TECHNICAL PAPER 28

SPECIFYING HOT-MIXED LIME MORTARS

HISTORIC ENVIRONMENT SCOTLAND
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Cover image: Gauged hot-mixed lime mortar pointing repairs at Crawfordjohn Heritage Venture, South Lanarkshire.

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SPECIFYING HOT-MIXED LIME MORTARS

ROZ ARTIS

AUTHOR BIOGRAPHY

Roz Artis

MA (Hons), MSc, Dip.Bldg.Cons (RICS), MRICS IHBC

RICS Certified Historic Building Professional

Roz is a Chartered Building Surveyor and an RICS Certified Historic Building Professional. She has been Director of the Scottish Lime Centre Trust (SLCT) in Charlestown, Fife for the past 15 years, during which time her career has focused on the appropriate repair and care of traditional buildings, particularly the reinstatement of external lime finishes. Roz is a past committee member of the Building Limes Forum (BLF UK), a Director of Dundee Historic Environment Trust and a member of the Scottish Churches Trust grants committee. She has published several papers on the practical use of lime and other mortars contributing to periodicals including the BLF Annual Journal and the Building Conservation Directory.

PREFACE BY HISTORIC ENVIRONMENT SCOTLAND

Hot-mixed mortars have a long history of use in Scotland, with evidence visible throughout the country on traditional buildings and structures. Since the lime revival of the mid-1990s however, their preparation and use has been largely superseded by dry bagged natural hydraulic limes (NHLs) that have very different properties to their historic predecessors. A renewed focus on traditional materials and questions about the compatibility and authenticity of modern lime mortars on traditional masonry structures has encouraged a revival of interest in the use of hot-mixed mortars for repair and conservation. This HES series of Technical Papers aims to assist building professionals in understanding the evidence for the historic use of hot-mixed mortars, and why these materials are still relevant. It serves as a starting point for discussion on the revival of traditional mortars in Scotland and how they fit into the wider suite of mortar repairs for traditional buildings.

Hot-mixed mortars are prepared by mixing fresh quicklime with aggregate and water, generating heat and producing a sticky, lime-rich mix. The benefits of hot-mixed mortars are known by practitioners and craftspeople, and have been documented in historic and recent texts on traditional building and conservation. They are favoured by many masons for their workability and early stiffening, allowing efficient building and economy of materials. From a specifier's point of view, they are often the best method of producing an authentic, lime-rich mix for use on traditional buildings. However, historic mortars can be complex in their ingredients and properties; matching them with commercially available materials can be challenging; there are no agreed standards for their preparation and use; and, up until recently, little guidance has been available. Concerns over health and safety of using quicklime on site, and the perceived need for specialist equipment has been a further disincentive for their specification and use.

Yet there should be nothing inherently difficult or specialist about hot-mixed mortars; and with appropriate training and guidance they can again have a role in building conservation projects. More generally, there is a need for further research and wider appreciation of the properties of traditional lime mortars: durability without high strength, breathability, capillarity and a sacrificial nature – but these qualities must be seen in the context of good building detailing and maintenance, without which defects and failures will inevitably occur. This paper considers the route to successful specification of hot-mixed mortars on conservation and repair projects. It also considers areas where further research and training is required for mortar specification generally. It is hoped that the principles it sets out can be adopted more widely and result in better quality and more appropriate specifications for traditional lime mortar repairs in Scotland.

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1. INTRODUCTION

In recent years there has been a growing interest in the use of ‘hot-mixed’ lime mortars for the repair, conservation and restoration of traditional masonry structures in the UK and Ireland. Much of this has arisen from a renewed focus and examination of traditional lime mortars, which were usually hot-mixed, as an addition to the already available suite of mortars used in historic building conservation. Some of this resurgent interest in the use of hot-mixed mortars has come from individual craftsmen and women, or building conservation contractors working on relatively small conservation projects. On such projects, overall control of the work by the skilled craftsperson or designer can be retained, in a way that may be more difficult on large contracts. The growing confidence and interest in the preparation and use of traditional hot-mixed mortars has nevertheless left specifiers somewhat behind. Most architects, building surveyors and engineers are unfamiliar with specifying lime mortars generally, and therefore specification of lime mortar is typically based on standard proportions, adopted from other sources, or sub-contracted out to specialist lime consultants.

The author is very aware of the poor standard of mortar specifications (in general) produced in the UK and the lack of understanding of lime binders in particular. Equally, for the mainstream building contractor, ensuring their site operatives maintain the knowledge and experience necessary to produce consistent, repeatable mortar mixes (of all types) remains a challenge and has resulted in the increasing use of silo mortars on large construction sites and of ready-mixed, dry bagged mortars on refurbishment contracts where lime mortars are called for. This paper examines the challenges facing the specifier in understanding the technical qualities of hot-mixed mortars, their appropriateness as building conservation materials and how to effectively communicate appropriate specifications for mortars of all types.

