SPAB Conference Report

Conservation Mortars for the 21st Century

Seminar presented by the SPAB
Tuesday 14 November 2017
St Andrew's Church, Holborn, London, EC4A 3AF
Chaired by Tim Ratcliffe, SPAB Technical Panel member and architect

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Cover images (top, left, right): Lime kiln at Amberley Museum, Repointing at the SPAB Working Party in Lumsdale, SPAB Fellow Emily Hale working with lime. Photo credits: Ralph Hodgson

Seminar Aims

Its aim was to explore past and present thinking about the use of mortars in conservation work and to consider possibilities for the future.

Speakers

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The SPAB and Mortar: an Introduction

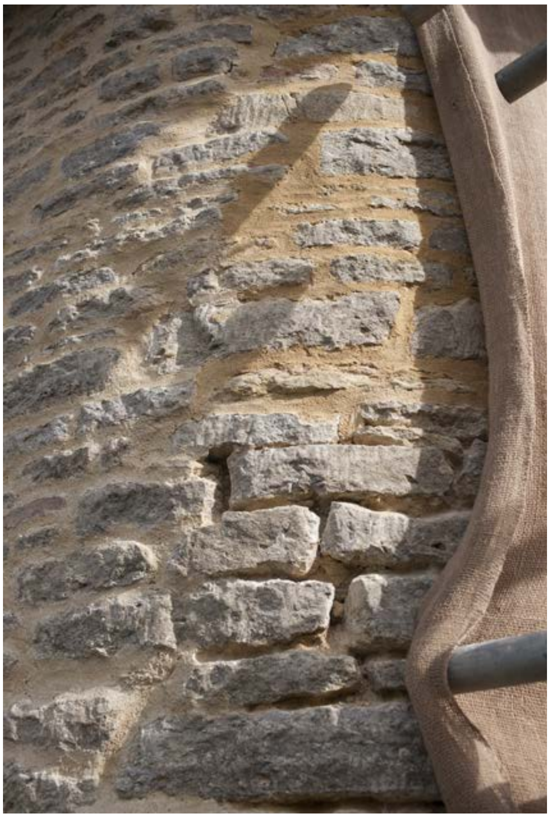
Matthew Slocombe - SPAB director

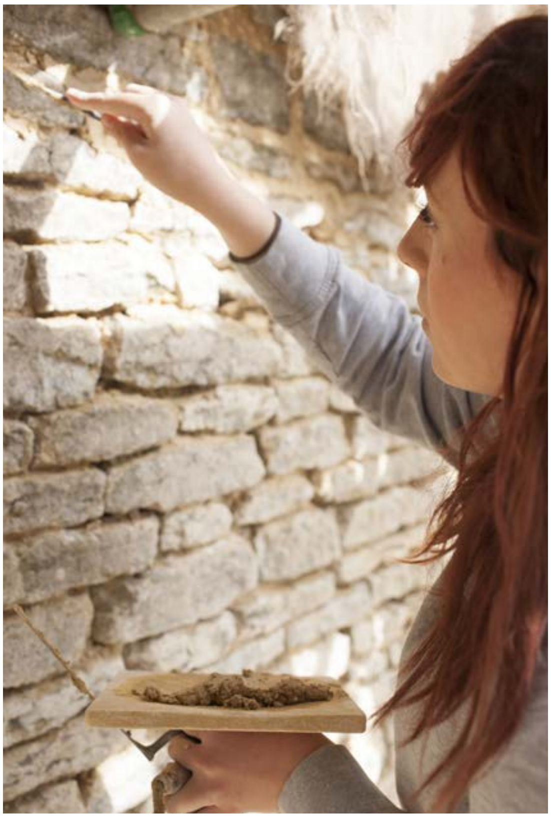
The SPAB has been interested in mortars throughout its 140-year history. Discussion offers an opportunity to consider not only the state of the 'lime revival' but also the growing recognition that earth-based mortars were once commonplace and deserve greater recognition in the conservationist's palette of materials.

