NYMNPA

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From: Andy Rollinson
Sent: 16 April 2019 08:58
To: Hilary Saunders
Subject: Thirley Cotes

Hi Hilary. I spoke with David Bamford yesterday and he has assured me the revised plans will be with me very soon. In the meantime, please find Lime Wash information.

Regards

Andy

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HOT LIMEWASHES and SHELTERCOATS

NIGEL COPSEY

THE REVIVAL in the use of hot-mixed lime mortars has been gathering pace across the UK and Ireland over the past three years, and the use of quicklimes in conservation and repair is now becoming increasingly routine. This has injected new energy and insight into the wider lime revival, affecting not just construction mortars but also decorative finishes and surface treatments.

As craftspeople began to use hot-mixed lime mortars again they initially struggled with procedures which had not been used for 40 years or so, and historic accounts and the experiences of others were not as readily available as they are now. Rules for producing and using hot-mixed lime mortars had to be re-discovered, initially by trial and error. Hot-mixed mortars are forgiving of inexperience, however, and historic texts now provide a mine of expert opinion and direction. It should perhaps be no surprise that using the right materials, manipulated as they were in the past, allows compatible like-for-like repairs to be carried out with comparative ease and efficiency.

While mortars and limewashes have a long history, with documentary sources dating back to Pliny, shelter coats are a product of the lime revival, and of Baker's lime method in particular. They can be defined as 'aggregated limewashes' for the treatment of friable or previously soiled stonework of particular importance and significance, offering a sacrificial layer that fills pores and seeks to match the tone and character of the stone when newly carved.

In addition to their decorative function, limewashes also play an important role in protecting the fabric. Recent research has demonstrated that the application of limewash to any masonry substrate, from the least to the most porous, enhanced the drying of the fabric at the surface and to surprising depth and with greater efficiency than when there was no limewash at all. This is due to the pore structure of calcium carbonate which is 'perfect' for the poulticing of moisture. It is the high free-lime content of limewashes and mortars that provides the key to effective and efficient breathability (Wiggins 2016).

Traditional thick limewash on Tetbury Town Hall

THE VALUE OF HOT SLAKING

Many problems experienced in recent years stem from the slaking and mixing of lime. Since the lime revival began, limewashes and sheltercoats have been made by diluting putty limes, themselves made by slaking quicklime in an excess of water. Historically termed 'drowning', this method was considered by all commentators to deliver a weakened lime with deficient bond strength and less cohesion and 'tenacity' – the key standard for a good mortar, along with good workability. The importance of matured lime putty was asserted by Vitruvius, Pliny and others, but always in the context of high status stucco finishes and fine colour washes. These putties were slaked alone but, as when lime was slaked with sand for mortars, the water was always added to the lump lime and in just sufficient quantities to effect the slake plus a little more water to deliver a stiff, dough-like paste. This was laid down to allow all slaking to occur. Lime putty, used neat as a mortar, was the norm for gauged brickwork and perhaps for bedding the finest ashlar. It was rarely used as a binder (Langley 1750).

More generally and in more recent centuries, running lime to putty was an efficient way of removing unslaked lumps which would otherwise impede the achievement of very fine surface finishes. This is made explicit by many sources:

> *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. (Nicholson)*

Running quicklime to putty became more common for plastering and building during the 20th century because it was a quick and easy way of slaking large volumes of lime. However, it was always used in the knowledge that the resulting mortars would be gauged with gypsum or ordinary Portland cement, which were assumed to counter the inherent weakness of mortars made with this material while speeding the initial set, although not the carbonation of the lime. It was a response to the demand for mass housing and increasing time pressures in the construction industry.

The idea of laying lime putty (albeit

Recent conservation to the figures at Crowland Abbey church, Lincolnshire by Alex Carrington using hot-mixed mortars and shelter coats

Hot applied sheltercoat to protect eroding sculpture at St Mary's Church, Old Malton

differently made) down for a minimum of three months is indicated by Alberti (1460), but he is unique in this prescription, which appears in his chapter on ornament. Millar (1897) indicates that plasters should be hot mixed and the resulting coarse stuff laid down to allow for late slaking for up to three months, although two weeks seems to have been the norm for both coarse stuff and, for fine finishes, lime putty.

During the 19th century, lime was also sometimes run to putty for convenience, but with the expectation of gauging with natural cement. The following mid-19th-century account, for example, describes the preparation of mortars at Fort Warren (Boston Harbour) mixed by mortar mill and lime slaked by being thrown into a surplus of water:

> *The lime, thus deluged with water, loses probably some portion of its binding qualities, but the mortar at Fort Warren almost always contains hydraulic cement; and as this substance sets rapidly, it is highly essential that the lime should be thoroughly slaked before the admixture of the ingredients... the lime is reduced to [a] milky consistence, and allowed to remain in the vat as long as possible. It should be remembered, that the above method applies only when cement is added to the lime. When no cement is used, the lime must be slaked in the ordinary way, as the drenching of the lime would greatly impair its binding properties. (Wright 1845)*

Limewashes too were made by adding just enough water to lump quicklime for it to slake. More water was then added and stirred in to achieve the desired consistency, typically thick enough that a dipped brush does not drip. The limewash was used immediately, first run through a sieve or otherwise, depending upon the situation, while still hot, for maximum effect.