2. MAKING A HOT-MIX

2.1. What is a hot-mixed mortar?

A 'hot-mixed lime mortar' is defined as a mortar "prepared on site by mixing quicklime with aggregate and water" (Historic Environment Scotland 2016).

2.2. Preparation of hot-mixed lime mortars

Today hot-mixed lime mortar is prepared by mixing quicklime (usually air or non-hydraulic quicklime which has been kibbled or ground to a powder) with damp sand. This initial stage triggers the slaking process (hydration of the calcium oxide) owing to the naturally moist state of the sand. Water is then added to achieve a workable mortar suitable for immediate or later use. In modern work, a gauging of hydraulic lime (usually dry bagged NHL) or pozzolan (reactive materials that impart hydraulicity to the mix) may be added, usually as a slurry, prior to immediate use of the mortar. In the past, additives such as wood or peat ash, brick dust or other pozzolanic materials may have been added, or remained in the mix from the limeburning process giving characteristically complex and locally distinct mortars (Figure 1).

Figure 1: Historic hot-mixed mortar in a rubble wall, showing characteristic white lime inclusions

The sequence of photographs in Figure 2 illustrates the simplicity of preparing mortars using quicklime (lump lime) and sand. This method of producing a mortar is the easiest and least labour intensive method of mortar production. Research of historic archival sources indicates that this was historically the most common method of producing a lime mortar (Copsey 2018).

Figure 2: Sequence of photographs illustrating the hot-mixed mortar production method, covering quicklime with damp sand, allowing to slake and adding water to produce a mortar

2.3 Analysis of historic mortars

The analysis of thousands of samples of historic lime mortars at the Scottish Lime Centre Trust clearly suggests that the majority of mortars, plasters and renders were prepared in this manner (Schmidt 2018). Typically, the presence of lime inclusions “whitish coloured, unmixed lumps of binder” which may be “unmixed dry powder, unmixed lime putty, re-precipitated lime or hot lime inclusions” (Forster 2012) can indicate a mortar has been prepared from mixing quicklime and sand together in one operation (Figure 1). However, it is less clear without further analysis to determine how soon after the initial mixing a mortar was used. Typically, hot-mixed lime inclusions in thin sections display a fractured nature (Forster 2012) or shape deformation (Building Limes Forum Ireland 2014).

3. WHY SPECIFY HOT-MIXED MORTAR?

There are a number of advantages in using hot-mixed lime mortars rather than modern dry bagged NHL-based lime mortars or lime putty mortars. These advantages are set out in detail elsewhere (Wiggins 2018; Historic Environment Scotland 2016) but can be summarised as follows, with consideration given to how these advantages can be realised in mortar preparation today:

3.1 Authenticity

Replicating the complex matrix of a hot-mixed mortar creates the most technically appropriate and aesthetically pleasing mortar work. The visual characteristics of hot-mixed mortars have long been recognised; indeed in the decades since the lime revival of the 1990s it was not unheard of for crushed chalk, limestone or shell to be added into repair mix specifications in order to mimic the lime inclusions created by the original hot-mix process. Historically, hot-mixed mortars may have also featured remnants of the kiln fuel (coal, peat or wood ash), either accidently or deliberately added, which add a ‘richness’ to their complexity, that is sadly lacking in today’s high purity quicklimes. Historically, quicklimes would differ widely in terms of their technical performance and appearance (primarily colour) around the country depending on geology, the fuel used and the method of burning.

Locally specific limestone cannot routinely be specified today, but may be appropriate on small scale lime burning conservation projects where a local source is identified, for example works undertaken at Balmerino Abbey in 2016; the conservation of Kiln 11 at Charlestown Limeworks in 2000; and the consolidation of the garden walls at Culross Palace in 2006. Unfortunately, UK derived quicklimes today are ‘hard burnt’ (Oates 1998), that is, burned at temperatures above 1100°C (Holmes & Wingate 1997). These high calcium limes are primarily produced for steel fluxing, water treatments, chemical applications and ground consolidation works, a very small proportion being for use in mortars in hydrated form. For the bulk of their non-building applications high purity is desired. There is no current lime burning facility in the UK exclusively producing lime for building work. The physical form of the quicklime in the past has been as ‘lump lime’, basically the same shape as the pieces of limestone that were fed into a kiln. Today, quicklime is commercially available in ‘kibbled’ or ground powder forms which are unlikely to exactly replicate the frequency and size of lime inclusions found in historic mortar work.

