Plastering in the UK and Europe was based upon three main ingredients: earth (clay-bearing sub-soil, improved with sands as necessary, often with organic additions, such as ox hair or hay); sand or limestone aggregates *and quicklime.*

These are, of course, general categories. A sub-soil is made up of sands, silts and clays in varying proportions. Sub-soils will everywhere reflect the underlying geology, so that sub-soil over limestone geology will naturally contain limestone aggregates, as well as sands and silts. Elsewhere, the aggregates might be of sandstone, of schist or of granite. The underlying geology will, therefore, contribute significantly to the character and performance of an earth mortar.

Some sub-soils will be fit for purpose just as they are dug. The harrowed fields of southern Spain might as well be composed of collapsed and levelled rammed earth structures, so similar do the earths appear to those raised up into the buildings that populate the landscape. The sandy earths of the Vale of Pickering in North Yorkshire, laid down upon the floor of a post-glacial lake may be mixed with water and/or quicklime and used without improvement and typically throughout North Yorkshire, the same earths may be found on the walls of dwellings as lie just beneath the surface of surrounding fields or gardens. In many cases, however, a sub-soil will need improvement before it may be used. If it carries too much clay, then sand will need to be added during mixing – if not to improve workability, then to reduce its shrinkage after application. That said, the addition of quicklime and the addition of organic matter, such as hay, or hair, will allow the use of sub-soils richer in clay, and shrinkage is less of an issue in mortars for mass wall construction than for plastering.

Typically, traditional earth mortars differ from modern, eco-build earth mortars in having a high proportion of fine sands and silts and a lower proportion of coarse sharp sands. Modern 'clay mortars', made with just clay and sharp sand lack the complexity, as well as the tenacity of historic earth mortars, indicating that the presence of high volumes of silt is as significant to their character and performance as is clay and coarser aggregates.

(York House Graph)

Until at least 1800 in the UK, and until later elsewhere and, most certainly in North America, plastering systems included both earth-lime mortars and lime mortars, applied in a unified craft practice. Until 1800, the majority of stone buildings of all status were built with earth or

earth-lime bedding mortars, pointed to the exterior with lime rich, hot mixed mortar and plastered within with an earth-lime basecoat over which was laid a haired, lime rich finish coat of between 4 and 8 mm. If the intention of the builders was that the building would be rendered, then pointing and dubbing out would be performed with the same earth-lime mortar as the build. In the earlier periods, it is likely that exterior renders systems reflected interior plastering systems, to be later displaced by thoroughgoing lime-sand render coats. There remains scant evidence for this, but some remains in parts of North Yorkshire and in Asturias. Although for adobe construction,

"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

(Yeomans Course, York House windows, Asturias photos)

Similar systems predominate in Spain, Italy, France and Ireland in our observation and were doubtless as common elsewhere. In Spain, a thick, probably hot limewash was applied to a basecoat of earth or earth-lime. Ukrainian migrants carried the routine use of similar mortars into northern Alberta during the later 19thC, used in conjunction with timber-framed farmsteads and earth bedding mortars remained common

in masonry buildings in Georgia, USA as late as the 1930s (Chapman 2014).

The quicklime addition to a clay-bearing subsoil might be as little as 5%, delivering twice this proportion upon slaking with the earth mortar. It was sometimes higher than this. Alex Gibbons has had great success in Cumbria using exterior renders of equal proportions of lime and earth, hot mixed with quicklime. The lime finish might be pure lime plus hair, or include very fine aggregate, such as chalk or other limestone dust.

Lime-sand plasters had been common enough before 1800, but the enclosure of common lands in Britain, and their general consolidation in the hands of the ruling class, meant that earth for building was no longer so readily available to the common man, or even to the bourgeoisie, at the same time as lime-sand stucco'd interiors had increased in status and desirability throughout the 18th century, increasingly displacing previously panelled or wainscotted interiors.

The use of quicklime continued, however.

The routine use of previously slaked putty lime as a binder, as opposed to its being used on its own for fine finish coats, was a mainly 20th C development and was predicated upon the assumption that small volumes of Portland cement (for building) or of opc or gypsum (for plastering) would be added before use – speeding the set and compensating for the loss of 'tenacity' and of binding qualities offered by quicklime drowned and run to putty, which had always been understood historically. In Roman practice, quicklime would be slaked to a dough-like putty and laid down for late slaking to take place, before being used for fine finishes. In later practice, quicklime would be slaked by adding a slight surplus of water, diluted when the slake was complete and then run through a sieve to remove unslaked lumps before use for finish coats or for very fine masonry joints, as in gauged brickwork or the finest ashlar. Or else, quicklime would be added to a small excess volume of water, constantly stirred, until slaking was complete and subsequently diluted and sieved. In most cases, it would be used on its own, without aggregate addition. Gypsum had been a common addition to pure lime putty finish coats and the finishes of run-in-situ mouldings in the past, but had not generally been added to the previous sand-lime coats, though Gilmore allows it in 1860s USA when fast setting was essential (see below). Millar talks about running previously dry-slaked lime to a paste for plastering binders in 1897 (see below), whilst observing that traditional hot mixing persisted in Scotland, as well, in my observation, as in northern England and elsewhere.