Slaking itself takes a matter of minutes but significant heat remains for longer – sometimes for days if the mortar volume is large. Great store was placed on maximising the temperature of the slake in this and other mortar-making methods, whereas drowning the lime minimises the potential temperature. Quicklime slaked with too little water may reach 300°C before the addition of more water, which will bring the temperatures down below 100°C, typically to around 70°C in limewashes and to around 55°C in mortars. With precise water addition, the slaking temperature will be around 100°C. Too little risks 'chilling' the lime, reducing the effective binder content.

In modern, scientifically controlled hydrated air lime production, it is demanded that quicklime slakes at temperatures of 85–98°C to achieve the optimum surface area and porosity of the dry hydrate. Historically, significantly higher temperatures were generated. Van Der Kloes (1914) is unique in spelling out the perceived importance of maximising the temperature of the slake (others presumably took it as read). These temperatures sound alarming, but are easily managed and are, in truth, no more than those encountered in the average domestic kitchen. A minimum of 100°C is required; significantly greater temperatures than this will indicate insufficient water to effect the slake.

In our own practice, we have made limewashes by this method, as well as by incrementally feeding powdered quicklime into small volumes of water to produce a paste the consistency of 'extra thick' double cream, which, upon cooling overnight would appear as a putty lime. Stiffening only occurs upon cooling – used hot, the liquid flows. (Historically, grouts were always used hot to take advantage of this.) As a result, a hot limewash may be applied in thicker coats without crazing, effectively becoming putty on the wall. In historic specifications, two or three coats of lime white (as limewash was called during the 19th century) is indicated. No 'seven water-thin coats' specified here – nor, indeed, are they likely to be found on historic surfaces, where limewashes can easily be confused for fine finish coats.

In our experience (gained through using quicklimes over the past ten years, both for hot-mixed mortars for all uses and for limewashes), limewashes and sheltercoats are best mixed directly from quicklime, made thicker than modern convention, and applied while still hot. This results in a strong and immediate bond to masonry and other substrates, and even 24 hours later they would be very difficult to remove.

The intimacy of the bond between lime, water and aggregates as a result of hot mixing is particularly well-demonstrated in the case of sheltercoats. Even coarse aggregates will be held in suspension in the liquid. If left for some days, these aggregates will sink to the bottom, but stirred they will once more remain in suspension for as long as required. Compare this to modern sheltercoats; mixed cold from matured lime putty, the aggregates compact at the bottom of the bucket, requiring a hammer and chisel to remove them. Application is often a race against time.

It has been a maxim of the lime revival (Schofield) to use hot water in the dilution of putty lime for limewashes, the better to engage any pigments. However, when mixing directly from quicklime, the heat comes free. Furthermore, the addition of the aggregates and pigments before or (when using powdered quicklime) during slaking locks all of the ingredients together more effectively than


York House, Malton: a hot-mixed and applied sheltercoat with copperas pigment


Earlier copperas pigmented wash to York House


Early copperas pigments on the stonework of Crowland Abbey church


Hot lime washing in a threshing barn at Thornton Dale (Photo: Sam Baxter)

cold mixing. Hot water was used to slake some hydraulic quicklimes in the past, accelerating an otherwise slow process, especially when hydraulic quicklime had been previously pulverised. Likewise, added fats or oils will be melted and properly engaged with the other ingredients in a way that simply does not occur when the limewashes are mixed cold, something that has led to the spectacular failure of such treatments in recent years.

Hot limewashes and sheltercoats dry out less readily than cold-mixed varieties, carbonate efficiently and give very good coverage. They are cost-effective and have proved appropriately durable. The north elevation of York House in Malton was given a Hamstone dust, fine sand, copperas and quicklime sheltercoat in 2007. This continues to require no replenishment.

It should be said, however, that many of the beneficial properties of hot limewashes and sheltercoats endure when they have cooled – there are advantages in hot use, but good bond and good coverage remain available after cooling. As with hot-mixed mortars, it is the process of hot mixing that delivers an enhanced general performance with a strong bond between lime, aggregates *and* water– the method of slaking is key. Similarly, limewashes slaked in the traditional way were not always used hot, but our experience has been that hot use offers genuine advantages. Whether used hot or cold, the evidence would seem to be that they were generally used freshly made and applied much thicker than recently. Historically, two coats were usually specified.

