the earth stone and lime company

building conservation consultancy and practice

Hot Mixed Lime Mortars.
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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.

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.

Alternatively, earth-lime mortars may be mixed by the 'ordinary method' (see below), particularly when mixed from lump lime and when greater volumes of lime are added. 1 slaked lime to 5 earth was a not uncommon proportion.

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.

Lime Mortars

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.

Lime tempering

Most old texts stress the need for lime mortars to be well-beaten before use. This is usually said to increase strength. A dry-slaked or sand-slaked mortar will be made more workable by beating; a mortar hot mixed to a wet mortar is immediately eminently workable. In the Yemen, lime slaked by aspersion to a thick, dough-like putty was then beaten, traditionally for 3 days. It is used only for lime wash. Little research has been done into the effects of beating, but that which has indicates that beating achieves good workability with less water content, reducing shrinkage. Also, that it reduces larger pores to around 1 micron – the optimum for capillary movement of liquid phase moisture. Roller pan mixers make sufficient beating quick and easy, and were used from an early period for projects of any scale.

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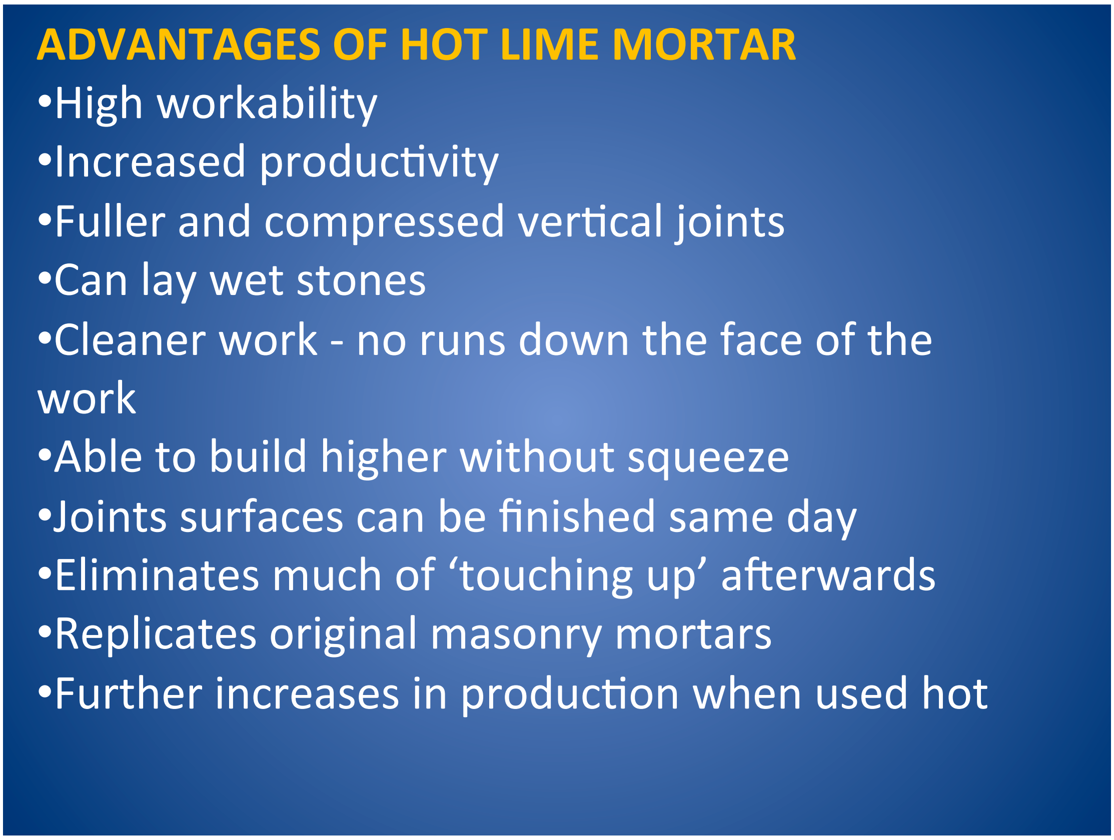
Controlled and reliable gauges of pozzalanic material may be added as necessary without losing workability. In many cases, this will not be necessary.

- 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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