Hot-Mixed Lime Mortars

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Abstract

Most lime mortars, for most uses, for most of history, were hot-mixed using quicklime. Lime mortars commonly used today, for conservation and repair, or for new build, tend to be Natural Hydraulic Lime-based or designed 'products', less often putty lime mortars. This seems anomalous and confounds our general inclination towards like-for-like, compatible repair using authentic materials, – as well as the requirement of BS7913 (1998). Serious consideration of the historical method and advantages of hot lime mortars and the practicality of their use in a modern context has been sparse, with the notable exceptions of Alan Forster (2004 and since) and Gerard Lynch (2007). As a building conservation and repair company, we have routinely used lime rich hot lime mortars – for building, re-pointing and plastering - for over 5 years; this paper discusses historic and modern examples of hot mixing and our own practical experience of both and contends that hot mixed high calcium lime mortars that respect historic precedent represent a viable and eminently appropriate modern response to the conservation and repair of old buildings.

1. Introduction

In the authors' and others observation (Forster 2004, Lynch 2007, Holmes 1993), the vast majority of lime mortars – and very many earth mortars – encountered in old buildings of traditional construction were 'hot-mixed', quicklime being slaked in intimate association with aggregate, whether sand, stone-dust or subsoil, an initial 'dry-slake' being followed by the addition of water sufficient to produce a workable mortar. Forster argues that the initial dry-slake (quicklime mixed with moist or moistened sand) is a crucial aspect of improved performance in hot mixed mortars promoting a thorough drying and subsequent lime-enriched wetting of particularly porous aggregates (2004). Recent coverage of the subject by English Heritage (2011) has focused – like Lynch – upon 'dry-slaking' followed by storage of the dry mix as the primary method of hot-mixing, distinguishing somewhat from 'hot-mixing' what was most likely and most often a stage in the general method of preparation of hot mixed mortars. The storage of a dry mix for later knocking up with water would seem a superfluous activity in the context of most building works, fraught with potential for loss of quality and the particular qualities of hot mixed mortars. The indicator for hot mixing is accepted to be the inclusion of lime 'lumps' within the mortar (Figs 1 & 2). Particularly in hot-mixed earth mortars, streaks of lime remain evident. These characteristics are observed in our own hot mixed mortars, even when these are made using powdered quicklime. Very few lime mortars today are hot-mixed, even in the context of building conservation. Putty Lime and increasingly natural hydraulic lime mortars have been preferred, as well as heavily promoted (Allen et al, 2003) contradicting not only historic precedent and the principle of like-for-like repair, but risking clear incompatibility. The recently published Practical Building Conservation volume 'Mortars, Renders and Plasters' assumes a much wider historic use of Natural Hydraulic Lime mortars than may be supported by the evidence of buildings the length of the oolitic limestone belt of England, and across North Yorkshire, in the experience of the authors, though NHL's were used more widely as transport improved, of course. These, too, were typically hot-mixed and not pre-slaked to a powder form as today.

Figure 1 : West Rutland, Vermont, USA; lime lumps indicators of hot-mixing.

Figure 2: Similar in an earth base-coat plaster from York House, Malton (Gourley)

2. Observations and discussion, materials and performance

As may be generally evident to all who work upon the conservation and repair of old buildings, the vast majority of historic lime mortars contain a high proportion of lime – 2:3 or 1:2 or 1: 1 ½ being typical (Forster 2004 Lynch 2007). The majority of lime mortars specified today are 1:3 or, increasingly 1:2 ½ and more often than not, natural hydraulic limes are used, not high calcium limes, though even NHL was rarely used in so lean a proportion in the 19th Century (EH 2011). Neve (1726) offers numerous examples of common mortar mixes where lime content by volume significantly exceeded that of aggregate.

An increase in percentage of high calcium lime will not lead to an undue increase is compressive strength; it will increase vapour permeability; an increase in the percentage of NHL will lead to an increased compressive strength and a decreased vapour permeability (Banfill & Forster 1999). Whilst the 'lime revival' in the UK was founded upon the use of putty limes (as well as some uses of quicklime), over the last 15 years NHL-use has come to dominate and high calcium lime mortars have acquired an undeserved reputation for poor durability, when poor workmanship may be more likely responsible for failure. In most cases where mortar analysis is carried out, these identify the original use of hot-mixed quicklime mortars. In as many cases, the use of similarly hot mixed mortars for the repair or conservation of these buildings is not subsequently recommended. Too frequently in these instances, NHL is preferred.