ADDITIVES

There are several traditional formulae consisting of lime (not whiting) thoroughly slaked and thinned to a cream after slaking to which various additions are made, such as salt, alum, powdered glue, oils and fats and casein (skimmed milk), and a selection of formulae is shown in the table opposite. The effect of salt is probably to hold the moisture and facilitate the carbonation of the lime, while the addition of a small quantity of alum improves the working qualities and is thought to increase the hardness of the surface. Caseins and glues give greater binding properties to the mix.

Although done with cold putty limes, NPA research (Jackson 2005) demonstrated that the most efficient and durable limewashes were those composed of lime and water (with pigments as desired), and not those containing tallow or molasses or linseed oil. It was concluded that most additions were to help with the adherence of the material to the substrates, not durability.

While the addition of salt to lime washes may seem counter-intuitive, there is clear evidence that it improves the bond with the substrate. In 2014, even a hot limewash struggled to uniformly attach to the repaired and previously abused timbers of the Jesuit Mission Church in Fort McMurray, Alberta, Canada, but the addition of common house salt (which was often specified in limewashes coloured with copperas/ferrous sulphate without salt addition) effected good attachment to the timbers. The addition of house salt to limewashes for masonry structures remains common in many countries but is usually unnecessary, and in the UK's damp climate the risk of salt migration into the fabric may outweigh any benefits.

Common limewash pigments include copperas (ferrous sulphate) and various natural earth pigments (iron oxides) such as ochre. Copperas was a by-product of the alum industry of North Yorkshire, and in London and Yorkshire it was not uncommon for an alum-copperas wash to be applied to masonry as a thin coating in the 19th century.

All of the above indicates that craftspeople in the past – when exterior limewashing with or without additives was routine – understood far more than we do today. To give them and the buildings they created due respect and recognition, we should use the materials they used, manipulated and applied in the same way. Not only will this offer compatibility and something more truly 'like-for-like', but it will make the lives of masons, plasterers and conservators easier and less frequently frustrating.

Hot limewash with salt on the timber walls of the French Jesuit Mission Church (1910) at Fort McMurray, Alberta (Photo: Ben Gourley, MacDonald and Lawrence Timber Framers)

A CHEAP WASH

For the outside of wooden cottages, barns, out-buildings, fences, etc, where economy must be consulted, the following wash is recommended: take a clean barrel that will hold water. Put into it half a bushel of quicklime, and slake it by pouring over it boiling water sufficient to cover it four or five inches deep, and stirring it until slaked. When quite slaked dissolve it in water, and add 2lbs of sulphate of zinc and one of common salt, which may be had at any of the druggists, and which in a few days will cause the whitewash to harden on the woodwork. Add sufficient water to bring it to the consistency of thick whitewash. To make the above wash of a pleasant cream color, add 3lbs of yellow ochre. For fawn color, add 4lbs of umber, 1lb of Indian red, and 1lb of lampblack; for gray or stone color, add 4lbs of raw umber and 2lbs of lampblack. The color may be put on with a common whitewash brush, and will be found much more durable than common whitewash. *Jacques (1860)*

A TALLOW WASH

The basis of most lime wash recipes is the mixing of a quantity of tallow, which may be from 2 to 10lbs, into a bushel of quicklime to form an insoluble calcium soap. The tallow should be placed in the centre of the quicklime and the whole should be slaked together. If the quicklime is slow in slaking [suggesting moderately hydraulic], it should be covered with sacking, and hot water should be used. The addition of pigment may necessitate an increase in tallow, but a useful mean to remember is 5lbs tallow to a bushel of quicklime. *C Williams-Ellis (1919)*

WG SCOTT RECIPES

The following recipes are taken from WG Scott's 'White paints and painting materials' (*Modern Painter*, Chicago, 1910) and are reliable:

'Factory' whitewash for walls, ceilings, posts, etc (interiors)

[1] 62lb (1 bushel) quicklime, slake with 15 gallons water. Keep barrel covered 'til steam ceases to arise. Stir occasionally to prevent scorching.
[2] 2½lb rye-flour, beat up in ½ gallon of cold water, then add two gallons boiling water.
[3] 2½lb common rock-salt, dissolve in 2½ gallons hot water.
Mix [2] and [3] then pour into [1], and stir until all is well mixed. This is the whitewash used in the large implement factories and recommended by the insurance companies. The above formula gives a product of perfect brush consistency.

Weatherproof whitewash for buildings, fences, etc (exteriors)

[1] 62lb (1 bushel) quicklime, slake with 12 gallons hot water.
[2] 2lb common table salt, 1lb sulphate of zinc, dissolved in a gallon of boiling water.
[3] 2 gallons skimmed milk.
Pour [2] into [1], then add the milk [3] and mix thoroughly.