In addition, sources of aggregates today may be very different to those exploited historically for lime mortars, especially if the '400 yard' rule was applied, meaning that for bulky building materials such as stone, brick, lime and sand, the most local source would be used. In terms of aggregates this might be beach, river or pit sand. Today, aggregate quarrying is a much more large scale, industrialised process, though it is possible to closely 'match' most aggregates derived from historic mortars with reference to national sands and aggregate databases. Where beach sands have been used historically, it is possible to mimic these by the addition of crushed sea shell for example. While the authenticity of a hot-mixed mortar as a means of preparation is not disputed, achieving a visual and technical match can be more difficult where local materials are no longer available.

3.2 Performance

Increasing numbers of practitioners feel that the performance of hot-mixed mortars are superior to today's slaked lime and sand mortars (whether they be putty or NHL based mortars) in terms of their tenacity, stickiness and durability, mostly owing to the fact they are usually much more binder rich than their dry bagged lime mortar equivalents. The superior performance of hot-mixed mortars can be explained by its microstructure (Wiggins 2018). Typically, hot-mixed mortars are found to contain 1 part binder to anywhere between 0.2 – 2 parts sand (even allowing for a point count of the unmixed lime inclusions which are acting more as carbonate aggregates). Related to this is improved frost resistance; the slaking process of mixing quicklime, sand and water produces an exothermic reaction and the steam produced can effectively entrain air within a mortar, leaving more pore space to accommodate the expansive force of water freezing and precipitation of salts.

This heat generation achieved through slaking may also have a positive effect on the bond characteristics between the lime and aggregate. In theory, this has the additional benefit of extending the seasonal window of working with lime mortars into the winter more successfully (with the proper protection in place) without loss of performance, although traditionally the 'lime season' was generally from April until September when the risk of frost was much less likely (Scottish Lime Centre Trust 2006). Recent research (Copsey 2018) however does indicate that winter working was more common historically than previously assumed. Most traditional lime burning facilities only burnt the limestone between April and September – the winter months being used for repairs and relining of refractory bricks inside the kiln pots.

In terms of compatibility, the use of mortars that act sacrificially to the substrate is well understood (Brocklebank 2012). The use of hot-mixed lime mortars (depending on the provenance of the quicklime and/or gauging with hydraulic lime) would achieve this. The open pore structure of hot-mixed mortars translates to very high mortar permeability once fully carbonated – a 1:3 quicklime/sand mix has been tested against a 1:3 NHL3.5 dry bagged lime/sand mortar and found to possess nearly double the permeability of the NHL mortar (Brown 2017). This quality can be used to aid drying out very wet structures.

3.3 Workability

There is an improvement in workability when using hot-mixed lime mortars, which are sticky, malleable and adhere well to masonry. Workability is very important in achieving high quality work and improving efficiency on site. While often little understood by the specifier, this is well understood and appreciated by the operatives on site.

Another advantage of using hot-mixed lime mortars, whilst they are still hot from slaking, is their ability to stiffen up more quickly than more modern dry bagged NHL mortars or putty mixes. This is especially so in the case of laying hard, dense impervious masonry units such as granite, basalt, whinstone and schist type stones in a mass masonry wall, where such stones can 'swim' and 'slide' if bedded in 'cold' mortars of any type. The advantage of using hot-mixed mortars whilst still hot or warm is that the rate of stiffening is increased and the stones are less likely to move out of place. As the mortars stiffen more quickly, an efficient build rate can be achieved. Small voids in the construction are taken up by the volume increase upon quicklime slaking.

This volume increase upon quicklime slaking is of advantage in filling wall cores between two leaves of masonry and consolidating masonry arches for bridges and vaulted structures which are usually built dry with a liquid hot-mixed lime grout poured over the dry stonework. There is also some evidence to suggest that a better sand/lime bond is formed when hot-mixed mortars are prepared. This has in the past been attributed to the caustic nature of lime, whereby the hot slaking process can 'etch' the grains of sand and achieve a better 'grip' (SLCT 2006), although Wiggins (2018) suggests this phenomenon is more likely attributable to the high binder content. This is particularly evident if compared to lime putty/sand mortars which are easily broken.

The preparation of hot-mixed lime mortars is also much cheaper in terms of materials purchase, where quicklime typically retails about £11.50 per 20 litre tub compared to roughly £13 for a 25 kg bag of NHL. The volume increase on quicklime slaking yields twice as much binder and therefore more mortar than dry bagged or putty based mortars. Manufacturers and suppliers should be able to provide a figure for the bulk density of their quicklime to allow accurate proportioning and batching of hot-mixed mortars.