Breathing Buildings: an Introduction

Douglas Kent- SPAB technical and research director

The SPAB Approach places value on the fabric of buildings. Fabric embodies history but also governs technical performance, including moisture movement and 'breathability'. Pre-1919 solid-walled buildings have many positive performance characteristics, provided the role of lime and earth-based mortars is properly understood. Post-1919 cavity-walled construction functions quite differently.





Left and right: SPAB Fellows Emily Hale repointing with lime. Photo credits: Ralph Hodgson

The Lime Cycle and Lime Types: an Introduction

Stafford Holmes - architect and SPAB technical panel member

The lime cycle illustrates how limestone (calcium carbonate) is burnt to form quick lime (calcium oxide). Quick lime can be used as it is in mortars, or slaked first in water to form putty. Limestone formations exist across the UK. When there are clay inclusions, as with grey chalk or Blue Lias, the building lime formed has hydraulic properties. This means there is some degree of set under water or in damp environments. Quarrymen knew the properties of the limestone they extracted and exploited their potential accordingly. Limestone was burnt in kilns to form lime for building (and agriculture), but the form of these kilns varied considerably across the country. Also vital to the composition and properties of mortar was the choice of aggregate, which could vary from a coarse material for rubble wall construction to something far finer for pointing ashlar stonework. An old wall can include several different types of mortar for purposes such as bedding, pointing or capping. There is a long tradition of adding materials such as wood ash to mortar for 'pozzolanic' effect, modifying the setting properties.

Mortar Selection and the Role of Mortars: Part 1

Bill Revie - construction materials consultant

Unslaked quick lime was often used to make historic mortars, but this is not always easy to distinguish. Large inclusions of lime in a mortar can indicate that it was mixed using quick lime, but equally this can be the result of residual under-burnt lime in unscreened putty and from unmixed putty. Various forms of analysis are possible. This can be done chemically, but X ray diffraction allows the mineralogy of a mortar to be explored, which can help assess hydraulicity and lime type. Additionally, chemical composition can be determined by X ray fluorescence, and by other techniques, which can often permit the source of the limestone to be established. Limestones of Scotland, published by the Geological Survey in 1949, is one of many invaluable reference works when an original limestone source needs to be identified. Aggregate composition can be assessed through petrological analysis. Exploring the cross section of a mortar sample through magnification allows the fabric and material's structure to be assessed. Through this its relative porosity can be gauged. At microscopic level, it is also possible to determine whether hydrated (putty) or non-hydrated limes were used. Putty lime mortars have a relatively 'plastic' structure. Some non-hydraulic limes, when mixed with certain sands, seem to acquire hydraulic properties, but the reasons for this need to be explored further.

Exact replication of an historic mortar is possible to achieve but this can be costly and sometimes unnecessarily complicated. It is often more practical to create a modern mortar with very similar properties. This can sometimes be done by gauging of the mortar with a pozzolan, in a proportion of about 10% pozzolan to the volume of lime.

Mortar Selection and the Role of Mortars: Part 2

Dr David Wiggins - project engineer

In old walls, moisture and salts migrated outwards through the mortar joints which were deliberately more porous than the surrounding masonry joints. This produced sacrificial weathering in the mortar. Water is the engine of decay, but salts are the primary agent of decay, mobilised by wetting and drying. Fine pores in lime mortar draw water away from the wall by capillary action. This has a poulticing effect. However, if pore size is below 200 nanometers capillary action is impaired. This is the case with cement which has a pore structure that acts as a 'plug' not a 'poultice'. NHL 3.5 is sometimes little different from cement in terms of pore size. Natural hydraulic limes (NHLs) can also have a low free lime content. Pre-bagged proprietary NHL mortars often have additives that change the mortar's surface chemistry. The chemistry of lime mortars is like home-baking: if the ingredients and mix of an old mortar are replicated the same results should be achieved in a modern version. Using a non-hydraulic lime is generally the best starting point when designing a modern mortar for an historic wall and a hot mix (using quick lime, not putty) is the best way to achieve it. Pozzolans can help modify the mortar's properties and can be valuable in some contexts, though they take a proportion (perhaps 10%) of the useful free lime