Lighthouse whitewash

[1] 62lb (1 bushel) quicklime, slake with 12 gallons of hot water.
[2] 12 gallons rock-salt, dissolve in 6 gallons of boiling water.
[3] 6lb Portland cement.
Pour [2] into [1] and then add [3].

Note – Alum added to a lime whitewash prevents it rubbing off. An ounce to the gallon is sufficient.

Historic sources reveal a wide variety of hot-mixed limewash recipes.

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Comparative costs of hot mixed air lime mortars and NHL mortars

Some points: *1 tonne of CL90 powdered quicklime in 25kg bags from Tarmac should cost £360 including delivery. A similar quantity of NHL around £600, plus delivery. A tonne bag of powdered quicklime from either Tarmac or Singleton Birch should cost no more than £200 plus delivery, and maybe less.

*To mix a quicklime mortar takes no more time than to mix an NHL mortar. Indeed, a quicklime mortar may be let out of the mixer immediately slaking is complete (no more than 5 minutes), whereas NHL suppliers' recommendations are that NHL mortar should be mixed for at least 20 minutes.

*After initial wetting of the substrate, a hot mixed lime mortar pointing requires no further water, spraying etc in its aftercare - it should be hung down with hessian, or similar, and left alone. It is usual to 'knock back' a hot mix the following day. It should again not be sprayed at this time.

*Good practice with NHLs is very different - the substrate should be very well wetted; the mortars require immediate protection from drying too quickly and require ongoing hydration before and after knocking back - regular misting with water for at least 14 days, and for as long as practicable - if this is not done, the NHL will be weaker than it would otherwise be; enjoy lesser tenacity/integrity as a mortar and be more likely to fail and less likely to perform properly. Indeed, regular hydration is technically required for so long as the silica set is developing, this being between 2 and 3 years. Inadequate ongoing hydration during this period will potentially lead to mortar shrinking away from the stone, allowing ready ingress of water to the wall.

* Because of the high bond strength and adhesiveness of a hot mix, there is significantly less waste of the mortar during use. Pointing and bedding is much easier.

*Because a hot mixed air lime mortar sets by carbonation, any surplus material can be used the following day or days, simply covered or put into tubs to keep it 'fresh', or knocked up again. NHL should not be knocked up once the initial set begins (within a few hours), so that there is inevitably more waste.

It is very difficult, therefore, to see how it can be considered more expensive in either labour or materials to prefer hot mix (at 1:3, quicklime: aggregate) to NHL - in truth, it is less expensive and much more cost effective.

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Hot Mixed Lime Mortars.
December 2017.

General specifications.

The most commonly found historic mortar proportion encountered in fat and feebly hydraulic lime mortars is 2 lime: 3 aggregate. This was achieved by hot-mixing 1 quicklime: 3 aggregate. Successful mixes might also be 1:2 or 1:4. Historic mixes of 1:3 are rarely, if ever, found before the 20thC, when cement-gauged slaked lime mixes were typically 1 binder:3, eg 1:2:9. The additional strength of the cement compensated for the loss of lime Though a 1:2:9 mix was typically weaker and less tenacious than a traditional lime mortar mix, it gained an initial set quickly. Historically, hydraulic lime mortars were mixed from quicklime at 1:2 or 1:1, being mainly used underwater and underground. Fat lime pozzalan mortars (the pozzalan generally either trass, brickdust, forge ashes or wood ashes) were mixed at 1:3 quicklime: pozzolan, or richer. These, too, were generally used underwater. For less routinely wet places, the pozzolan typically formed 1/3 part, or less, of the aggregate in a 1:3 mix. For concretes, however, mixes were much leaner – between 1:6 and 1:8 or 9, initially with blue lias or feebly hydraulic quicklimes; later, with Portland cement. In the UK, concretes for all uses were mixed hot – the gravel, sand and quicklime mixed together before slaking, with necessary water then added. Elsewhere – in Spain and France – the quicklime might be initially slaked before mixing with the aggregates whilst still hot. Hot lime mixes more readily and initimately than cold, with less effort and more efficiency.

Mortar aggregates might be well-graded limestone dust and/or well-graded sharp and/or silver sand, or both. They might be a clay-bearing sub-soil, typically very fine in historic examples. The addition of limestone dust, 5mm to dust (or brick chips) will enhance porosity and aid carbonation at depth, as will chalk aggregate or powdered chalk, which latter seems to reduce shrinkage and assist 'flowability' in a relatively , and appropriately stiff mortar.

Hair (or hemp) can be added at 'dry-slake' stage or just before the mortar is used, during 'sweetening'. Pozzalan may be added either stage also, but may accelerate stiffening for being hot mixed.