The conditional 20thC practice of slaking quicklime to a liquid putty led into the key assumptions (and confusions) of the lime revival, that putty lime was a traditional binder and was slaked by drowning in an excess of water and laid down for a period of months before mixing with aggregates for use. Generally, during the 18th and 19th centuries, when putty was not used immediately and whilst still hot, it was laid down for no more than two weeks. This period of repose remained common in the 20thC.

As late as the British Standard of 1951, the prescribed method of making lime putty subscribed to this historic understanding – quicklime being added to twice its volume of water in the first instance, with more water and quicklime being added incrementally as the slake proceeded.

"Lime putty. Lime putty may be prepared from the quicklime or dry hydrate of either non-hydraulic lime or semi-hydraulic lime.

preparation from quicklime. The slaking vessel or pit should first be partly filled with water to a depth of about 1 foot and enough quicklime should *then* be added to cover the bottom and come about half way to the surface of the water. Stirring and hoeing should begin immediately, and the quicklime should not be allowed to become exposed above the surface of the water. Should the escape of steam become too violent or the quicklime become exposed, more water should be added immediately. The mix should boil gently and, as it thickens, more water should be added. Water and quicklime should be added alternately until the requisite quantity of milk of lime is obtained.

The stirring and hoeing should continue for at least five minutes after all reaction has ceased. The resulting milk of lime should then be run through a sieve of 1/8 inch mesh into a maturing-bin. It should be protected from drying out and remain undisturbed for a period of at least two weeks to permit it to fatten up to a lime putty.

Preparation from dry hydrate. The hydrated lime should be mixed thoroughly with water until a mixture of the consistence of thick cream is obtained; this should then remain undisturbed for not less than 16 hours. If left longer, it should be protected from drying out. "

Until the 20thC, the primary use for lime putty was in situations where residual lumps of unslaked lime would be a nuisance and where significant tenacity was not required – for fine plaster finish coats and for the very fine jointing of gauged brickwork and finely jointed stone ashlar. This putty was made by slaking lump lime with a minimum of water (to guarantee that the slake reached the minimum necessary temperature of between 100 and 120 degrees centigrade) and then laying the emergent 'dough-like' material down for all late slaking to

occur (as was done by the Romans for fine stucco finishes), or by thinning the dough-like material with more water after the slake was complete to facilitate its being run through a sieve to remove the unwanted lumps.

The mortar for all previous coats, as for building mortars, was hot mixed from quicklime – the quicklime slaking along with the sand. This was typically achieved by forming a 'basin' of the necessary sand, placing the lump lime in the middle of this and adding just sufficient water to the quicklime to achieve the slake (or just enough and a little more to produce a thick paste); banking the sand over the slaking lime until the slake was generally complete (a matter of minutes for the purer limes), closing down cracks in the sand caused by the expansion of the lime, and then mixing the lime and the sand together whilst both remained very hot. This was termed the 'ordinary' or 'common' method of mixing (and slaking) by Spanish, French, British and North American authors historically, indicating its frequency. The operation might be carried out on a flat surface, within a shallow mortar pit in the ground or in mortar boxes.

When just enough water was added, a dry-mix of sand and hydrated lime would emerge. This could be stored for a period, even indefinitely if contained within barrels in a damp cellar, but more commonly it was thrown through a screen to remove larger lumps of aggregate and unslaked lime and immediately mixed to a mortar for use. When the mortar was to be mixed for immediate use, a little more water might be added, but in either case, more water would be added to produce a workable mortar for immediate or prompt use.

Immediate use was not recommended for plastering, however, due to the risk of late slaking of the quicklime under- or over-burned in the kiln. The late slaking of these lumps would disrupt and break a finished plaster surface, leaving it riddled with 'bullet holes'.

The response to this hazard was not, however, to make putty lime, laying this down to 'mature' – it was to hot mix the mortar as above (to generate the necessary tenacity) and to lay down this mortar, or coarse stuff, for a period of time to be sure that all slaking had occurred.

It was generally understood that the hot mix method delivered a mortar of greater tenacity, bond strength and workability than did the mixing in of cold lime putty that may have been 'drowned' during production.

It was also a reliable and economic method of adding sufficient lime for maximum workability and performance whilst producing a mortar for immediate use.

The vast majority of historic lime mortars have at least 1 part of lime to 2 parts of aggregate and more usually 2 parts of lime to 3 parts of aggregate by analysis. That this high lime content was *critical* to their performance was ignored during the lime revival, which prescribed mortars of 1 part of slaked lime to 3 parts of aggregate – a binder-aggregate proportion with zero historic precedent before the advent of cement-lime mortars (1:2:9; 1:3:12) early in the 20thC , when the additional power of the cement might be calculated to compensate for the inherent weakness of drowned putty lime.