The preparation of hot-mixed mortars and limewashes also allows for the incorporation of a variety of animal fats and vegetable oils to increase the water repellency of the mortar, an effect which can be used to advantage given an increasingly wet climate. The heat generated melts and leads to saponification of the fat – forming a calcium stearate soap – for example, tallow limewash. There are many historical documents referring to the preparation of mortars by the hot-mixed method going back to Vitruvius' *Ten Books of Architecture* (over 2,000 years ago) right up to the 1951 BSI Code of Practice 121 for masonry. Many of these have been well documented in Building Limes Forum UK publications over the last twenty years. Historic Environment Scotland have commissioned research into this archival evidence base as part of their hot-mixed mortars research programme (Copsey 2018).

Another advantage of making mortars by the hot-mixing method is the relative ease of preparation, depending on the scale of production. For smaller jobs, with smaller requirements for volume mortar production, it is easy to see how simply mixing the three ingredients could be convenient for hand production on a hard standing or in a metal bath.

3.4 Challenges

The author's experience is that the production of large amounts of hot-mixed mortar requires certain types of mixer in order to ensure the ingredients are combined correctly and safely. During the recent reconstruction of the Botanic Cottage in Edinburgh, the specification required the production of a hot-mixed 'coarse stuff' for gauging on site with natural hydraulic lime. The masonry contractor only had access to a 5/ 3.5 'brickies' mixer (a free fall rotary drum mixer) for the production of the large volumes of mortar that the job required. The first trial production was unsuccessful, with slaking quicklime (kibbled) billowing out of the mixer, causing a hazard. A certain amount of water has to be added to get the materials to 'turn' in these mixers and this resulted in a hot slurry being produced due to the rotary action. Despite trying different methods of loading the materials, the contractors were not able to achieve a satisfactory mix in terms of consistency or safely. In the end, the Scottish Lime Centre Trust made the hot-mixed coarse stuff in its own forced action mixer (300 litre capacity) safely and well mixed and it was transported to site for gauging with NHL 5. The masonry contractor had not been appropriately instructed or trained in the preparation and use of hot-mixed mortars. This highlights the importance of a detailed specification and description of works, careful contractor selection and appropriate training for contractors being included as part of the project brief.

4. CAUSES OF FAILURE

4.1. Slow slaking

With the resurgence in the interest of using hot-mixed lime mortars there has been some debate about the point at which these mortars are used after mixing. Recent research into historic texts (Copsey 2018) shows clearly that the point at which the mortar was used depended very much on the application. For building work, it was typically used while still fresh and 'hot', while for finishing work it was used when well-matured. The appropriate point at which a hot-mixed mortar is used is critical to the success of work, particularly for external finishes. While the majority of historic lime mortars were prepared as hot-mixed mortars, further research is required to demonstrate how soon after mixing they were used, stored, or modified with additives. Practice may vary depending on the materials available, the proposed use of the mortar, and local traditions. Thomas Hamilton's 1818 specification for the construction of the monument to Robert Burns in Alloway called for the "lime to be kept in the state of shells covered up with sand and slaked only at such lengths of time before using as shall from the nature of the lime be directed by the inspectors and must be mixed up with the sand whilst hot". However, in ancient Rome, highly polished and painted lime-plastered walls were sometimes found to be 'pitting and popping', disrupting the surface finishes. As the damage can be avoided by using well matured lime, a law was passed to ensure that lime for finishing plaster was stored as a lime putty for at least three years (an early example of a building standard). There are many schemes of historic lime plasterwork which show that the undercoats were prepared as hot-mixed mortars, which would then be laid down to mature; ancient methods that have continued into good practice for plasterwork today.

4.2. Slow carbonation

It is important to remember that commercially available CL90 quicklimes are pure high calcium limes and so rely on carbonation to achieve a set, unlike hydraulic limes. At depth, where a hot-mixed lime mortar has been used in the core of a newly built or repaired wall, the carbonation process will take many months, even years to occur fully while carbon dioxide in air and dissolved in moisture reaches the pore structure of mortar far from the surface of a structure. Strength gain is slow during carbonation, so new mortars should be protected from frost and rain. Unsightly streaks of lime appearing on the surface caused by migration of free lime leaching from uncarbonated mortar is a risk after binder rich hot-mixed lime mortars have been placed (Figure 3). This again highlights the need to consider including provisions to manage the curing process after new work is completed. This could include protecting the work in exposed or wet locations at certain times.

4.3. Wet or exposed locations

The hot lime mortar project undertaken by Building Limes Forum Ireland has found that hot-mixed lime mortars do not perform well in situations of high exposure or constant dampness (BLFI 2014). In such conditions, a hydraulic set is essential and this can be achieved by gauging NHL hydraulic lime or a pozzolan into the mix. Experience has shown however that at least 25% of the binder content in a hot-mix must be hydraulic lime before any hydraulic set becomes discernable. More durable mixes can be made with the lime component comprising two to four parts NHL hydraulic lime to one part quicklime. The performance of these mortars can be adapted to suit more exposed or wet conditions. Gauged mixes retain some of the workability, adhesive and frost resistance advantages of quicklime, yet improve the durability and absorbency control of the cured mortar by adjusting the hydraulic component and other additives.