Our most commonly used mortar is 1: 1: 2; quicklime: < 5mm limestone aggregate: < 4mm sharp sand, sieved down or not, according to intended end use. Alternatively, 1 quicklime: 2 sharp sand: ½ limestone dust: ½ chalk powder. Other times 1:3; quicklime: sharp sand.

When hemp is added (at the hot mix stage) for plasters, to enhance insulation value and reduce shrinkage, this will displace the equivalent (by volume) gauge of sand aggregate.

For earth mortars, the gauge of quicklime is generally 5 - 10%, wet-slaked with the tempered and otherwise improved mud. It was frequently more than this, depending upon purpose. Quicklime may be added successfully as powder or as still slaking putty dough. The addition of powdered quicklime to an earth mortar mixed beyond the liquid limit to fully engage the clays, will bring the mortar below this limit and increase its workability.

The temperature reached during slaking of a sand-lime mortar 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. When slaking to putty, the necessary water may be added to the lump lime, the slaking material stirred and then diluted with more water once the slake is complete. If the quicklime is added to the water, the ratio of water to quicklime should be around 2:1, with more quicklime and more water added as slaking proceeds, care being taken to neither burn nor chill the lime.

The volume of water necessary to complete the slake should be worked out according to the form and source of the quicklime 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, or steadily by sprinkling.

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 sugar 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 sand covering, which will also begin to dry out. These cracks should be closed to retain the necessary heat of the slake. The sand and lime may then be mixed together whilst still very hot, more water being added to bring the mix to a mortar consistency. Alternatively, the dry sand and lime mix may be passed through a screen to remove larger unslaked lumps of lime. The screened material may be stored for later mixing to a mortar or, more typically, be mixed through to a mortar. As more hydraulic limes, much slower to slake, came to be used during the 20thC, this method was varied – water was added to the sand-enveloped quicklime and left for 12 to 24 hours, before being mixed with the sand after cooling and 'banked' in a minimally moist condition and left for late-slaking to proceed, before being later knocked up to a mortar.

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.

"The Mortar in which rubbed and gauged Bricks are set is called Putty, and is thus made:

Dissolve in any small Quantity of Water, as two or three Gallons, so much fresh Lime (constantly stirred with a Stick) until the Lime be entirely slacked, and the whole become of the Consistency of Mud; so that when the Stick is taken out of *it, it will but just drop; and then being sifted, or run through a Hair Seive, to take out the gross Parts of the Lime, is fit for Use".*

(Batty Langley 1750 London Prices of Bricklayers' Materials and Works)

From British Standard CP 121.201 (1951)

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

A) *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 then 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 lime-putty.

Both may be used immediately (still hot) or shortly afterwards.

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.

H) Gauging with NHL.

When the binder content is 50/50 (slaked) air lime/NHL the mortar will be typically 80% less strong than if NHL alone had been used (Foresight 2003).

Gauging with NHL will produce a feebly hydraulic lime which will set up more readily in damp situations and have a high free lime content contributing good effective porosity. It will be appropriate for exterior renders and harling coats where driven rain is common and where more rapid setting is required. It can encourage the use of appropriately deformable, effectively porous and ‘softer’ lime mortars by craftspeople unfamiliar with hot mixed air lime mortars and who can find the adhesiveness of these a culture shock. NHL gauged mixes are less ‘sticky’ although they retain good workability. The variability in strengths between different ‘brands’ of NHL, as identified by Historic England research is not especially significant in the context of gauging, which is offering a ‘helping hand’ to the air lime mortars in particular environments. The free lime contribution of the NHL will be highest in most NHL 2.0s.

Which NHL? Practitioners in Scotland tend to use NHL 2.0 at a ½ air quicklime: 1 NHL 2.0: 6 aggregate, having before used NHL 5 and NHL 3.5. Bill Revie recommends the use of NHL 5.0.

1:1:6 air quicklime: NHL: aggregate would an alternative mix and closer to the typical historic lime: aggregate proportion than the above.

Gauging of ‘common mortar’ with hydraulic lime became common in Northern Spain at the end of the 19thC. Work done with gauged harling mortars in Scotland over the last 20 years, often in severely exposed situations, have proved entirely successful to this day (Frew and Revie HES Technical Paper 2017).

Mixing method:

Hot mix the air quicklime by methods A to E above. Once slaking is complete, add the chosen volume of NHL and add more water as necessary; use promptly. Coarse stuff may be mixed and stored ahead of time, but the mortar will be cold.

Alternatively, add the NHL at the same time as the quicklime. This may stiffen more quickly than with the above method, the heat of the slake accelerating the on set of the hydraulic set. Use immediately.