Whilst 2:3 mortars might be mixed from putty slaked in the traditional way and to a traditional initial consistency, they could not be produced with over-wet modern putty limes slaked by drowning, lest these had been laid down for decades.

Hot mixing methods, however, allow the water content to be readily controlled by the mortar mixer.

A succession of French, British, Spanish and North American engineers in the later 18th and earlier 19th Centuries rigorously tested their materials and methods. All concluded that the maximum amount of sand or other aggregate that could be added to 1 part of quicklime, without compromising the workability and necessary performance of the mortar, was three parts, in the case of pure and feebly hydraulic limes. Prior to this time, lime mortars were frequently richer than 2:3. They were never leaner than this, however, though, if the quicklime was in the form of powder, and would therefore leave no unslaked lumps to perform as aggregate in the mix, 1:4 would be (and remains) an appropriate maximum of sand to one part of quicklime.

Pure/fat or feebly hydraulic quicklimes will typically double in volume upon slaking, so that a 1:3 quicklime: sand mix will deliver a 2:3 lime: aggregate mortar.

Hydraulic limes, also hot mixed and used almost exclusively for underwater or routinely wetted works, expand less on slaking, so that the prescribed maximum proportions were 1 or 2 parts of sand to 1 part of quicklime, depending upon its hydraulicity.

This, too, was substantially missed by the lime revival, as well as the fact that more than feebly hydraulic limes were rarely used for building in the air historically, lest the only limestone locally available was itself hydraulic, at least until the late 19thC, when they were quickly displaced by cement-lime mortars for general building.

Hydraulic lime mortars, even at 1:3, tend to be too hard and brittle for use in conjunction with traditional historic fabric and are generally too low in *effective* porosity to be compatible with either earth-lime or sand lime mortars prepared using pure or feebly hydraulic quicklimes. A pure or feebly hydraulic lime mortar with a high free lime content, typically hot mixed, delivers a very high level of effective porosity, actively keeping traditional fabric dry – protecting timbers from decay and masonry from frost damage, as well as preferentially 'harvesting' damaging salts, whilst maximising the thermal performance of the structure (Wiggins HES Technical Paper 28 2017).

Hot mixing was the most efficient method of producing mortars of necessarily high free lime content, though masons and plasterers were thinking much more of what 'felt right' – what method and lime: aggregate proportion gave them a material of eminent workability, 'tenacity' and bond, which made their work not only durable but which allowed them to achieve what they wished to with the material, economically and efficiently. This material was deformable during its sometimes lengthy period of carbonation – able to respond to the settlement and flex of a traditional building without cracking or separation. Earth-lime mortars offered similar properties, as well as excellent workability and bond strength.

For plastering, a hot mixed lime mortar delivers a material with excellent adhesion and excellent cohesion – it sticks to almost any substrate and within the mortar, the lime, aggregate *and water* are intimately combined and locked together. Used hot, the mortar will readily stiffen, but without drying out too rapidly – hot mixes are reluctant to let all their water go too quickly. Quicklime is also the cheapest form of lime, reducing the cost of a project. There is very little waste of material – left-over mortar may be re-tempered indefinitely, so long as it is protected from drying out.

There was a long tradition of pulverising lump lime to a coarse powder before slaking. This became the norm when mixing in mortar mills. It had been common enough before, especially as it would accelerate the otherwise slow slaking of hydraulic limes. There was a general understanding from at least the 17thC that mixing powdered quicklime

intimately with the sand or other aggregate before slaking delivered a mortar of even greater adhesion and tenacity than that achieved by the 'ordinary' method (Moxon, de la Faye, Dossie)

In modern usage, using commercially available powdered quicklime eliminates the need to lay down the coarse stuff to allow for late slaking – hot mixed plastering mortar may be used with confidence whilst still hot or immediately after cooling. In our own practice, we tend to hot mix the plasters with powdered quicklime for use the following day. Used hot, the plaster is 'tackier' than when cooled. After cooling, it has greater 'elasticity' but without loss of adhesiveness.

Most of the benefits associated with hot mixing endure after cooling, though a hot mixed mortar used when still hot will offer maximum porosity and harling (thrown exterior rendering) in Scotland was routinely done with the mortars still hot. There is much textural and anecdotal evidence from around the world that plastering was as routine with hot mortars as it was with cold, certainly for the first and second coats of three-coat plaster schemes. The possible ill-effects of late slaking could be dealt with prior to the application of the putty lime finish coats.

The routine use of hot mixed lime mortars of high free lime content should not be seen solely as a 'conservation' issue, though they offer a truly 'like-for-like' and compatible option for the repair and conservation of old buildings of traditional construction. It is as relevant to eco-build projects, and especially those involving the use of earth mortars and solid wall earth construction. High free lime mortars will keep these buildings dry and prevent the potential accumulation of moisture within their fabric associated with the use of cementitious (or strongly hydraulic lime) mortars. A building the fabric of which is healthy will be healthy for those who live or work within it.