4.4. Unpredictable materials

There have been several cases where hot-mixed mortars have been used as exterior finishes where later surface disruption has been observed. This is due to slow and delayed slaking of particles in a particular brand of hard burnt quicklime (Figure 4). Figure 3 shows a hot-mixed mortar (air quicklime) laid ‘hot’ as bedding mortar for granite masonry that has not carbonated in over five years after placing. Poor carbonation is not specific to quicklime mixes, and can occur with all types of mortar mixes, as a result of poor preparation and aftercare; however this particular source of quicklime has inhibited carbonation owing to its dense nature. Knowledge of the available products on the market, and appropriate specification of materials can prevent this type of failure.

Figure 3: Leaching of mortar caused by poor building detailing and excessive wetting of masonry

Figure 3: Pitted harl finish caused by the expansion of a particle of slow slaking quicklime after placing

4.5. Avoiding failures

Mortars (of any type) can perform poorly or fail for all sorts of reasons, most often through poor workmanship, inadequate or inappropriate specification and lack of appropriate detailing elsewhere on the building. Issues of poor workmanship can include: poor choice of materials, too much water, freshness or otherwise of the quicklime being used, inaccurate proportioning of materials, not having the right plant and machinery available for mixing (requisite for the size of the job), using the mortar at the appropriate interval after initial mixing, poor preparation of the substrate, application techniques, finishing and aftercare of mortar work. All of these issues are common to all types of mortars, not just hot-mixed mortars. Some practitioners feel that hot-mixed mortars can be more forgiving of some of these issues, particularly of proportioning and mixing methods. This does not relieve the specifier of the duty to provide detailed and appropriate specifications and descriptions of work, including the need for training/demonstration and sample panels where appropriate.

Unfortunately, lack of attention to these issues in detail is typical at specifier level and consequently at contractor level. The production of inadequate specifications is commonplace, failing to set out the requirements properly and neglecting to identify and remedy other defects on a building which compromise the success of mortar work. Often the responsibility for these elements is simply passed on implicitly to the contractor. The matters of poor substrate preparation, failure to rectify existing building defects, or shortcomings such as inadequate detailing, poor proportioning of mortar ingredients and the lack of aftercare of mortars can all lead to failure. Addressing these aspects adequately is important for all lime mortar specifications.

With hot-mixed mortars, the issue of choosing the right quicklime and ‘resting’ the mortar appropriately (to avoid slow slaking) are of paramount importance to the success of the work. All hard-burnt quicklimes can exhibit slow-slaking, depending on the source and method of manufacture, but the quicklime produced at both Shapfell and Buxton in Northern England are widely regarded to be less prone to this phenomena than others. Slow slaking is less of a risk for rubble-core or building work, but unreliable quicklime sources should nevertheless be avoided.

5. DEVELOPING A SPECIFICATION FOR LIME MORTAR REPAIRS

A guiding principle of building conservation is ‘conservative repair’ – often defined more specifically as ‘like for like’ repairs. This is laudable, but if followed dogmatically it does carry a risk if consideration is not given to changes in the buildings’ environment; changes that have taken place in use or design; the nature of the repair proposed; site conditions; and the nature of the substrate being repaired. All, some or none of these factors may have been considered when the building was constructed. Thus, as with all repair work, a mortar specification should be ‘fit for purpose’, which should include attention to authenticity, appearance, texture and finish, particularly for traditionally constructed or listed buildings. Specifiers should be able to develop a repair strategy tailored to the building. This requires a good understanding of the many factors involved in order to prepare a strategy, including a limework specification that will produce the required performance outcomes. The following aspects should be taken into account:

- Prevailing site conditions
- Stone (or other masonry unit type) type, absorbency, strength, finish and condition
- Location and function of the mortar (bedding, pointing, surface finishes etc)
- Building details
- Exposure
- Season of working
- The cultural significance of the building and how the repair strategy affects this
- The character and appearance of the building being repaired

The choice of mortar for bedding and weatherproofing is as critical to the performance of a wall as the masonry units and associated detailing. By using different binders, sands or aggregates, additives and finishes, it is possible to design mortar mixes that can achieve a wide range of performance characteristics. Critical to this is not only a good understanding of the performance characteristics of the range of materials available, but also delivering good working practices on site.