Lastly, St Astier kibbled hydraulic quicklime is becoming available in the UK. This may be used instead of hydrated bagged NHL. Cornish Lime have settled upon a mix of 1 part hydraulic quicklime: 3 parts Calbux 90 powdered quicklime: 12 parts aggregate as being the most workable and appropriate for use in the Cornish climate. All quicklime would be added at the same time, the high reactivity of the air quicklime accelerating the otherwise slower slake of the hydraulic quicklime. This would offer a feebly hydraulic lime.

Sand-Slaking. This can be – and can be confused as – a hot mix method, but most often the mixing of the sand and aggregate takes place after the slaked lime has cooled. The measure of lump lime was placed in a ring of the sand with which the mortar would be made and water sufficient to slake the lime to a dry hydrate would be added, the sand banked over the slaking lime. It was most typical for the slaking of more energetically hydraulic limes which are both slow to slake and prone to late slaking. Sufficient water would be added to slake the free lime. The addition of more water than this would initiate the hydraulic set. The British Standard says that the lime should be left for 36 hours before being mixed with the sand, after which it might be stored for up to 10 days before the water sufficient to make a workable mortar (and to initiate the hydraulic set) would be added. As a method, it guarantees the minimum necessary temperature of the slake, but by the time of mixing, the lime will have cooled. It gives a 'shorter' mortar than hot mixed methods, with lower water retentivity and lesser adhesiveness, cohesiveness and workability.

Curing.

Rapidity of initial set will be variable depending upon the moisture content of the repaired fabric, the relative porosity of the substrate and the relative humidity of the atmosphere, as well as the relative humidity within the pores of the mortar itself.

Using hydraulic mortars, whether NHL or Portland cement-gauged limes, we have become accustomed to relatively fast-setting mortars and worry when setting is slow. We have become unaccustomed to initial shrinkage of placed lime mortars, and worry when this appears. A typical pozzolanic mortar will be ready for 'knocking back' within 1 or two days of placement, without drying too fast, even during cold weather.

We have also become accustomed to regularly wetting pointing mortars after placing, which is *essential* for hydraulic lime mortars to properly set. Whilst this may sometimes be necessary with hot mixed air lime mortars, *generally it is not*. Continued spraying will inhibit or prevent the onset of carbonation and 'case-hardening' and promote ongoing shrinkage. Ideally, therefore, mortars should be placed and hung down with hessian or other protection and left alone until stiffened and knocked back. After case-hardening, occasional spraying may be recommended, but is not strictly necessary *unless pozzolan or NHL has been added to the mortar* – the water given to make the mortar is generally sufficient to facilitate the set and setting will not begin until the water content is reduced.

For repointing, the mortar should be relatively stiff whilst still pliable. Mortar should be pushed into pre-wetted joints with a pointing iron and left slightly full. It should not be tidied up or over-worked.

As the mortar begins to set and stiffen and approach leather-hardness, surplus mortar should be scraped away using lengths of plastering lath and the face beaten with a stiff bristle brush to remove laitance and to roughen the surface.

If initial set is tardy (due to saturated substrates, low temperatures and/or high relative humidity), use lath to remove the latience earlier than this, to open the mortar to the air, but do not attempt to 'knock back' until further stiffening has occurred.

Unless reproducing a particular historic pointing pattern, full, flush pointing should be the default finish.

Regular misting after this stage will be of benefit for 7 – 14 days, but is not essential so long as the curing is slow and steady. Early misting may prevent the onset of carbonation and should be avoided until carbonation is underway, as indicated by 'case-hardening'.

Fat lime mortars gauged with either NHL or pozzolans will require more misting and even regular re-wetting to set and to bond within themselves and to the substrates properly. This should be done for as long as possible. Failure to deliver on-going hydration will deprive the mortars of necessary 'tenacity'. This necessity was well understood historically; it is rarely fully appreciated in modern usage of hydraulic mortars.

Protecting the work with hessian is recommended for at least 7 days – longer, if the mortar is hydraulic. The necessity for protection independent of atmospheric humidity applies particularly to hydraulic mortars.

The water necessary to bring a fat lime to a workable mortar consistency is all the water necessary to effect carbonation and set. The mortar needs to lose a fair proportion of its moisture content in order for carbonation to begin and this begins only at the outer face initially – producing 'case-hardening'. Carbonation to full depth may take a long time. *In the meantime, the mortars are load-bearing and entirely fit for purpose, and, in solid wall construction, will* *accommodate settlement of the fabric without cracking or disruption*. Immediate or rapid hardening of mortars is a demand of modern – *not of traditional* - construction technology.

Traditionally lime rich mortars carbonate more slowly than the over-lean putty lime mortars specified during the lime revival. There is more lime to carbonate. This should not be viewed as a problem. Once 'case-hardening' has occurred, further protection of hot mixed fat lime mortars should not be seen as essential, though it remains so for hydraulic mortars.