The perceived lack of durability of putty lime mortars may be largely explained by the use of mortars gauged at 1:3 which may not even reliably have contained a true quarter part of lime, depending upon the water content and bulk density of the putty lime used. To mix even the most matured lime putty at a gauge of 1:2 or richer in lime, is to produce a mortar too wet and sloppy for practical use. Such gauges were only realistically achieved historically by the use of quicklime – the mixer is in complete control of the water content of a hot-mixed mortar, and most historic mortars, whether for building or for plastering, were hot-mixed in the authors' experience and observation, and this approach is undertaken in the authors' practice. 1: 3 assumes that minimal binding is the only purpose and function of lime in a mortar.

It does not take account of the role of lime itself as aggregate or as a vehicle of flexural, even tensile strength. It assumes that the sand is well and evenly graded, which was not always the case historically, with sands tending to be relatively fine and incorporating clays on occasion. It takes no account of the role of high lime content in delivering vapour permeability, particularly in a mortar composed otherwise of non-porous aggregates.

Figure 3: Prospect House, Slingsby. Pointed with hot-mix 2008. Stone geology the same as opc-pointed buildings to either side, but fabric now so dried out that this would not be assumed at first glance.

The authors' experience over the last five years is that hot-mixed mortars contribute significantly to the drying of the general fabric of a building (Fig 3) The moisture handling capacity of the masonry fabric is important and the mortar's role in facilitating this is essential. Whilst it is clear that this favourable moisture transfer potential far exceeds that of cement it is also our observation that it exceeds that of NHL mortars in current use. Undue moisture retention within the fabric of a masonry building leaves not only the masonry units vulnerable to salt and frost action and decay, but will promote decay in embedded timbers and compromise the thermal performance of the wall (Hughes 1986).

Compelling evidence exists suggesting that very few original or historic lime mortars have failed due to poor specification, manufacture or anticipated natural weathering – failing either in doing their job of protecting built fabric from external decay mechanisms, due to an absence of regular maintenance, or to the uninformed or ill-advised use of incompatible materials in the repair of old buildings. Very many buildings in the UK have been needlessly repointed with ordinary Portland cement over the last 70 years; almost as many did not need to be repointed at all. In countries less wedded to opc, or to superfluous, not to say damaging 'refurbishment', such as in New England, USA, the majority of traditional buildings, in the authors' experience, retain their original – hot-mixed - mortars, usually in very good a condition. In the harsh winters in the UK of recent years, the authors have observed more failure of harder, reputably more 'durable' NHL mortars in stress situations and very little, if any, failure of putty lime or hot-mixed quicklime mortars (Fig 1). As detailed by Malinowski and Hansen, (2011) the exterior of Lacko Castle, Sweden was successfully replastered with both hot-mixed and putty lime mortars, practice much informed by prior technical and archaeological research. Both mortars have performed well in a cold climate. Notably, the craftsmen expressed a preference for the hot-mixed mortar.

1: 2.5 has become quite commonly specified, but usually with the lime being NHL and delivering greater strength, therefore, to a mortar the compressive strength of which even at 1:3 is likely to significantly exceed that to be found in the vast majority of old buildings in the UK, and to be immediately incompatible, therefore, even where the host mortars are of lime. Historic mortars in the UK rarely exhibit a compressive strength greater than 3 Mpa; the majority, less than this. Many buildings in the UK, in fact, were built with earth mortar and only pointed with – frequently haired – lime mortar. In 19thC London, Blue Lias Lime (an NHL 3.5 in modern terminology), considered an eminently hydraulic lime, was used for below ground and underwater foundations - for Westminster Bridge, for example where the specified lime was to be 'the best Blue Lias Lime...used hot from the kiln, where practicable' (Holmes & Wingate 187 1997 & 2002), and yet many 'conservation' architects in Yorkshire today habitually specify NHL 5.0 at 1: 2.5 for the repointing of soft and porous stonework bound by soft lime or earth mortars (Fig 4). This may perpetuate the problems caused by ordinary Portland cement use; it is to continue to denude the construction industry of the care, consideration and craftsmanship demanded by the use of appropriate, authentic and compatible lime mortars.

The compressive strength of a typical NHL 3.5 after 28 days will be already up to 3 times stronger than a typical, historic hot-mixed mortar; and more with an NHL 5.0. This raises issues surrounding its compatibility with an historic lime mortar and its interaction with the masonry (or carpentry) substrate, not only of relative inflexibility and potentially damaging differential stresses, but of relative impermeability and salt concentrations, which have been demonstrated to accelerate deterioration (EH 2012). 1 : 3 might be seen to have historical resonance – it is a common proportion offered in 19thC mortar specifications (where these have survived); as it was in antiquity, as specified by Vitruvius (1960), for example. In both cases, the 1 part lime is either implicitly or explicitly of quicklime – the volume of which increases upon slaking. Vitruvius talks of laying down slaked lime in putty form *only* in the context of fine interior plastering.