The Existing Palette of Materials

Tim Ratcliffe - architect and conference chair

In the early period of the 'lime revival', most believed that it was normal practice in the past to slake quick lime in water, producing a putty, and to let this putty mature before use. Realisation has grown that limes were in fact often hot-mixed, using quick lime and wet sand. Since transportation of materials to site was one of the greatest difficulties of construction in the past, lessening the weight of materials that had to be transported for mortar use, through hot-mixing, made perfect sense. Hot-mixed mortars could be used while still hot or when cold. Nowadays they can be obtained in pre-mixed, bagged form. Natural Hydraulic Limes (NHL) were seen for a time as a conservation panacea, but are now judged to have properties that are uncertain, particularly because unspecified additives are sometimes included, but also because hardness increases over a long period. The potential of pozzolans to modify air limes is now being re-explored. Traditionally, pozzolans included tile and brick dust, as well as porous particulates that improve carbonation. Aggregates in the mix also have an extremely important effect on the final mortar. Hydraulic limes, with a natural clay content that affects the set, were traditionally graded Feeble, Moderate and Eminent. Current European standards give an NHL rating linked to compressive strength after 28 days, though NHL mortars often continue to strengthen for up to 2 years. Feebly hydraulic UK-derived 'grey limes' had a strength below the lowest grade of modern hydraulic lime (NHL 2) but are not now routinely available. NHL 5 hydraulic lime, once it has achieved final hardness, is not far off the strength of a traditional Portland cement mix and modern cements are generally much stronger than their 19th century equivalents. The conservationist's palette now needs to embrace earth mortars as well as those based on lime.

Earth Mortars, Plasters, Renders

Alex Gibbons - earth buildings specialist

In the USA, earth has been more readily accepted in the modern era as a legitimate building material. The same has been the case in Normandy, France. In the past, builders in Normandy used earth on a grander scale than in the UK and the Normans were quite prepared to use earth even where weather impact was great, such as the on the ridges of roofs. In the UK, lime has been preferred to earth for modern historic building conservation work, even though physical evidence suggests that earth was the more common building material across the country. Being cheaper, it was used even in limestone areas where building limes were readily available locally. Lime mortar might be used for surface pointing, but earth mixes were common for bedding mortars. It is entirely possible today to carry out like-for-like repairs in earth-based materials.

Lime and earth were sometimes used in combination, with quick lime added to earth or earth added to quick lime. Quick lime in an earth mix assisted frost-proofing. Today this combination offers conservation possibilities such as a 'hot mud grouting' mix to fill holes in solid earth walls. Earth can be the most appropriate and effective material in many contexts, such as for the bedding and pointing of cobbles, and can have great durability. Sometimes, applying a lime-based render to an earth substrate produces problems. A quick lime/earth mix can be far more effective. All earth work requires regular maintenance, such as limewashing. Sub soil for building work in earth is best sourced locally and finding the right materials can be the hardest part of the exercise. Mixing is strenuous work but is greatly assisted by a roller pan mixer. Some clay is needed in a mix, and can be identified through simple tests. Fibres, ranging from chopped straw to animal hair, reed and rush are also required. Earth work carries risks when undertaken by non-specialist contractors. It is not possible to specify mixes closely because they are infinitely variable, depending on site conditions. The feel of the material is crucial and its correctness will be evident to someone with experience. If like-for-like repair of historic buildings is to be taken seriously, earth deserves more consideration, though the difficulties of specification mean that it will always present challenges for architects and surveyors.