The strength and durability of hot mixed high calcium limes may be enhanced by the addition of small volumes of pozzolanic material, though their primary purpose is to somewhat accelerate the set in over-moist fabric. Pozzolans are fired clays. Hydraulic limes are produced from clay-bearing limestones, the clays fired in the kiln along with the free lime, the two combining to provide an hydraulic set. In craft practice historically, a small volume of pozzolan was often added to final pointing mortars or to exterior renders to enhance their durability and to hasten their initial set, or was added where elevated moisture levels would inconveniently slow the initial set of a non-hydraulic mortar. The addition of up to 10% of a pozzolan *as a proportion of the lime content* will

not disrupt the effective porosity of a mortar high in free lime. Traditional pozzolans were brick dust (from bricks fired at around 900 degrees C); trass (volcanic ash from central Europe); true pozzolan (volcanic ash from the Naples region of Italy); ashes and clinker from blacksmiths' forges and wood ash. Smeaton also includes crushed ironstone, a sandstone, which he called 'minions'. Hot mixed lime mortars on or close to the North York Moors often contain chips of iron-rich moorstone within the otherwise limestone dust aggregate – this may have been added for feeble hydraulic set. Wood ash was probably the most common pozzolan in vernacular usage, along with pulverised brick, where bricks were being made. Pulverised fly ash and calcined china clay, both used in the concrete industry are useful modern pozzolans. Coal ash was commonly used as a pozzolanic aggregate in industrial cities, forming the aggregate as a whole. This was collected and processed before distribution for use.

For underwater work, the volume of pozzolan was higher – John Smeaton, the English engineer, concluded that 2 parts of sharp sand to one part pozzolan to one part high calcium quicklime, (hot mixed), was the minimum of pozzolan necessary for the mortar to set reliably underwater. Earlier mixes for such uses were 1 part quicklime to 3 parts pulverised pozzolan (aggregate and dust), and no sand. Langley (1750) says that these would be mixed with 'hot lime,' indicating mixing by the ordinary method.

Hot mixed mortars are easy to produce and are more tolerant of inexperience than other forms of lime mortar. Contrary to common assumption, the use of quicklime is no more hazardous than the use of other routinely used alkaline binders, such as Portland cement, hydraulic or hydrated lime. Properly slaked, the temperature of a hot mixed mortar will not exceed 120 degrees Centigrade during slaking and will fall to between 50 -60 degrees C once sufficient water to produce a workable mortar is added. This process takes a matter of minutes. The same or significantly higher temperatures are encountered in the average domestic kitchen every day. Quicklime is used in a wide range of applications across the world – soil improvement; soil stabilisation; water purification, as well as in the manufacture of lightweight concrete blocks.

Eye protection is essential when working with any calcareous binder; gloves are always advisable, as is robust clothing and common sense. When the mixing method may involve dust (which it need not), appropriate dust masks should be worn. Quicklime should be stored in a dry place.

Quicklime is available in most parts of the world, and can be made on a small scale wherever there is a supply of suitable limestone or sea-shell. It is sustainable. A high calcium lime mortar will absorb almost as much carbon dioxide during its set as was produced during the burning of the lime it contains. Only free lime will re-absorb carbon dioxide, so that most hydraulic limes will absorb a relatively small amount of the carbon dioxide produced in their manufacture and Portland cement next to none. The production of Portland cement is a major contributor to global warming.

There has been a revival in the use of hot mixed lime mortars in the UK and Ireland over the last 3 years, with many craftspeople – masons, bricklayers and plasterers - embracing their routine use once more. What began as a grassroots 'rebellion' against the routine specification of what were perceived as over-hard and generally inauthentic hydraulic lime mortars, has been significantly enhanced by on-going research projects and papers commissioned by the Historic England Architectural Conservation Research Team and its equivalent at Historic Environment Scotland, as well as by the enthusiasm of a growing number of professionals, and especially structural engineers. Alarm at the indiscriminate use of modern hydraulic lime mortars has only grown as a result. Initial anxieties that hot mixed air lime mortars might prove as overly sacrificial as drowned putty lime mortars of similar chemistry (the premature failure of which had led to the uncritical embrace of hydraulic lime mortars in the UK during the 1990s) have been proven by experience and observation (as well as historic precedent and material science) to have been unfounded, and the vast majority of craftspeople, once introduced to hot mixed mortars, would not wish to use anything else, reiterating the preferences of their forebears - since so long as it was that the mason, bricklayer or plasterer designed the mortars they used (generally until the end of the 19thC), they chose to use hot mixed fat or feebly hydraulic lime mortars, or, indeed, a combined system of these mortars and earth-lime mortars.

Mixing Methods

Earth-lime Mortars.

Any clay-bearing sub-soil, free of organic matter will be appropriate. The clay content should not exceed 20%, however, and will be more typically lower than this. The full palette of assessment tests may be found in most books about earth building, but the simplest and most pragmatic is that adopted by Irish stonemason, Patrick McAfee:

Taking your available sub-soil, mix to a mortar and apply small areas of plaster to a wall, the first as found; the second with one gauge of sharp sand; the second with two gauges and so on. Choose the mix that shrinks the least. The same may then be applied with and without organic matter – which might be hair, hemp shiv or hay (or other grass finer than straw). The best mix selected, the same may then be trialled with varying proportions of quicklime, starting at 3% and rising to 10%. Too little or too much quicklime will promote shrinkage.

