HOT LIME MORTARS

In the Ten Books On Architecture, Vitruvius discusses the slaking of lime for mortars in two separate contexts: for bedding mortar and for stucco/plasterwork. He clearly supposes that the lime will be slaked and the mortar prepared in a different manner for each. For plastering, he asserts the necessity of slaking the quick-lime in an excess of water, as well as of allowing this lime to mature:

"…Stucco work…will be all right if the best lime, taken in lumps, is slaked a good while before it is to be used, so that if any lump has not been burned long enough in the kiln, it will be forced to throw off its heat during the long course of slaking in the water, and will thus be burned to the same consistency. When it is taken not thoroughly slaked but fresh, it has little crude bits concealed in it, and so, when applied, it blisters…(the crude bits) break up and spoil the smooth polish of the building" (Dover Press, 1960, p204). Few plasterers today would doubt the good sense of this advice.

Discussing lime in general, however, and in the context of building, Vitruvius suggests a different procedure. After discussing the changed character of calcium hydroxide, he says that limestone "…its pores being thus opened and its texture being rendered loose…readily mixes with sand, and hence the two materials cohere as they dry, unite with the rubble, and make a sound structure." (p46)

If there is any doubt that he is discussing hot lime mixing, the point is reinforced in the next section, when he discusses pozzalans. He attributes significance to the similar appearance of burned limestone and volcanic rock, and similar properties, therefore. Less understandably, he considers sand, too, to have been formed by fire. Crucially, however, and leaving aside his attempts to imbue his treatise with a measure of 'scientific' analysis, he then describes craft practice:

" When the three substances [lime, sand, pozzalan], all formed on a similar principle by the force of fire, are mixed together, the water suddenly taken in makes them cohere, and the moisture quickly hardens them so that they set into a mass which neither the waves nor the force of water can dissolve" (p47)

A 'hot lime' mortar is one that is made by the mixing of quick-lime (unslaked calcium hydroxide) into wet sand at a proportion required to produce a mortar that will require no further additions. The mortar may be used immediately, whilst still hot, or it may be set aside, as coarse stuff, for later use.

There are clear practical advantages of hot lime mixing for the mason: it would be quicker and less troublesome than mixing in matured lime putty; the heat of the exothermic reaction may assist the viability of winter-working, at least until the mortar cools; it may even lessen the discomfort of cold-weather-working for the mason himself.

Recent research has demonstrated that there are also clear structural advantages, and an understanding of these, however intuitive or empirical, will have been the main motive for the use of hot lime mixing in the past. There will have been a tradition of mixing in this way, and although direct knowledge of the Roman tradition of such mixing (as elucidated by Vitruvius) may not have been available to medieval masons, the practical advantages will have been as much a part of their experience. The ferocity of the exothermic reaction when quicklime is slaked, in combination with the aggregate, seems to alter the properties of the mortar, rendering it ultimately stronger and more durable, and even improving the bond between the mortar and the individual masonry units. It is thought that the heat etches the grains of silica, improving the ability of the mortar to resist compression; it is wondered, even, if a beneficial chemical change occurs upon the surface, at least, of siliceous aggregate, and even on the surface of brick or stone the mortar bonds. It would seem, of course, that for the latter effect to be achieved, and for these reasons, then the mortar would have to be used immediately, whilst still very hot.

The increase in bond, strength and durability achieved in a hot lime mortar seems to exceed that achieved by the same quicklime slaked in an excess of water, to make a putty lime which is then matured before mixing, cold, with the same aggregate.

The mixing of different limes 'by volume' already requires attention and flexibility from the mason. The amount of lime in a measure of hydrated lime or of hydrated NHL will be greater than in the same measure of putty lime. The volume of the latter added to a mortar will need to be greater than that of a dry powder. Furthermore, research by Mike Lawrence has demonstrated that the amount of active ingredient present in different putty limes can vary significantly. This will not be news to anyone working sensitively with lime: a mortar design is arrived at as much by 'feel' as it is by strict adherence to quantities. It is also heavily informed by historical precedent: it will be based upon an analysis of the original mortar, and by the relative volumes of the ingredients of these mortars. For all that Vitruvius states flatly that 1:3 is the correct proportion of lime to sand, and for all that this remains the default position for lime mortars today, many historic mortars are demonstrably richer in lime than this.