Hot Mixed Mortars

Nigel Copsey - mason and tutor

Earth-lime mortars, containing c10% quick lime were once common across the UK. They were chiefly used for bedding, and pointed over with a lime mix. Putty lime was very rarely used as a binder before the 20th century, being considered weak in its binding qualities. Putty lime-based mortars (usually of just lime putty) seem to have been used for specialist work: gauged brickwork, ashlar and fine plasters. Otherwise hot-mixed limes were the norm. Dover's Roman lighthouse was built with a hot-mixed lime mortar and the material remained common into the 20th century. In wetter areas the hot-mix might include an hydraulic lime or might possibly be gauged with natural cement. Hot-mixing adds positive qualities to a mortar. Academic research has been mistaken to focus on putty lime and also mistaken to suggest that putty was laid down for a long period to mature, except for specialist uses, particularly fine finish plaster coats. Historically, quick lime could be in powder or lump form. Proportions might be 1:3 quick lime:sand which worked because the lime was unslaked and undiluted. In putty form, with water present, a 1:3 mix is too weak. Masons prefer a mix that is relatively lime-rich since it is then most workable. Hot lime is active, not passive in its poulticing effect, drawing moisture from a wall. There is also evidence to suggest that, if used well, hot-mixed air lime mortars can survive winter conditions with little need for the protection of work provided the building is well-detailed. Hot lime mixes contain a high free lime content and if they do not achieve full carbonation quickly this is not necessarily a defect – it can have advantages in traditionally-built flexing structures. Free lime also has value in reducing carbon dioxide in the atmosphere when it carbonates. Hot mixes are not difficult to use and deserve reinstatement as the standard lime-based mortar for construction and conservation.

20th Century Materials: Concrete and Cement

Stuart Tappin, structural engineer

Mortars and mixes used in 20th century construction need thought when their conservation is being considered. Traditionally-constructed buildings using lime mortar can stand quite considerable structural movement without failure. More rigidly constructed 20th century buildings, employing cement mortars, perform quite differently in structural terms. Joints filled with mastic were sometimes used to accommodate movement. Lack of movement joints leads to cracking, and new expansion joints have sometimes been cut crudely, in retrospect, as a remedy. A more sensitive stitching of cracks is possible. Some 20th century buildings were constructed very traditionally using materials such as brick and stone, but increasingly steel was introduced to create a structural frame or reinforcement for concrete. Embedded metal can be vulnerable to corrosion, and this can apply to reinforcement or to early cavity ties. The conservation-based repair of concrete is a new science, compared to traditional masonry repair. At Dudley Zoo in the West Midlands, reinforcement bars to some of the listed structures had sunk in their concrete during construction, leading to corrosion of the iron and spalling of the underside of the concrete. A new concrete reinforcement repair method had to be devised for the buildings' conservation with the aim of using like-for-like materials. This involved painting the exposed steel reinforcement, then applying a thin cement slurry, before a final (thin) cement mortar to the surface. The aggregate for these repairs needed to be finer than in the original concrete. Trial mixes were required and the work involved considerable skill.

Lime Research

Alison Henry - Historic England

Research always leads to new questions and HE's research should be viewed as a work in progress. It covers NHLs, hot limes and earth mortars. Work on NHLs is being undertaken by by Christiano Figuredo as part of a PhD at Bath University. Modern categorisation of hydraulic limes does not reflect performance in real life. Conventional strength tests after 28 days are far too early since NHL strength continues to be gained up to 2 years. HE initial results also suggest that conventional categorisation is misleading with, for example, some NHL 3.5 mortars becoming stronger, over time, than NHL 5s. Work has also been done on permeability and capillarity. Overall, HE results show that informed choices about conservation mortar strength are difficult to reach from British Standard NHL numbers.

HE feels that pozzolans can be useful in improving the strength of air limes to the limited extent that is desirable for much conservation work. Blended mixes of this kind seem to reach full strength earlier than NHLs, which can also be useful. HE believes that professionals should "think carefully before specifying NHLs" for conservation work. More research is planned on pozzolanic mortars.

HE's work on damp towers is being carried out at Oxford University. It suggests that wood ash can act as a useful pozzolan in mortars affected by high levels of dampness. Quick lime in hot mixes can also offer helpful expansion within joints, closing-up any voids left during the pointing or bedding process.