The chosen earth-sand mortar should be well mixed and well-tempered and taken beyond the liquid limit to facilitate engagement of the clays. The addition of the selected proportion of powdered quicklime, again well-mixed in, will bring the mortar back beneath the liquid limit and deliver a usefully elastic mortar with good workability and bond strength.

With experience, this process will be achieved by 'feel' alone.

The setting up of earth-lime mortars does not rely upon carbonation, although this will occur with time, but upon the chemical reaction between clay minerals and lime. The lime changes the character of an earth mortar in ways advantageous to the craftsperson and to long term performance.

Hot mixed Lime Mortars

There are different methods of hot mixing, some of which will involve slaking the lime to a hydrate, which may be passed through a sieve; others in which the quicklime is slaked alone initially and then mixed whilst still hot (or is screened and left to cool before final mixing) and others during which the powdered or kibbled quicklime is mixed with the sand before slaking and brought straight to a mortar. In our experience, whatever the method, mixing the lime and the aggregate whilst the lime remains hot delivers the best mortar. Quicklime was usually slaked to a dry hydrate when it needed to be transported long distances, or by sea, when air-slaking would compromise its ultimate performance, although it was not uncommon for plastering during the 19thC, facilitating the removal of unslaked lumps, before mixing to a mortar. It was not uncommon in Italy for fine stucco finishes, mixed with marble dust.

The temperature reached during slake should be a minimum of 100 degrees C. If just the right amount of water is added, the temperature of

the quicklime will be around 100 degrees C or a little higher. If too little water is added (which risks 'burning' the lime, the addition of more water during slaking then risking 'chilling' the lime, which leaves the mortar 'short'), temperatures within the lime may reach 300 degrees C. If too much water is added – or if quicklime is thrown into an excess of water – the temperature of the slake may not reach 100 degrees C – the lime will be 'drowned' and may lack binding qualities.
The volume of water necessary to complete the slake should be worked out according to the form and source of the quicklime, therefore, before mixing. Just enough water will deliver a 'dry slaked' mortar; just enough and a little more, will deliver a thick paste.

Necessary water should be delivered in one go, steadily by sprinkling or incrementally when quicklime powder is used.

Method: A) mix quicklime and naturally moist aggregate at 1:3 and leave to 'dry-slake' for about 3 - 5 minutes or until super-fine dust begins to form or to rise from the mix, whether hand-mixing or mixing in a pan-mixer. Drum mixers are not generally suitable and hot mixing in these should be treated with great caution. Use tyre-rubber trugs (usually available from agricultural feed suppliers) – plastic buckets will melt. The maximum temperature at the dry-slake stage will be around 150 Degrees C, sometimes up to 175 Degrees C, sometimes less, around 102 Degrees C, depending upon the moisture content of the sand. It should not be left to become too hot, however. **Wear eye protection and dust masks and all other appropriate PPE, as for all lime (and cement) products. Have sugared water solution (Diphoterine) to hand for eye-wash.**

Incrementally add water sufficient to make a mortar of the desired consistency.
Leave for 10-15 minutes before use or set aside for later use, when a little more water may need to be added during the beating. Maximum temperature after the addition of additional water and the completion of the slake will be unlikely greater than 58 Degrees C

B) Heap moist sand and hollow the heap. Add lump or kibbled quicklime at typically 1:3 proportion by volume. Add the water necessary to effect the slake (typically around 2 volumes of water for each volume of quicklime) before mounding the sand over the quicklime. As the quicklime expands, cracks will appear in the the sand covering, which will also begin to dry out. These cracks should be closed to retain the necessary heat of the slake.

Modern quicklimes may be highly reactive, so that they will 'spit' upon the addition of water – in this case, ensure coverage of the quicklime with sand before beginning to add water. As the quicklime slakes, continue to add water (but do not drown or burn the quicklime) and to agitate the mix with shovels. Add more water once most slaking is complete and until the mix has been brought to the required mortar consistency. Use immediately or leave for later use. The mortar should be well beaten.

A version of this in a pan mixer might be to lay alternate layers of lump lime and aggregate in the mixer, which is turned off. Turn on the mixer and add water incrementally until mortar is produced, or

C) Using granulated or lump lime. Add all aggregates to the pan mixer and well mix; add granulated or small lump lime. When well distributed, add a full bucket of water and then train the hose into the mixer at low pressure, stopping occasionally, until a sloppy mortar consistency is achieved. This will begin to stiffen as slaking proceeds and as the mortar cools. If not used hot, it may need knocking up with more water before use. This method produces no dust. It may be achieved in a drum mixer, though pan mixers are always to be preferred.