In the case of hot lime mortars, how does one reliably guage the necessary volume of quicklime to be added to achieve a quantity that is 25%, at least, of the final mortar? It will not be enough to simply fill a bucket with quick-lime. The quicklime is full of air; the grade of the granules may vary; whatever their size, a lot of the volume of the bucket will consist of air - air not only within the quicklime, but between the granules (or lumps) of quicklime as well. Typically, quicklime will increase its volume threefold upon slaking.

The successful mixing of hot-lime mortars will have relied, therefore, upon the experience and judgement of the mixer; and 'feel' will have very much informed the original design, as much as will an assessment of the size of the lime lump. Preparation either at the lime-kiln, or on site will have sought to minimise the variability, and the problem of variability. It would obviously make practical sense to break the quicklime down into as small a size as possible, even to powder, if practicable. However, variability would remain, and judgement be paramount. Mortar mixing was a separate and important trade throughout the medieval period and even C19 specifications stress the necessity for experience and skill in the mixing of (typically hot lime) mortars.

If all that was required of the mixer was that he 'followed instructions'; that he paid attention to the guaging of the mix, then it is highly unlikely that mortar-mixing would have been considered a trade at all. On most building sites today, the guy who mixes the mortar is little more than a labourer. He is asked to guage the mortar, but too often with a shovel, not with a bucket or other measure; he is never asked to 'feel' it, and the patchwork of differently guaged cement-mixes upon many modern buildings is the consequence.

I would like to argue that the demanding nature of hot-lime mixing required on-site specialisation; that hot-lime mixing defined that specialisation. The mixing of putty-lime mortars for plastering required a similar sensitivity and attention to detail, of course, as did their preparation.

The presence of small lumps of lime, whether already air-slaked or unslaked, is taken to indicate that the mortar was made using the hot-lime method. It is important, however, that we do not assume that a mortar that lacks these lumps was made using another form of lime; that it was not made by the hot-lime method.

It defies common-sense to imagine that a hot-lime mortar has, by definition, to include lumps of lime, and that the manufacture of a hot-lime that has no lumps, and is perfectly mixed, is impossible.

Many factors might influence the presence or otherwise of lime-lumps.

From the moment it leaves the kiln, quicklime is water-hungry; it will begin to slake in contact with moisture. This slaking may begin locally in contact with particularly humid air. Quick-lime that is not fresh, therefore, or which has been in contact with the ground during storage may be partially slaked when used. The lumps may

be lumps of lime already slaked when hot-mixing took place which resisted dissolution in the added water. Alternatively, they may be agglomerations of lime unslaked at the time of mixing; of lime that did not contact sufficient water to either dissolve or to properly slake. They are likely to have slaked later, more slowly, and to have remained in a lump, being held within the mortar by then, and under compression.

The wetter the mortar, and the more thoroughly mixed, and the more finely ground it was, the less likely this latter effect would be.

The fresher the quicklime, the less likely premature 'air-slaking' would be likely to occur.

Most of the discussion of and research into hot lime mixing has focused upon the hot lime mixing of high calcium, non-hydraulic air-limes. It would seem that the hot mixing of such limes enhanced their mechanical strength and durability (and which benefit is implicit in Vitruvius's discussion of lime mortars).

Vitruvius also clearly expected that mortars containing pozzalanic additives would be mixed by the hot-lime method. Whilst it is obviously the case that pozzalans can only be added at the same time as the water, given their hydraulic set, it is common enough these days to add them at the last minute to matured coarse stuff. Vitruvius does not consider this approach. This may simply reflect common practice with non-hydraulic mortars, of course.

It does raise the question of how, in the past, hydraulic lime mortars were mixed. Wherever hydraulic limestone was available historically, it was used by masons. There is no evidence, however, that NHL was produced or supplied, or used in a hydrated form (??). The modern process by which such hydrated limes are achieved relies on sophisticated and expensive technology. It would seem very likely, therefore, that when it was used, pragmatism, if nothing else, would dictate that NHL was mixed hot—quicklime of NHL would be mixed with wet aggregate and used immediately. Whilst it could, of course, be slaked with an excess of water, its immediate use would remain essential. Masons already used to hot lime mixing with high calcium lime, would be highly unlikely to consider this option with an NHL, lest, perhaps, they were using it for plastering and wanted to have some confidence that all of the lime had slaked.