Figure 4 : Pond Farmhouse, Crambe, earth mortar, hot-mixed, haired lime pointed. A Cruck house from circa 1580

The Fitzwilliam Estate Agent's memo book 1734-1807 from Malton, North Yorkshire (NYCRO ZPB III 5/2/1) contains numerous small contracts with local masons to build or to rebuild houses in Malton. Though the labour costs are detailed by measured rates, the decisions about mortars are left to the craftsmen. Mortar for building – which was still predominantly earth mortar at this time – was to be 'the best that could be got'; subsequent pointing was to be 'in lime', supplied sometimes by the masons themselves, sometimes by 'My Lord', implying the ownership of some kilns, at least, by the Estate. 'Daubing' (with earth mortar) was to be followed by 'plaistering in lime' (Fig s 2 & 6). Many earth mortars were themselves gauged with quicklime. Analysis of samples from within York House, Malton, showed varying degrees of calcium carbonate content, though some of this will have been limestone aggregate – naturally occurring or introduced (Fig 5). Whenever lime is specifically mentioned in 18th and 19th Century building accounts, its volume or quantity is always expressed as a dry measure, in either bushels or chaldrons.

> *"1st July 1748. Agreed with Percival Luccock for himself and (sic) behalf of James Luccock, his partner to build a wall to Fenton and Robinson's yard adjoining Water Lane 7 foot high with the coping at 5s per rood and to do it with old stone in the yard. They are to have two chaldern of lime allowed to mix with the mortar which is to be taken fresh out of the kiln, and Mr Turner to see it measured. Witness my hand, Percival Luccock."* (P 18)

A later agent, in the mid-19thC, William Copperthwaite, did generate standard specifications. For lime mortar, the required mix was 1: 3. (Copsey P 40 ZPB III 8/7/2 Valuations of Fixtures, 1853-1862, NYCRO)The evidence of buildings in Malton from this period is that the 1 part lime was quicklime and that the mortars were hot-mixed, generating a ratio of around 2:3, allowing for impurity.

Modern, industrially produced quicklimes are fired at around 1300 degrees C (Lafarge Tarmac Literature) and tend to be very pure – and much more so than those produced locally in small kilns being fired to around 850 – 950 degrees centigrade (EH 2011 Hughes et al 2004)– and has been shown in the authors' tests to increase in volume upon slaking by 2.2 times upon incorporation of the one molecule of water necessary for slaking to take place (and after which, if only this amount of water is added, a dry powder will result). A 1 : 3 gauge of quicklime to aggregate by volume will therefore deliver a sand: lime proportion, of just less than 2 ¼ : 3. This is very much richer in lime than the standardised 1 : 3, but equates very well with historic precedent, and, therefore, with the original mortars of most of the buildings encountered by the authors in practice. The manner of the slaking will also entrain air into the mortar being mixed.

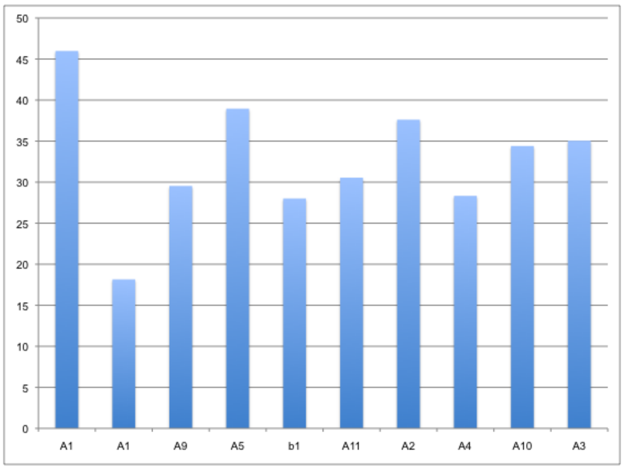

Figure 5 : Copsey, Gourley & Allen : % CaCo3 content in earth mortars, York House, Malton. It is considered that quicklime was added less liberally to earth mortars, at between 10-20%

Figure 6 : polished earth and lime plaster sample, York House, Malton, showing both quicklime and oolitic limestone content, lime finish coat of lime and hair only, with naturally present aggregate within the burned limestone (Gourley)

A quicklime mix of this order will 'feel' very sticky and lime-rich by comparison to a one to three mix of aggregate to putty lime, which will feel very plastic, but also a little slippery. Beyond this, to mix putty lime of even the English Heritage-recommended minimum bulk density of 1.4 kg per litre (English Heritage 2011) at a ratio of more than 1 : 3 creates the risk of the resultant mortar being rather sloppy and insufficiently stiff for use for anything other than plastering, perhaps significantly. A similar increase in volume will occur if quicklime is slaked to putty, in an excess of water, but much free water will remain. A given volume of quicklime, therefore, will economically produce twice its volume in putty lime.