HE's work on hot lime mixes is examining whether there are provable benefits in preparing the mortar in this way. Considerations include pore structure, bonding potential and pozzolanic effect. Microscopic analysis suggests some steam-formed round pores may survive in hot mixes, even after knocking-up. However, hot-mixed limes are not a single product and performance will inevitably vary. Failures can be a result of conditions and specification. Workmanship and protection are very important to performance.

The final strand of HE mortars research concerns earth-based materials: "We've had a blind spot about earth" and we should "give earth a chance". HE grant-aided work at Old Barham Hall dovecote in Lincolnshire, involving conservation builder and SPAB technical panel member Anthony Goode, showed that earth mortar for bedding joints was more compatible and appropriate than the NHL mortar originally specified for repairs. The earth, excavated close to the building, worked well and took no longer to use than a more conventional mortar, once contractor-training had occurred. HE guidance on use of earth mortars is planned.

Skills for Specifying

Roz Artis - Scottish Lime Centre

Twenty five percent of professional indemnity insurance claims are the result of poor specification. Specifying for conservation requires the use of eyes, ears and hands as well as inquiry. Understanding issues including materials, construction, past alterations and failures is essential to effective specification. Specification sometimes sets out to be prescriptive (offering an explanation of everything to be done) or alternatively states intended performance (what the work aims to achieve). Whatever the approach, standard National Building Specifications are not ideal for conservation work. Lengthy written specifications also tend to be ignored by contractors. Far more effective can be illustrated powerpoints which offer visual pointers to those working on site.

Discussion

Why do NHLs differ in strength within one product?

Bill Revie: a possible factor is that material may be taken from a various strata within one area of the quarry.

Lime mortars with crushed limestone dust have produced very few failures, why might this be?

Alison Henry: possibly the limestone has some pozzolanic effect.

Nigel Copsey: fine aggregates also improve workability. Chalk flour has been used successfully as an additive. Counter-intuitively, fine aggregates don't seem to worsen shrinkage cracking either.

Ironstone has been mentioned as a pozzolan. Ironstone is one of the materials often used as galleting in mortar joints. The purpose of galleting is often debated, but might it have some pozzolanic effect if iron leaches into the mortar as it sets?

Bill Revie: gallets are more likely to have a physical than a chemical effect on the joint, but the point could be worth exploring.

Tim Ratcliffe: iron was added to mortars in the form of blacksmith's scale and this fine material certainly acted like a pozzolan, affecting the set.

What is the role of wood ash in lime mortars?

Nigel Copsey: ash was present in lime kiln debris, but it was also added deliberately for its pozzolanic effect. Wood ash and quick lime alone can produce a robust concrete. Wood ash as an additive also seems to help mortars in vulnerable locations, such as wall tops, where it appears to help counter the effects of regular wetting and drying.

Stafford Holmes: it's the aluminates and silicates in wood ash that act as a pozzolan.

Would the availability of a greater range of quick limes help conservation work?

Alison Henry: Historic England is interested to support the reinstatement of grey chalk lime production in the UK, though there are many planning obstacles. In the absence of this, pozzolans can help achieve different setting properties in non-hydraulic limes.

Stafford Holmes: builders can be encouraged to burn limes themselves.

Nigel Copsey: craft brewing has shown that it is possible to reintroduce local alternatives to large-scale manufacture. The Scandinavians are already doing this. My own lime burning in Yorkshire was initially done as an entertaining experiment, but has proved useful and economic.

Could Historc England/Heritage Lottery Fund build local lime-burning into their grant conditions?

Alison Henry: lime burning requires skill, but the possibility is worth exploring.

Why does manure assist earth-based parging, used for the inside of chimneys?

Alex Gibbons: earth-based materials often perform well without the need for any manure additive. Historically manure may have been incorporated accidentally as part of the mixing process, but the manure may help with hardening and water-shedding.

Stafford Holmes: the potassium content may be an active ingredient.

Free-lime seems to be the key ingredient of lime-based materials. A 1:2:9 cement/lime/sand mix seems to have a reasonably high degree of free lime. How useful is it?