This method can be used for powdered quicklime also. Procedure as above. When hose not available, add full bucket of water to mixer and then gradually add another as the slake begins. Little more water will be needed, but may be added when slaking is complete according to end use of the mortar.

b) or c) will also be the methods if the intention is to 'dry-slake', adding just enough water for the slaking of the quicklime to take place and leaving a slaked 'dry-mix' mortar to be set aside for later knocking up and use, or to mix a 'coarse stuff' which will be moist but not so moist as to be used as a mortar without the later addition of more water during knocking-up.

D) As for B), but add sufficient water to effect the slake all in one go – just enough for the quicklime to slake to a dry hydrate or a little more water to produce a thick dough-like paste. Cover with sand and leave to cook. Temperatures within the quicklime should not much exceed 100 degrees C. Mix sand and lime together whilst still very hot, adding more water in small increments as necessary (do not 'drown' the lime after first wetting).

If the quicklime is hydraulic, add just enough water to produce a dry slake, cover and leave to cook (slaking may take 24 hours). This will dry the sand. Mix sand and lime together after 24 hours, screen or sieve as necessary and set aside as a dry mix for later use. If for immediate use, mix straight to a mortar as soon as slaking is complete and use immediately. The latter method may retain unslaked lime lumps which may disrupt the mortars in situ.

E) Add good helping of water to the mixer (but not significantly more than is required to effect the slake), then sand and/or other aggregate, which will produce a sand slurry. Then add the quicklime and more water as necessary, bringing quickly to a mortar. This method will minimise dust. It may be characterised as a 'wet-slake' method, with all ingredients, including necessary water, all together from the start.

F) Mixing putty lime or limewash. Add just enough water and a little more to lump lime. Stir as slaking proceeds. Once slaking is complete, add more water as required (for lime wash eg). Thick, dough-like lime putty should be pressed through a sieve to remove lime lumps. The use of powdered quicklime will remove the need for sieving, but stirring will be essential as slaking proceeds.

Alternatively, add powdered quicklime to a small quantity of water (no more than three times the volume of the powdered quicklime) to produce a thick, dough-like putty. This may be mixed with sand at 1:2 or diluted with more water (and well-mixed) to produce a limewash, which should be mixed thick enough that a dipped brush does not drip and applied whilst still hot for maximum effect.

G) Slaking by immersion or aspersion. This was not uncommon in the past. For the immersion method a basket of lump lime was held underwater until soaked ('until it stops whistling' Del Rio 1859) and then tipped out onto a board (for immediate use) or into a barrel (to cook and be stored for later use) to slake to a dry powder. As such, it could be sieved before mixing to remove lumps. Mixed whilst still very hot, it delivers a good, workable mortar. The aspersion method saw the lump lime laid out in 6" layer before sprinkling with just enough water to effect the slake. This was done on site, close to the works. Once slaked, the hydrate was banked up with sand for prompt use – being knocked up to a mortar within a week, typically. Lime slaked by immersion and loaded into sealed barrels might be transported long distances without premature carbonation – from England to the West Indies, for example. Lump lime could not be similarly transported without risk of some air

slaking. Some stucco workers in Italy still deploy immersion slaking, but mix and use the lime: marble dust finish mortars hot.

Typically for plasters and renders, hot-mix (to a mortar) the day before use, using Calbux 90 powder, although base coats may be applied hot. The mortar will improve overnight, becoming somewhat less 'tacky' and more elastic. When lump lime is used, the coarse stuff mortar may need to be laid down for longer than 24 hours to avoid late slaking. Some quicklimes – in either powder or lump – will require longer than 24 hours storage after mixing to avoid the risk of late-slaking. This is only necessary for plastering. Pointing mortars made from lump lime may require similar. For pointing, we tend to use powdered quicklime.

Aggregates

Good aggregate selection is essential for successful lime mortars. Sand aggregates should be sharp, well-graded and generally free of organic matter. A well-distributed grain size is more important than the presence of coarse grains – finer sharp sands will often shrink less than coarser varieties. Most engineers settled upon an optimum of two parts sharp sand to one part fine sand to one part quicklime. The addition of fine limestone aggregate will enhance the effective porosity of a mortar as well as its plasticity. High proportions of limestone aggregate will increase the compressive strength of a lime mortar. Although this has not been quantified, and is based upon observation and experience, hot mixing seems to engage a pseudo-hydraulic activity in a hot mixed lime mortar – clay-bearing aggregates such as granitic sands or pure silica aggregate such as slate dust will generate tougher, harder mortars when hot mixed, as will iron-bearing aggregates, without significantly compromising effective porosity.

Some Historic Mixes

Numerous historic texts on plastering survive and may be readily accessed on-line. The excerpts below are taken from texts reviewed as part of a literature review produced for HES during 2016-2017 (Copsey HES Technical Paper 27 2017).

Historically, the terms quicklime and lime were used inter-changeably.

Millar A (1872) The History of the Royal Society of London Vol 4 London.

P363.

A letter of Mr Musgrave to Mr Aston, dated at Oxford, January 31 1684/5 was read, containing an answer to Sir William Petty's query about mortar and plaister, as follows….