This difference alone may begin to suggest why the majority of historic, lime-rich building mortars were mixed hot on site and not made with putty, leaving aside other possible reasons, such as the reduced transportation costs from kiln to site of quicklime; the greater speed and efficiency of mixing quicklime with aggregate compared to mixing – particularly suitably stiff – putty lime. Quicklime was slaked directly into the aggregate, mixed and used either immediately or sometime afterwards.

Accepted wisdom (Smeaton Project 1990s, Forster 2004, Lynch 2007) – and most certainly our experience and observation – is that hot-mixing delivers a benefit in performance terms: in mechanical and bond strength, though the precise reasons for this are not known. The enhanced performance of hot-mixed mortars does not rely upon their being used hot – it endures, however long the mortar may be laid down, so that it is the process of hot-mixing that delivers the benefit. Something happens, and in the authors' own experience of using hot-mixed mortars, sheltercoats and limewashes supports this (Fig 7).

Figure 7 : Hot-lime sheltercoat to Hildenley limestone Early English Doorway, Bossall, near York

A hot-mixed limewash offers better immediate coverage and more 'depth' than the best quality pre-mixed limewash, itself made from the same quicklime, but made up into a limewash from putty. It may be applied more thickly without crazing. A sheltercoat mixed hot will hold the fine aggregates of the shelter coat in suspension for much longer than a putty lime based sheltercoat – often for as long as it takes to apply each batch, saving alot of arduous stirring and suggesting a more intimate bond between lime and aggregate and has proved very durable upon York House in Malton, and the more so than proprietary limewashes used alongside. A hot-mixed mortar will cure and carbonate faster than a putty lime based mortar and seem to acquire a faster initial strength. A hot-mixed plastering mortar, suitably rich in lime – has been practically shown to exhibit better early adhesion properties than cold manufactured materials, even when deployed at close to the liquid limit.

It is the authors view that *the higher lime content is critical to the proper performance, durability and bond strength of a high calcium lime mortar.* In addition to favourable technical enhanced performance of such mortars they also represent a like-for-like repair material in the context of building conservation and repair (BS7913, 1999; Forster, 2010).

Figure 8. St Andrews, Bywell detail. Mortar 6 quicklime: 20 sand before mixing; afterwards 13: 20

Analysis of lime mortars within the masonry of the Anglo-Saxon tower of St Andrews Church, Bywell, Northumberland (Ellis 2010) showed a typical lime : aggregate proportion of 1: 1 ½ in most periods of intervention. Often distinct mortars were encountered, the leanest sample was 1:2. The aggregate was relatively fine sand gathered from the banks of the nearby River Tyne, as well as small intrusions of probably Roman brick, which will have behaved more as porous particle than a pozzalan. Our repointing mix was 6 parts quicklime : 20 parts aggregate (from a nearby river-side quarry), mixed hot, equating to 3. 25 slaked lime: 5 parts aggregate by volume – pretty much the same as originally, though this mix was arrived at prior to receipt of the mortar analysis (Fig 8).

Richard Neve, in The City and Country Purchaser (1726), consulted a variety of craftsmen in the south of England, who offered up their preferred mortar mixes. '36 bushels of pit-sand to 25 bushels of quicklime' (London) ; 4 : 3 (parts of Sussex); 1 : 1 ½ (elsewhere in Sussex); 1 : 2 ¾ ; 1:1. In one case, where the craftsmen explicitly offered different proportions for quick and run (putty) lime mortars, the proportions were 32 bushels of lime: 36 bushels of sand for a putty lime mortar, as opposed to 32 bushels of quicklime to 48 bushels of sand. The former would generate a mortar of slightly less than 1 : 2 in proportion, the latter would be richer in lime than aggregate. Clearly, therefore, all masons sampled by Neve were using mortars very much richer in lime than any generally specified today. Their buildings, however, are those we work upon today as masons and conservators and with the mortars and fabric of which our repair mortars need to be compatible and approach authenticity. Neve is clear:

"From all these various Proportions (of lime and sand) above-mentioned, all asserted by able Workmen, I think it is reasonable to infer, That the Proportion of Lime to Sand in making of Mortar ought to be various, according to the goodness or badness of these materials; and therefore is rather to be regulated by the Judgment of experienced and skilful Workmen in each particular Country, than by any stated Proportions". (Neve 1726 199)

Alberti, many years before, and speaking generally of construction put it another way:

"the business of the experienced workman is not to demand the best possible materials, but rather to make sensible and appropriate use of those available" (1486 & 1988)

Which is to say, that the primary Standard should be *craftsmanship* and the intimate understanding, experienced selection and accomplished use of the materials of one's craft.

