘The Masons of Djenne’ 2009, p 123

When Making mortar ordinary lime mortars are thus made by hand, it is customary and convenient to slake the lime by the first method described, and **in no greater quantity than may be required for immediate use**. The operation should be conducted under a shed. **The measure of sand required for the " batch" is first placed upon the floor, and formed into a basin for the reception of the unslaked lime. After this the latter is put in, and the larger lumps broken up with a mallet or hammer; the quantity of water necessary to form a stiff paste is let on, from the nozzle of a hose, or with watering-pots, or even ordinary buckets. The lime is then stirred with a hoe, as long as there is any evolution of vapor, after which the ingredients are well mixed together (p202) with the shovel and hoe, a little water being added occasionally if the mass be too stiff.** At this **stage of the operation, it is customary to heap the mortar compactly together, and allow it to remain until required for use. When circumstances admit, it should not be disturbed for several days, and during the period of its consumption should be broken down and " tempered" in no larger quantities than may be required for use from day to day.**

Gillmore QA (1864) PRACTICAL TREATISE ON LIMES, HYDRAULIC CEMENTS, AND MORTARS. CONTAINING REP0RTS OF NUMEROUS EXPERIMENTS CONDUCTED IN NEW YORK CITY, DURING THE YEARS 1858 TO 1861,

The Mixing Operation **is carried out either in a pit or on a close-boarded platform of wood. The sand and lime are measured into the correct amounts to give the required proportion, and the sand is formed into a circular bank on the platform. The lime is then placed within this bank, or ring, and water is sprinkled on with a hose-pipe, which is best suited to the purpose when fitted with a rose or some form of sprinkler. Steam will be generated during this sprinkling operation, and <u>when this has ceased,</u> the lime is stirred with a 'larry'…<u>The sand is then shovelled, starting from the outside of the ring first, on to the lime, the larrying operation being continued the while.</u>** When thoroughly mixed, the mortar is left to stand for a week or so before being used, when it should be 'buffered', or beaten up again with the larry and shovel. For use, it is customary to add more water, as the wetter it is, up to a point, the easier it is to handle, but this should not be over-done.

Newbold/Lucas Modern Practical Building 1950

“ The setting of lime mortar is the result of three distinct processes which, however, may all go on more or less simultaneously. First, it dries out and becomes firm, Second, during this operation, the calcic hydrate, which is in solution in the water of which the mortar is made, crystallizes and binds the mass together….Third, as the per cent of water in the mortar is reduced and reaches 5%, carbonic acid begins to be absorbed from the atmosphere. If the mortar contains more than five per cent this absorption does not go on. While the mortar contains as much as 0.7 % the absorption continues. The resulting carbonate probably unites with the hydrate of lime to form a sub-carbonate, which causes the mortar to attain a harder set, and this may finally be converted to a carbonate. The mere drying out of mortar, our tests have shown, is sufficient to enable it to resist the pressure of masonry, while the further hardening furnishes the necessary bond” Richardson quoted in Kidder/Nolan 1920

Four modes of measuring lime have been employed…

The most ordinary mode is to measure it in lumps, as it comes from the kiln; a second method is to measure it in slaked lime powder; a third, in quick lime powder; and a fourth, in slaked lime putty or paste.

The first method is usually employed by builders, when their works are not on a large scale, and is always supposed to be adopted, if nothing be said to the contrary….

In ordinary practice, the cohesion of the mortar is greatly impaired by too large a proportion of sand, **which should not in general exceed two volumes, for every volume of lime paste**.

In preparing ordinary mortars, it will be convenient to place the unslaked lime upon a plank floor, under shelter from the sun and rain, and then (without covering) to surround it with the proper quantity of sand. The water, requisite to produce a thick paste, previously ascertained by experiment, should be poured on the lime with the aid of watering pots of known capacity. The lime must then be well stirred, so as to expose every part of it to the action of the water, and afterwards left to itself, until the vapors have ceased entirely. The ingredients may now be thoroughly incorporated by means of the hoe and shovel. If the mixture is made with difficulty, a little water may be added, but only enough to produce a homogeneous mass…. Wright (USA) 1845

The problem with BS EN 459-1:2010 Building lime

- Classes do not equate with historic classifications
- Standard mortar mixes - not representative
- Testing at 28 days - not representative
- Curing regime for NHL 2 suppresses strength development
- Classification is too wide

→ Little realistic information for end users

BS EN 459 is not suitable as a tool for specifying NHL binders

The degree of burning is more important than with other types of lime, for clinkering and fusion occur more readily and a much higher proportion of clinker may be formed. This clinker is comparatively inert unless the particle size is reduced by grinding; if it is extremely finely ground, a 'natural' cement results.

It is unusual for an eminently hydraulic lime to be supplied in the hydrated form, because of the difficulty in ensuring the complete hydration of the oxide whilst at the same time retaining the efficiency of the hydraulic components. Geeson 1952

(US) National Bureau of Standards Circular No.30:

"This question of the strength of a mortar is apt to be given undue weight. Since masonry is assumed to weigh 150 lbs/cu ft, then the compression load at the bottom of a wall will be 150 over 144 times its height in feet. A mortar with a compressive strength of 100 psi should, according to this reasoning, be able to carry a wall 100 x 144 over 150 = 96 feet or about 9 stories. A mortar joint in a wall may possibly be 9" wide by 30' long by ½ " thick. In the joint the ratio is 9 divided by ½ = 18. If a mortar has a strength of 100 psi when tested in the form of a cube, it should theoretically have a strength of 1800 psi when laid up in a wall.

Quoted in Boynton & Gutschick 1964

Mortar strength…is often greatly over-emphasised to the detriment of other **essential mortar properties**, such as **workability, water retentivity, and bond-strength**…and those builders who strive for high or maximum mortar strengths usually obtain inferior mortar for normal, above-grade masonry construction.

Before the advent of Portland cement in the United States…(1886 on), all of the masonry mortar was a straight lime-sand mix that inherently possessed very low compressive strength. True, some of the lime produced was derived from impure limestone that had varying (but usually faint to moderate) hydraulic qualities; other pure limes were mixed with crude, unwashed sand containing clay that acted like a mild pozzolan with lime. While both of the latter types of mortars possessed slightly more strength than the pure ('fat') lime- clean sand mixes, all would be regarded today as extremely weak in compressive strength (ranging between 50 to 300 psi *.34 – 2.0 Mpa)(*in 28 days).

Boynton & Gutschick 1964

Of the numerous factors contributing to sound masonry, bond between the units and the mortar is generally recognised as a very important factor, perhaps *the* most important…***bond strength and extent of bond…***Principal reasons for lime's superiority over portland cement in producing intimate and durable bond are its higher degree of plasticity and water retention, and its greater fineness and inherent stickiness, which permits joints to be filled more readily and completely. Its ability to heal minute cracks and fill minute voids (autgeneous healing) also contributes to better bond.

Boynton & Gutschick 1964

(high free lime content in the binder is crucial to this effect)

Palmer, as long ago as the early 30s completely discredited (laboratory freeze-thaw tests as a measure of real world durability), claiming it was misleading and unrealistic. He contended, in fact, **that the most frost resistant materials are usually the most dense, but that they tend to remain excessively wet in the wall. " The most weather-resistant wall is one that remains relatively dry even though the materials composing it have poor records in laboratory freezing and thawing tests"**…the analogy between freezing a saturated mortar cube and a monolithic wall structure is ridiculous.

Boynton and Gutschick Durability of Mortar and Masonry 1964