5.1. Factors to consider

All mortars for the repair of traditional masonry and timber framed buildings should satisfy the following performance criteria:

- Have characteristics compatible with the natural stone (or other masonry unit type)
- Have adequate bond strength
- Have a degree of flexibility (this is measured by the modulus of elasticity)
- Be vapour permeable (in so far as it must be more vapour permeable than the masonry units)
- Be selected to provide the correct balance between permeability and absorption, suitable for the level of exposure & wetness of the environment
- Be durable
- Be capable of being finished to achieve the desired visual appearance
- Remain workable for long enough to allow details to be fashioned
- Provide the correct colour and texture
- Absorb water sufficiently in wetting and drying periods to match adjacent natural stone components
- Be reversible, i.e. never becoming so strong as to make repair by removal and replacement impossible without permanently damaging the host substrate

In addition, mortars should never:

- Become significantly stronger than the background
- Have a lower rate of absorption or adsorption than the surrounding units
- Create a barrier to diffusion
- Promote adverse reactions, either by introduction from the mortar constituents or through reaction with other building materials

A specification should not only include mortar mix(es) ratios but also include the methods of making mortars, preparation of the substrate or masonry units, application methods (by hand or machine), finishing techniques and very importantly, the aftercare regime that should be put in place in order for mortars to fully cure. In this respect, conventional National Building Specification (NBS) style specifications fall short, often failing to effectively communicate the intricacies of the processes and complicated with irrelevant clauses. NBS specifications also appear to propel the notion that one mortar mix fits all elements of a building, whereas a competent historic building professional will consider all environmental, material and workmanship factors and may produce a variety of mortar mixes to suit particular areas of a building, for example above eaves level masonry, for 'weatherings', i.e. elements of a building that protrude beyond the wall face and protect masonry, walling type etc. An example of a detailed mortar specification is given in Appendix A.

5.2. Mix proportions

In terms of making hot-mixed lime mortars, using either ground or kibbled (granular) quicklime can present problems in achieving accurate proportioning, there being air spaces in both but in differing proportions, i.e. differing bulk densities. Transposing the theoretical volume required into a weight equivalent is critical to making repeatable, consistent mixes, so bulk density information should always be sought from the supplier. The use of kibbled quicklime is preferable to ground or powdered quicklime as it is less likely to create hazardous dust clouds and also prevent 'balling' when wet sands are being used.

In the UK there are presently a small number of acknowledged experts, and quite a few more who are competent and knowledgeable, capable of specifying lime mortars proficiently. Building professionals unsure how to assess the building and prepare a competent repair specification are encouraged to take paid, professional advice from experts in this field. Specifications should be carefully tailored to each job and they should not re-use a specification from someone else's job, the last job, or put the onus on the contractor who also may not have the requisite skills or experience to design mortar mixes. This is true of all mortar mixes and is not specific to hot-mixed mortars. However, because hot-mixed mortars do not come with manufacturers' instructions, and are still seen as being 'specialist,' they should not be specified without expert input at specifier or contractor level.

Inadequate specifications are often produced, even for conventional dry bagged or putty based mortars. Instructions may be limited to the amount and grade of lime to use and the amount of sand, omitting the type, grading or provenance of sand or the method of preparation, use and aftercare. Many specifications include reference to old, now defunct standards which demonstrates a lack of understanding amongst building professionals. It is not uncommon for a specification to simply require a "traditional lime mortar", leaving the contractor to make his or her own decision, invariably defaulting to standard mixes or pre-prepared mortars. There is a lack of confidence, knowledge or training amongst building professionals in specifying mortars (of all types) and a misunderstanding of the role that mortars perform in traditional buildings. This points to the need for appropriate, targeted training aimed at both building professionals and contractors. For grant-funded work to listed buildings, arguably all specifiers and contractors ought to be able to demonstrate the requisite training and expertise, or be required to undertake such training before the works are undertaken on site.

5.3. Building Standards

The current standards for lime binders under BS EN 459:1 cover air limes (or non-hydraulic), known as Calcium Lime (CL), Dolomitic Lime (DL), Natural Hydraulic Limes (NHL), Hydraulic Lime (HL) and Formulated Limes (FL). These standards are aimed at the manufacturer to know that their range of limes meet the minimum compressive strength for a particular classification (at 28 days), and are less helpful to the end user, as NHLs, HLs and FLs may continue to gain strength for up to two years after placing.