An hydraulic lime thus mixed would combine the apparent structural advantages of a hot-lime mortar, as well as the additional (perceived) benefits for mechanical strength and durability of hydraulic set.

Victorian specifications for mortars and cements using Blue Lias NHL quoted by Holmes and Wingate sometimes explicitly required the hot-lime mixing of concrete and mortar and sometimes, perhaps, the slaking of NHL quicklime to produce a storable dry powder. However, the language of these specifications can be confusing to a modern reader. Even those specifications that seem to demand the slaking of NHL to dry powder may not actually require this, and rather assume that the mix will be a hot mix. The specification for the quay wall at Newcastle, for example:

"Mortar: For the front ashlar to be of the best Dorset lime from Lime Regis (Blue Lias) to be burnt at Newcastle, and when slaked to be mixed with one part of clear sharp sand…to one part lime, to be kept dry until wanted." (Holmes and Wingate, 2002, p188). Is what has to be kept dry until wanted the quicklime, or the sand and hydrated NHL coarse stuff? I would say the former, and that it is assumed (because normal practice) that the quicklime will be slaked into wet sand, not separately.

The specification for Westminster Bridge, London:

- "Lime: to be best Blue Lias lime, thoroughly burned, and quite free from core, and used hot from the kiln, where practicable.

- "Mortar: composed of Blue Lias lime in one part with three parts of clean, sharp river sand, free from all vegetable substance and screened. The lime properly slaked and thoroughly mixed with sand with no more water necessary to bring it to a proper consistency."

This is also somewhat ambiguous, but assumes, I believe, hot lime mixing, something which is supported by Holmes and Wingate's note that the specification calls for the mortar to be mixed by hand 'as practised in former times' (Holmes and Wingate 2002 p187)

There is no ambiguity in the specification for a house in Grosvenor Square, the foundations for which " were specified to be composed of one part fresh burnt ground Dorking stone to six parts clean washed Thames ballast. The ballast was sifted coarse and mixed in small quantities with the quicklime. While the mix was hot (still slaking) it was shot into the foundation trenches from a height not less than six feet." (Holmes and Wingate. 2002. P186). Dorking stone, of course, produced a naturally hydraulic lime, and was much used in the construction of C19 London.

In all these specifications, slaking was to take place on site, even when that entailed transporting quicklime, with all its attendant risk, from Dorset to Newcastle, some 400 miles. This strongly suggests that, at this time, there was little expectation of receiving, or demand for, NHL in a hydrated form.

I would suggest that the only practical method of using NHL until recent times was to use it 'hot'; certainly to bring it to site as quicklime, and for it to be slaked on site immediately prior to use. Vicat, in another example quoted by Holmes and Wingate specified that the lime used in the mortar of the foundations of the Souillac Bridge across the Dordogne should be slaked and made into a slurry before the addition of aggregate. By implication, the slurry was a result of slaking.

From the USA, also, in 1861 (Hitchcock, et al *The Geology of Vermont)*:

"To obtain lime for water cement, the impure limestone should be broken into small pieces and subjected to a heat sufficient to expel the carbonic acid…care must be taken that the heat is not too intense, for if it is, the rock will become partially fused, and a glassy substance will result from the alkaline and silicious constituents of the rock. After calcination, the rock should be thoroughly pulverized and mixed with sharp sand, after which water may be applied until the mass assumes the consistency of common mortar, when it should be used immediately, especially if it possesses the setting property of some cements. The proportion of sand to be used with the cement, varies with the composition of the lime"

The proportions of lime to aggregate in C19 specifications, for the production of below ground lime concrete foundations also support the notion of hot-lime mixing of NHL, since for Grosvenor Square, for example, this was 1part of Dorking lime to 6 parts aggregate – clearly too weak, had the lime already been slaked. However, given the typically more than two-fold expansion by volume of unslaked lime, the concrete would have been 1 part lime to 2.75 parts aggregate, much more fit for purpose, therefore.

Consideration, therefore, should be given to the use of hot lime mortars in the care and repair of old buildings, especially for built repairs and in the preparation of sheltercoats and limewashes.

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