The plaister used by our plaisterers here in Oxford is generally of two sorts, coarse and fine. 1. Coarse mortar is made of lime, sand and hair; the lime used here is of two sorts, viz 1. Chalk-lime, made of chalk-stone, dug at Netlebed etc and burnt; 2ndly, hard stone lime, which is made of hard rag-stone burnt; this last sort of lime is much stronger, and will go two yards square in five farther (for it takes up a far greater quantity of sand and water), than the former, which is the finer of the two, and the more glorious to the eye. One bushel of chalk lime, one bushel of sand, and one peck of hair, mixt altogether, with water, will make coarse mortar; but if you use hard stone lime then one bushel of lime will require a bushel and a half of sand, and a bushel of hair. 2ndly In the making of fine mortar, mix one bushel of chalk-lime with half a peck of hair, or a bushel of hard stone lime with a peck of hair, and as much water as is necessary. Coarse mortar is used next to the lathing, stone, or brick wall; fine mortar is drawn on the other, and makes it white and beautiful.

Neve R (1726) The City and Country Purchaser. Newton Abbott. David and Charles 1969 Reprint.

Lome: A sort of reddish earth, us'd in Buildings (when temper'd with Mud Gelly, straw and Water) for Plaistering of Walls in ordinary Houses.

White Mortar: this is used in plaistering of Walls and Ceilings, that are first plaister'd with Lome and is made of Ox or Cow-hair, well-mixed and tempered with Lime and Water (without any Sand). The common Allowance in making this kind of Mortar is one Bushel of Hair to six Bushels of Lime.

…The proportion of lime to sand in making of mortar, ought to be various, according to the goodness of badness of these materials; and therefore is rather to be regulated by the Judgment of experienced and skillful Workmen in each particular country; than by any fixed proportions.
…Some workmen tell me, that tis the best way not to use mortar as soon as it is made; nor,(in making it) to make the lime run before it is mixed with the sand (as some do), but rather to take the sand and throw it on the lime whilst it is in stones before it is run, and so to mix it together, and then wet it, by which means, they say, it will be the stronger, and when it has lain a while made before tis used, will not be subject to blow and blister.

Others advise to let mortar (when made) lie in a heap two or three years before tis used, for so, (say they) 'twill be the stronger and the better; for the reason of so many insufficient buildings (say they) is their using of mortar as soon as 'tis made.

Dossie R (1771) Memoirs of Agriculture and Other Oeconomical Arts Vol 2

The manner of preparing this mortar is as follows: **Take of unslacked lime, and of fine sand, in the proportion of one part of the lime to three parts of the sand,** as much as a labourer can well manage at once: and then, **adding water gradually**, mix the whole well-together by means of a trowel, till it be reduced to the consistence of mortar. Apply it immediately, **while it is yet hot,** to the purpose, either of mortar, as a cement to brick or stone; or of plaster for the surface of any building.

M. de la Faye. **Recherches sur la préparation que les Romains donnaient à la chaux dont ils se servaient pour la construction et sur la composition et l'emploi de leurs mortiers. 1777. Royal Printers, Paris.** Translation, Michel 2016.

…If we soak limestone after it has been burnt in a kiln, it will warm up and its pores will open, facilitating its mixture with the sand and give some solidity…**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.**

Higgins B (1780) Experiments and Observations made with the view of improving the art of composing and applying Calcareous Cements and of Preparing Quicklime. London. Cadell.

The workmen usually slake the lime mixed with the sand or gravel in great heaps…
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 keep their **mortar** a considerable time before they use it, to the end that the bits of imperfect lime, which **passed through the screen**, may have time to slake thoroughly.
Kelly T(1823) The New Practical Builder and Workman's Companion) London. Paternoster Row.

Fine Stuff, is pure lime, slaked with a small portion of water, and afterwards well saturated, and put into tubs in a semi-fluid state, where it is allowed to settle, and the water to evaporate. A small proportion of hair is sometimes added to the fine-stuff. Stucco, for inside walls, called trowelled or bastard stucco, is composed of the fine-stuff above described, and very fine washed sand, in the proportion of one of the latter to three of the former. All walls, intended to be painted, are finished with this stucco.

Pasley C W (1826). Practical Architecture. Reprinted 1862 by Royal Engineer Establishment, Chatham. Reprinted Shaftesbury. Donhead Publishing 2001)..

When lime is of inferior quality, or there are not the means for mixing the mortar well, it is considered that **one part of unslaked lime to two parts of sand** is the proportion **necessary for obtaining a compound of proper tenacity.**

If the lime be of good quality, and dependence can be placed upon the diligence of the persons employed making the mortar, one part of unslaked lime to three of sand, has been held as a better proportion than the above, and has very often been used in Government works.