"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. Hydrate of lime is soluble in 831 parts of water at 78 degs. F ; in 759 parts at 32 degs., and in 1136 parts at 140 degs. Third, as the per cent, of water in the mortar is reduced and reaches 5 per cent., carbonic acid begins to be absorbed from the atmosphere. If the mortar contains more than 5 per cent, this absorption does not go on. While the mortar contains as much as 0.7 per cent, the absorption continues. The resulting carbonate probably unites with the hydrate of lime to form a subcarbonate, which causes the mortar to attain a harder set, and this may finally be converted to 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 setting furnishes the necessary bond." (Richardson C (1897) Lime, Hydraulic Cement, Mortar and Concrete. Part I. The Brickbuilder Vol 6 April. Rogers and Manson Boston).

Hot mixed air limes enjoy a strong bond between not only the lime and aggregate, but between both of these and engaged water – they let this water go with some reluctance and rarely dry too quickly, even at the face. They are less likely to lose excessive water into even dry porous fabric.

Hot mixed shelter coats and limewashes perform better than those cold mixed from putty lime and may be applied hot or cold. They should be mixed to a relatively thick consistency – such that lime will not drip from a dipped brush.

Harled/rough cast render coats were typically applied whilst still hot (Revie).

Pozzolans

Pozzolans are typically fired clays added to an air lime mortar to enhance or to accelerate initial set. Mortars with significant volumes of added pozzolan will set underwater and were commonly preferred for hydraulic works over natural hydraulic limes. Common pozzolans historically were volcanic ash from Puzzuoli, Italy; Trass, volcanic ash from central Europe; low-fired brick dust; forge ashes, ironstone dust, coal and wood ash. Smeaton and others concluded that the minimum pozzolanic addition for underwater use should be one third of the aggregate, eg two parts sharp sand: one part pozzolan: 1 part quicklime. Such a mix, if all fired clay or other pozzolan combined with the lime, would leave no free lime in the mortar and no calcium carbonate, which served no function underwater. Underwater mortars were often richer in pozzolan than this and, before Smeaton, might be 3 parts pozzolan to 1 part quicklime.

For building in the air, the pozzolanic content was typically much lower – probably not exceeding 10%. Research into pore structures and functional performance of hot mixed mortars by David Wiggins (HES 2017) would indicate that up to 10% pozzolan (calcined china clay in this case) does not disrupt the necessary pore structure, but that this is progressively disrupted by volumes or weights of pozzolan in excess of 10%. In most situations, less than 10% will be sufficient, between 5 and 8%, depending upon the pozzolan. Such low level addition was very much the domain of craftsmen in the past – it is not much discussed by engineers or other professionals. Wood ash and pulverised brick would seem to have been the most commonly used. Primarily, these will hasten initial set in damper situations, but deliver a mortar of similar (and appropriately) lower strength to a straight air lime mortar, if sometimes a little stronger. This is comparable to a feebly hydraulic lime mortar. Grey chalks had typically between 3 and 6% clay content before firing.

The addition of unfired clays will deliver some feebly hydraulic properties to mortars when added to a hot mixed mortar. Oyster shells contain some clay and will have such an effect; as will degraded granitic aggregates and iron-rich limestone aggregates. Powdered slate dust will also enhance the set of otherwise air lime mortars.

Most of the performance benefits of hot mixed mortars endure and do not rely upon the mortars being used whilst hot.

- The vast majority of lime mortars – for ALL uses – were hot-mixed – quicklime and aggregate mixed together as slaking of the quicklime takes place, or whilst the slaked lime remained very hot.
- Quicklime increases in volume by up to 2.2 times upon slaking, depending upon purity – a 1:3 quicklime: aggregate mix becomes a 1:2 or 2:3 lime to aggregate mortar, depending upon the relative bulk density of the lime and aggregates. Henry Scott, Royal Engineer, suggested in 1862 that the volume of 50 lbs of quicklime should be the ‘datum’ for mixing with three similar volumes of sand. The bulk density of a given volume of sand will be greater than the same volume of pulverised limestone, or other porous stone dust.
- The lime:aggregate proportion of most of these mortars was typically 2:3 or richer; very rarely as lean as 1:3. However, analysis reads lime content, not effective binder content – unslaked lime lumps are

aggregate, not binder. Historic mortars erred on the side of 'too much', rather than too little lime.