Standards that are concerned with mortars for use in the construction of masonry include; BS 5628 Code of practice for use of masonry, and BS EN 998 Specification for mortar for masonry, and are really designed for new modern construction rather than repair of existing buildings. BS 5628 covers durability requirements for NHL mortars and the grades to be used to meet particular durability designations and actually makes an allowance for the longer term strength development of hydraulic lime (at 91 days) as compared to Portland cement (28 days). Neither standards have the scope to deal with air limes or hot-mixed mortars (gauged or straight) which of course covers the vast majority of the types of historic mortars found in traditional buildings. It would be possible to design a hot-mixed lime mortar with a gauging of NHL to meet the mortar durability classes 3-4 quite easily, though for higher classes this may involve the additional requirement of pozzolans, brick dust or formulated mortars. In this context, the use of straight NHL or HL bound mortars may be the only way to meet the standard where higher durability mortars are called for (classes 5-10). It can be argued that these standards are not fit for purpose for building conservation, and that the development of a new standard for traditional masonry repair should be considered.

BS 7913:2013 Guide to the conservation of historic buildings does provide some guidance:

> The conservation of historic buildings requires judgement based on an understanding of principles informed by experience and knowledge to be exercised when decisions are made. British Standards that are applicable to newer buildings might be inappropriate…It (BS 7913) is applicable to historic buildings with and without statutory protection.

And goes on to state:

> The correct choice of materials for conservation works is important for historic buildings. Where possible, existing materials should be investigated and tested so that good performance and aesthetic matches can be achieved…In historic buildings of particular significance the mortar composition should be based on an analysis of the original mortar.

At present, there are no standards for site-mixed mortars in the UK, and as most mortars are proportioned and mixed by labourers (with little or no understanding of mortars) the room for error is considerable, whether using hot-mixed or dry bagged materials. As mortar mixes are nominally quoted by volume, proportioning binders with differing bulk densities by bucket typically results in the production of mortars with insufficient binder, too much mix water and the use of inappropriate sands. Mortar silos on modern building sites, which contain binder and sand pre-proportioned, are increasingly used to improve the consistency and predictability of modern mortars. Many lime suppliers have developed a range of ready mixed, dry bagged mortars as a convenient way of making mortar on building sites with a tight site compound, (usually city/town centre sites). Formulated ready-mixed materials are also available for the production of pre-coloured mortars for surface repair of stone mortars and renders. However, these ready-mixed materials are far removed from their historic predecessors and tend to be expensive. The current absence of standards directly concerning mortars for use in traditional building applications, places an even greater reliance on both the skills and experience of the historic buildings professional and the craftspeople on site to achieve robust, appropriate works. If hot-mixed mortars are to be used routinely on work to traditional buildings, there is a strong case for more training of specifiers in the preparation of effective repair strategies, including site and building assessment, mortar specifications, accurate proportioning of materials for traditional mortars and the production of agreed standards.

6. PERCEIVED BARRIERS TO SPECIFICATION

There are a number of perceived and real barriers to the specification of hot-mixed mortars, many of which are common to all types of lime and cement mortars. They include Health and Safety issues, both of storage and handling, mixing plant and machinery, scale of works, lack of both contractor and building professional experience in executing work and specifying (respectively); and lack of mortar performance data for using modern, hard burnt, high calcium quicklimes. The lack of available hydraulic quicklime for those areas of the UK that traditionally used hydraulic limes, e.g. the majority of Scotland and Wales, is an additional barrier to authentic specification.

6.1. Health and Safety

Quicklimes, as with other lime and cement binders, are considered to be hazardous materials by virtue of their very high alkalinity. The major difference between a quicklime and a slaked lime binder is the exothermic reaction initiated by adding water to quicklime; its caustic nature and its hydrophilic properties means that it reacts aggressively with water, slaking wherever it comes into contact with moisture. This includes moisture in eyes, saliva, and sweat on skin. Such reactivity adds to the perceived hazard. However, the 'heat of hydration' is no different to that detected in cement, and particularly natural cement binders. Slaking quicklime with water alone can realise temperatures in excess of 400^{0}C in a very few seconds. In the context of hot-mixed mortars, this temperature increase is mitigated to some degree by the bulk sand content, lowering the temperatures to between 100^{0}C and 150^{0}C at the height of the slaking process. It is worth noting that the reactiveness of quicklime upon slaking is closely related to the temperatures reached in the lime kiln and the type of limestone being burnt. Modern, hard burnt, high calcium limes are usually more reactive than historic quicklimes which contained additional mineral content (giving rise to the production of hydraulic limes) as there was less 'free lime' to slake. In accordance with the requirements of the Construction Design & Management Regulations (2015), when preparing any construction phase health & safety plan for site operations containing hot-lime works, the main precautions to be taken should include the following:

- Appropriate site induction and training of all site operatives

- The specific hazards of using quicklime require to be set out in site safety briefings
- Preparation of the working area and all lime based materials by suitably experienced site operatives
- The adoption of PPE consisting of safety goggles (with vents), face masks, long sleeves and trousers and adequate glove protection to prevent burns to the skin
- The use of appropriate plant and machinery for the scale of mortar production (open faced, vertically orientated, rotary drum mixers are generally not suitable. Horizontally aligned, forced action mixers are more appropriate, as is hand mixing on a suitable hard standing or in a metal plasterers' bath)
- Adequate and safe storage provision for materials
- The site mixing area to be organised such that mortar mixing can be undertaken under cover during inclement weather
- Mixing should not be undertaken during particularly gusty or high winds
- Production of hot-mixed mortars should be separated from other trades on a site unfamiliar with the material
- Closely controlled storage of fresh hot-mixed mortars in heat proof containers
- Provision of qualified first aiders on-site and first aid kits, including diphoterine eyewashes (not saline), located close to the lime storage, mixing and working areas
- Risk assessments & method statements along with CoSHH assessments and material data sheets kept on site as an integral part of the construction phase health & safety plan

Most if not all of the above precautions are exactly the same requirements as for producing any other lime mortar. As a specifier, the author is reluctant to recommend the use of hot-mixed mortars when the contractor undertaking the works is not known, or where the contract administrator or clerk of works is inexperienced.

7. CONCLUSIONS

The use of hot-mixed lime mortars has historic precedent, and is undoubtedly the most authentic method of lime mortar preparation available to the specifier. With the increasing interest and demand for traditional lime mortars, specifiers need to understand the materials, processes and challenges these can present. They should be given the confidence to competently specify appropriate lime mortars for a wide range of applications.

Various training providers in Scotland and elsewhere in the UK offer bespoke courses on lime mortar preparation including hot-mixed lime mortars. Training needs to be tailored, and should include instruction aimed at developing confidence in appraising traditional buildings and skills to enable historic building professionals to prepare suitable and effective repair strategies. This should include an understanding of the performance characteristics of the variety of lime materials and products to suit a wide range of applications and environmental conditions; the specifying and undertaking of works using quicklimes, dry bagged lime and other binders, e.g. natural cement, as well as a range of additives appropriate to augment the workability and final performance of mortars, renders, plasters and limewashes. There are a wide range of products available, and the designer must understand the advantages and disadvantages of different materials and methods, in order to advise clients appropriately and to competently oversee work.

Most of the issues to do with specifying hot-mixed mortars are common to all lime mortar types. Specific issues relating to hot-mixed mortars can be addressed by further training, research, education and more defined standards. The wider use of traditional hot-mixed mortars can be supported and encouraged by the provision of training opportunities for contractors and specifiers. Historic Environment Scotland's ongoing research into hot-mixed lime mortars and the development of the Hot-Mixed Mortars Collaboration with heritage agencies from England, Ireland, Northern Ireland and Wales promises to improve the level of knowledge and understanding of traditional lime mortars, and increase confidence in their use in the traditional built environment.

APPENDIX A

Example of a hot-mix mortar specification for granite rubble masonry

Mortar type A	For bedding granite rubble masonry as per the attached drawings
Purpose:	To finish joints to plane, level and texture.
Masonry unit preparation:	Do not dampen individual units
Mortar:	Quicklime/ NHL 5/ Cambusmore concrete sand
Ratio:	(nominally by volume) 1 part fresh quicklime* : 1 part NHL 5 : 4 parts sand * in unopened sealed tubs not more than 6 months old
Batching:	For an 80 litre capacity forced action mixer: 16.5kg quicklime : 11.5 kg St Astier NHL 5 : 4 No. 15 litre buckets of sand
Mixing:	Combine all the above materials in the turning mixer to start the slaking process. Add water in small amounts to achieve a stiff but workable consistency for bedding such that the mortar supports the masonry units without squeezing out unduly.

Application: Using the mortar still hot, bed the granite masonry units. Where being used for finishing as building proceeds, the excess mortar should be struck off the bed and cast or pointed back into a level plane of the face of the masonry units either by throwing and flattening off with a trowel or by placing with a trowel into hungry bed joints. Joints in masonry should not exceed more than 10mm without the use of pinning stones set in mortar as the build proceeds or well bedded where pinning for pointing work only. Use only pinning stones derived from the offcuts of shaping the granite masonry units.

Curing: Cure with light misting with clean potable water such that the mortar does not fully dry at any time within the first three days, except where the walls may be damp, not wet, in which case the work should be covered only to avoid rapid drying on the face. Keep all work covered and ensure the top of the wall is under cover capable of protecting it from direct rainfall during the time when the site is unoccupied or when work is halted because of rain. Working in wet weather on an open wall head will not be permitted.

Note – this assumes that the quicklime is a high calcium air lime from Shapfell, Cumbria where the bulk density is 1100 kg/m3.

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Historic Environment Scotland
Longmore House, Salisbury Place
Edinburgh EH9 1SH
T. 0131 668 8600

Scottish Charity No. SCO45925
VAT Number: gb 221 8680 15