There is rarely any good reason not to take into consideration the historic documentary written and archaeological evidence from the original mortars and to seek to reproduce their character and their performance – not slavishly, but in general and in principle. Historic lime mortars were not standardised, but variable according to circumstance and to the craftsmen involved. Craft practices show remarkable consistency, however, on the available evidence, in producing mortars very much richer in lime than any generally, if ever, specified today and which were hot mixed using quicklime.

3. Hot Lime Mortar Manufacturing Method

Health and Safety considerations are those most commonly cited when it is chosen to ignore the common practice of the vast majority of masons and builders throughout known history, and until very recently. However, robust clothing, eye protection and dust masks, but mainly a little experience and common sense are all that are required to work safely with quicklime. Hot-mixing may be considered safer, in fact, than the production of putty lime.

3.1 Method

Whether hand-mixing in small batches or on a larger scale in a pan mixer, the authors mix the quicklime with the sand and/or other aggregates (typically limestone) these being usually moist, and leave it for some minutes, after which slaking will be well underway and the 'dry-mix' will be hot. At this stage, the quicklime will have been transformed into a super-fine powder (the primary reason that conventional mixers are inappropriate for hot-lime mixing), and will shimmer and flow within the mix, behaving much like a liquid. Water is then added, the mortar audibly 'quenched', and knocked up to a workable consistency, depending upon intended use. It should then be left for at least five minutes for the slaking to complete, at which time a little more water and more knocking up may be required. Water content will depend upon intended use. If the mortar is for plastering, we will tend to mix it the day before, rarely using it whilst still ‘hot’ for other than first base coats, sweetening it with a little more water just prior to application. For all other uses, immediate use is practicable although not essential. The mortar will fatten even more if left overnight. Pointing mortars may exhibit some slight shrinkage, which will be closed up the following day, during the aftercare process. It is common in North Yorkshire for hot-mixed mortars to contain animal hair, which may be to reduce the shrinkage of such lime-rich mortars. Hair is added at the slaking stage. It is characteristic of hot-mixed mortars that damping with sprays or hoses is possible without run-out of lime almost immediately after application.

4. Conclusions

Hot-mixing and hot-mixed mortars make sense of many aspects of lime work with which some have struggled during the accelerating and broadening revival in the use of lime. In the course of numerous training events, the authors have found that hot-mixing makes immediate sense to builders and tradesmen who may have used NHL but who have remained sceptical about the benefits or advantages of lime. Quicklime is also the most cost-effective of limes, and doubles in volume upon slaking, reducing the unit cost even further. It is once more readily available, is easy to use and the dangers of its use are over-emphasised. It offers technical and performance benefits over other commonly used limes. With a growing trend within the eco-housing and conservation industries for designed and relatively expensive ‘products’, quicklime and hot-mixing goes back to basics, may be made locally and on a small scale and is entirely compatible with both a sustainable and historically authentic future.

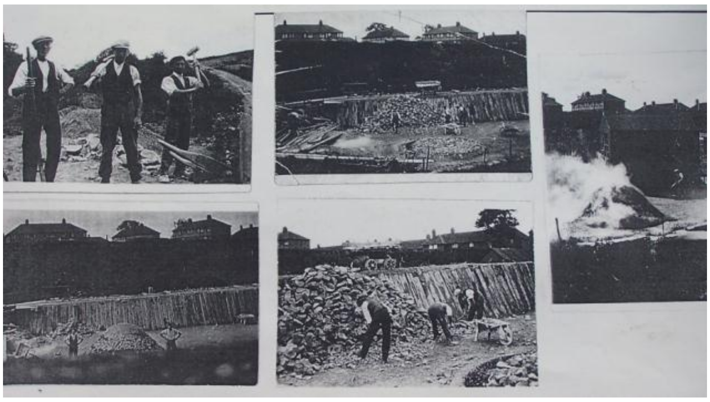

Figure 12: ‘primitive’ lime-burning in 1930s Malton (Blades).

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