- Putty lime mortars mixed at this ratio are generally too wet to be workable or may shrink unduly; aged putty lime (10 years old plus) is a very useful material in specialist hands and may be mixed successfully at historic proportions. However, putty lime was generally used on its own – as a mortar – for fine finish coats or for gauged brickwork, rarely as a binder. It was used immediately, or soon after slaking. Where used as a binder (increasingly in plastering during the later 19thC and into the 20thC), it was typically 'matured' for 2 weeks.
- NHL mortars mixed at this ratio would be generally too strong and hard for most conservation contexts, if they are not already at 1:3; Hydraulic lime mortars in the past were not mixed as lean as 1:3 – more usually 1:2. Hydraulic quicklime expands less upon slaking than high calcium limes. *For both fat and hydraulic limes, the typical proportions were considered* ***the most sand*** *that could be used without sacrificing workability and proper performance*. Masons were often criticised by more 'scientific' commentators for preferring more lime and less sand than this – but none of these critics entertained the notion of a mortar as lean as 1:3, slaked lime: sand, before the 20thC, when cement-lime mortars became the norm.
- The water content of a hot-mixed lime mortar is easily controlled by the mixer and may be varied according to intended use.
- Hot-mixed high calcium mortars are eminently breathable, before and after full carbonation.
- Hot-mixed lime mortars enjoy enhanced performance – better bond strength; greater than assumed durability and excellent vapour permeability – 2:3 ratio critical to this performance
-

Controlled and reliable gauges of pozzalanic material may be added as necessary without losing workability. In many cases, this will not be necessary.

- Hot-mixing is mistakenly assumed to be dangerous – the risks are entirely manageable and are the same as apply to all lime and cement binders. All limes are hazardous due to their high alkalinity.
- Hot-mixed high calcium mortars are accessible, economic and easy to use; make lime use straightforward; make sense to builders otherwise sceptical about lime and offer appropriate strength, compatible performance and authenticity for the repair and conservation of most buildings of traditional construction.
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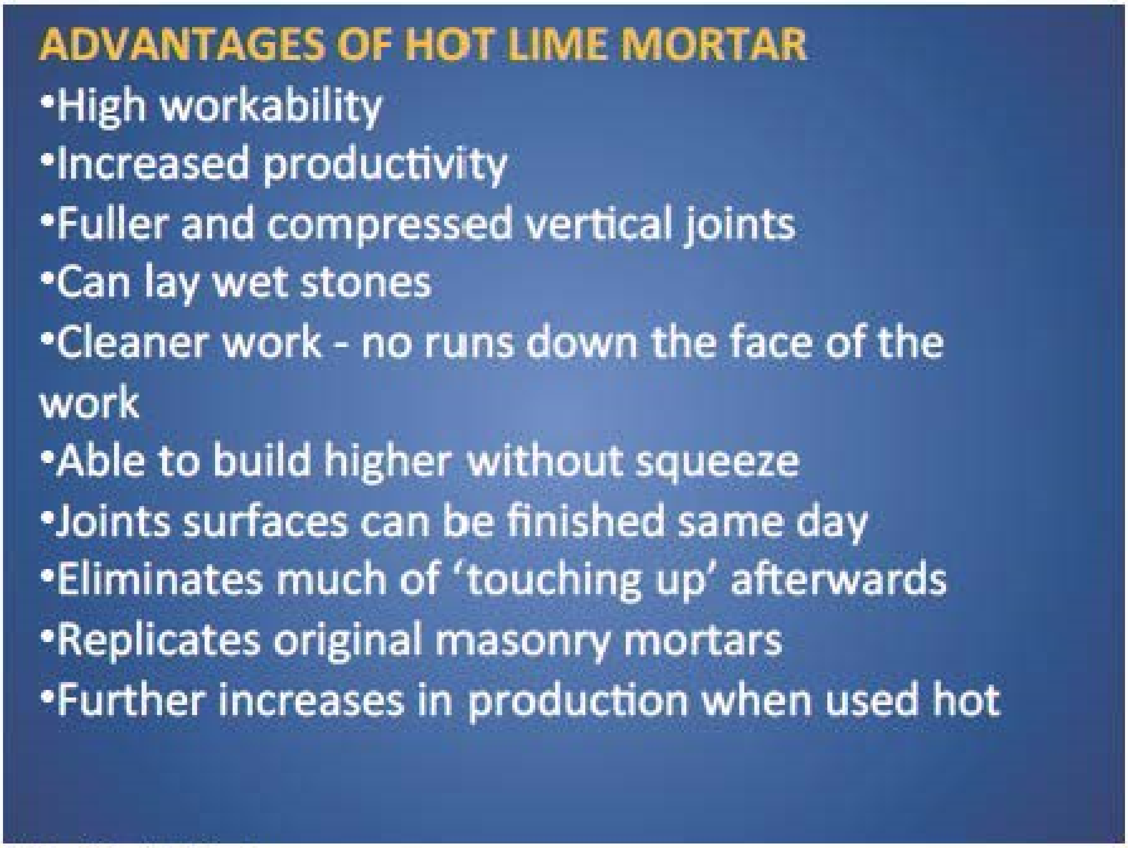

(Patrick McAfee).

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