It appears to me that, **for common mortar *[which is to say, fat or feebly hydraulic lime mortar]* <u>for the walls of buildings,</u> the former *[1:2, quicklime:sand]* may be considered the maximum, the latter *[1:3, quicklime:sand]* the minimum, proportion of lime that ought to be used….**

Loudon J C (1833 and 1846) edited by Loudon J W An Encyclopaedia of Cottage, Farm and Villa Architecture and Furniture London Longman, Brown, Green and Longmans

A whitewash which will adhere to woodwork, and preserve it from the weather, is thus composed : — **To three parts of unslacked lime add two of wood ashes, and one of fine sand, or of coal ashes sifted through a fine sieve. Let these be mixed with as much linseed oil as will bring the mixture to a consistence for working with a painter's brush,**. If the mixture be ground together, it will be an improvement. Two coats will be required; the first thin, and the second thick. The hardness of this wash increases over time. (Smith's Art of House- Painting, p. 36.)…

Wright, W H (1845) A Brief Practical Treatise; Mortars: An Account of the Processes Employed at the Public Works in Boston Harbor Ticknor & Company.

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….

1860, William Copperthwaite's specification for an extension to the Blue Ball Inn, Malton, North Yorkshire:

Bricklayer
The whole of the walls to be built with good hard well burnt bricks laid in <u>good mortar composed of North Grimston Lime Co lime and clean sand in the proportion of 3 of sand to</u>

1 of lime. [This 1 of lime will be quicklime]….To carry up all Chimney flues and properly plaster the same.
All the door & window opening to be discharged with 9" rough internal and 14" external openings, the whole of the external wall to be neatly pointed and black-lined.

Plasterers Work
The whole of the work to be plastered with good hair mortar composed of clean sand and Grimston Lime Co lime. All the laths to be good Baltic red fir laths. All the wall and stoothings to be finished 3 coats trowelled smooth for colour or paper. All the ceilings to be finished 3 coats with fine lime putty, the sitting room adjoining Newbiggin to have a neat plaster moulding 16" girth.

Jacques D H (1860) RuraI Architecture: Or, How to Build Country Houses and Out-Buildings etc New York.

Stucco and Stuccoing. —Take stone lime fresh from the kiln and of the best quality, such as is known to make a strong and durable mortar (like the Thomaston lime[*a high calcium lime from Maine*). Slake it by sprinkling or pouring over it just water enough to leave it when slaked in the condition of a fine dry powder, and not a paste. Set up a quarter-inch wire screen at an inclined plane, and throw this powder against it. What passes through is fit for use. That which remains behind contains the core which would spoil the stucco, and must be rejected. Having obtained the sharpest sand to be had, and having washed it, so that not a particle of the mud and dirt (which destroy the tenacity of most stuccoes) remains, and screened it to give some uniformity to the size, mix it with the lime in powder, in the proportion of two parts sand to one part lime. This is the best proportion for lime stucco….

Gillmor Q A (1864 & 1886, but written 1861) Practical Treatise on Limes, Hydraulic Cements and Mortars.

Coarse stuff [for plastering] **is nothing more than common lime mortar,** suitable for brick masonry, to which has been added a quantity of well-switched bullock's hair, to act as a kind of bond. The following proportion is a good one:

1 cask lime – 8 cubic feet of paste:
Sand – 16 to 18 cubic feet
Hair – 1 ½ cubic feet.

When ample time for hardening cannot conveniently be allowed, it will be advantageous to **replace 12 to 15 per cent of the lime paste in the coarse stuff, by an equal volume of hydraulic cement or plaster of Paris.**

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Millar (1897) - Plastering, Plain and Decorative. Shaftesbury. Donhead.

In most parts of England the lime for making coarse stuff *[for plastering]* is generally slaked by immersion, and is run into a pit, the sides of which are usually made up with boards, brickwork, or sand, the lime being put into a large tub containing water. When the lime is slaked, it is lifted out with a pail, and poured through a coarse sieve. It is sometimes made in a large oblong box, having a moveable or sliding grating at one end to allow the lime to run out, and also to prevent the sediment from passing through.

In preparing lime *[mortar - for Millar lime and mortar are interchangeable]* for plasterwork, the general practice in the north of England is to slake it for three weeks before using…**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, 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, *are the limes mostly used for building purposes.***

MORTAR …for plasterwork it is usually composed of slaked lime, mixed with sand and hair and is termed 'coarse stuff'…In Scotland the coarse stuff is generally obtained by slaking the lump lime…with a combination of water sprinkling and absorption. **The lime is placed in a ring of sand, and in the proportion of one of lime to three of sand, and water is then thrown on in sufficient quantities to slake the greater portion.** The whole is then covered up with the sand, and allowed to stand for a day; then turned over, and allowed to stand for another day; afterwards it is put through a riddle to free it from lumps, and allowed to stand for six weeks to further slake by absorption. It is next 'soured' - that is, mixed with hair ready for use. Sometimes when soured, it is made up in a large heap, and worked up again as required for use. This method makes a sound, reliable mortar. In some parts lime slaked as above is mixed up with an equal part of run lime. This latter method makes the coarse stuff 'fatter' and works freer….

Nigel Copsey 2017.