Alison Henry: even with free lime present in reasonable quantities, porosity of cement-gauged mortars may still be limited. Feebly hydraulic limes are needed in the palette of mortars, as an alternative.

Nigel Copsey: a 1:3:12 cement/lime/sand, may have a reasonable performance, possibly better than a modern NHL-based mortar, but it will never be as useful to conservation work as a hot-mixed air lime.

Stafford Holmes: if cement is available on site, experience suggests that it will be added in higher quantities than specified. I ban cement on my sites.

Vitruvius and Palladio mention a mix of 1:3 lime:aggregate. Neve, in the 18th century, suggests caution about this, indicating that, in Italy, marble dust was a factor in choosing this ratio. What proportions are best for the UK?

Nigel Copsey: it's highly likely that Vitruvius and Palladio were suggesting a 1:3 mix based on quick lime, rather than putty lime. Engineers have urged more sand in mortars to reduce cost, but masons prefer a lime-rich mortar.

Stafford Holmes: at Haddon Hall a mix more like 1:2 quick lime/sand was used, but appropriate mixes will vary with the type of lime involved.

How might mortars be modified when issues like the presence of bats make it impossible to carry out work in ideal conditions?

David Wiggins: it is not good simply to 'strengthen' mortar in order to compensate for climatic issues. It would be better to keep the working environment warmer by a small amount of heating and to offer protection for the work.

Hot mixed mortars are surely best in winter conditions?

Bill Revie: it is not enough to rely on the properties of a hot mix, though it will undoubtedly have some benefits. Protection is still needed.

Conclusions

The presentations and discussion have shown the complexity of the subject and the many areas where greater understanding is still needed. Some practices used in the initial phases of the lime revival may not now need to be modified. However, we are learning all the time through practice and discussion and it seems likely that hot mixes and earth-based materials will feature more strongly in the future. We also need to re-explore the potential of domestically produced feebly-hydraulic lime production.

Definitions

Hydraulic lime: Natural hydraulic limes are prepared from limestone with reactive silica and alumina impurities. The impurities contribute to the hardening process. They are classified as NHL 2, 3.5 or 5, in order of increasing strength, though the bands overlap. Before 1995 lime could be classed as feebly, moderately or eminently hydraulic, though this does not correspond directly with the current natural hydraulic limes (NHL) classification system.

Air lime/pure lime: Lime prepared from a relatively pure, limestone containing no significant amounts of reactive silica and alumina. The purest type is described as 'fat', the less pure as 'lean'. These limes will harden initially by drying out and in the longer term by absorbing carbon dioxide from the air to form calcium carbonate ('carbonation'). They cannot harden under water.

Galletting: Small stones pressed into a wide mortar joint before the mortar has set.

Grey lime: Lime from chalk containing a small proportion of clay, yielding feebly hydraulic properties.

Quick lime: Calcium oxide (CaO), the unstable material produced when limestone has been burnt but not slaked (hydrated by immersion in water).

Lime putty : Slaked lime stored in an excess of water.

Free lime: Lime in a mortar which remains uncarbonated as calcium hydroxide.

Hot mix: Prepared by slaking quicklime in aggregates or earth and mixing the ingredients in the hot state as the lime slakes.

Cement/Natural cement: A quick-setting binder for mortars. Examples are Ordinary Portland Cement (the material used as the basis for mortars by much of the modern building industry) and 'natural' cements (such as Roman cement).

Earth: Sub-soil used in mortars, plasters, renders and walling. Generally mixed with aggregate and other additives including lime, straw and animal hair.

Pozzolan: A material containing reactive silica and alumina that can be used to impart a hydraulic set to a non-hydraulic lime mix, or to confer a faster set upon a naturally hydraulic lime or Portland cement mix. Typical pozzolanic materials are volcanic ashes and lightly-fired clays from crushed and ground bricks.

Aggregate: Sand, crushed stone or other materials such as broken shells, brick, chalk, earth or porous particulates. Aggregates provide bulk, reduce shrinkage and assist setting. They can also influence mortar colour.