Hot-mixed lime mortars and traditionally constructed brickwork

Dr Gerard Lynch

Dr Gerard Lynch is an internationally acclaimed and respected expert in historic brickwork, a master brickmason, carver, educator and author. He has been awarded the Silver and Gold Trowels from the Brick Development Association and is a Licentiate of the City and Guilds of London Institute. Gerard was formerly a senior lecturer as head of trowel trades at Bedford College, Bedfordshire.

During the early 1990s the author, within his writings,[1,2] lectures and practical demonstrations, sought to broaden understanding of traditional building limes and lime-based mortars for brickwork. At the time there was a rather limited focus on various air lime (also known as non-hydraulic lime or high calcium lime) binders, solely in the form of putty, which was left to mature and then mixed with well-graded aggregate. This focus not only dominated publications, presentations and demonstrations on the subject, but also was quite problematic, because what became a generalised approach to traditional lime-based mortars somewhat skewed advice, too.

As part of this work the author pioneered a revival in the, then, generally overlooked historical vernacular practice of 'sand slaking', whereby a measured volume of quicklime was slaked (hydrated) within a chosen aggregate, at a suitable ratio. Depending on the aggregate, this created either a 'coarse stuff' or 'fine stuff' mortar, which was selected, prepared and used according to purpose. He also sought to establish that it is not best practice to generalise about lime and lime-based mortars, as tended to happen in the early years of the lime revival in the mid 1970s. Rather, there is a need to recognise the different types and classes of building limes, and acknowledge that historically these differences were exploited in various ways to meet the specific needs and subtle craft nuances of bricklayers, stonemasons and plasterers (or the 'wet trades' as they are sometimes called).

Since that time, and particularly over the past four years, the subject of slaking the measure of quicklime within the sand, often termed 'hot mixing', has come very much to the fore. This has initiated a lot of writing and research, alongside some healthy discussion and debate, on how hot-mixed mortars differ from other types of lime-based mortars. It has also prompted consideration of and opinion on why, how and where these mortars were, and still can be, used within the traditional wet trades – as well as where pause and caution should be exercised.

Furthermore, along with other writers, and many within the Building Limes Forum, the author has striven to bring about a growing and more meaningful appreciation of the various geological sources of limestone across the British Isles. These limestones, once fired (calcined) to quicklime and slaked to a putty or dry hydrate, produce air lime and also different types and classes of hydraulic limes, which all have a long and successful history of use as traditional mortar binders.

Additionally, the dramatically variable geology throughout the British Isles presents a wide range of aggregate mineralogy. Historically, the combination of different aggregates and the various building limes mentioned previously contributed to notable local and regional differences in materials. There were also subtle variations in mortar preparation and use between the wet trades. This paper concentrates on the author's craft – bricklaying – and examines hot-mixed lime mortars and traditionally constructed brickwork.

Traditional lime-based mortars for brickwork

Types of lime

There are essentially two main classes of calcium carbonate lime: air lime (non-hydraulic lime) and the range of hydraulic limes, formerly termed 'water limes'. Air lime – also referred to by such craft terms as 'high calcium', 'pure', 'rich' or 'fat' lime – is generally from relatively pure sources of calcium carbonate (typically 95%+) and this creates a building lime that can only harden (not chemically set) by reabsorbing carbon dioxide from the atmosphere in a relatively slow process termed 'carbonation'. Hydraulic limes, however, both chemically set (through the reaction of reactive minerals, such as silicates and aluminates, in the lime with the calcium hydroxide in the lime to form calcium silicates and calcium aluminates) and also harden during long-term carbonation.

The degree of hydraulicity of a lime and its resultant set strength are directly related to the proportion of clay minerals within a particular limestone; they are also influenced by the firing temperature and residence time of the limestone within the kiln. From the weakest to the strongest, the historical terms for each class are 'feebly', 'moderately' and 'eminently' hydraulic limes.

Terms used historically, and by necessity within this paper, to refer to the source limestones for building limes include 'chalk', 'stone' and 'greystone'. These need clarifying in order to avoid problems in both presentation and understanding:

- Stone lime is either:
  i. Lime from hard limestone, which the ancients (Vitruvius and all writers until Smeaton in the second half of the 18th century) believed produced a hard-setting lime, or
  ii. Greystone lime, and especially the lime from grey chalk.

- Chalk lime also has two possible meanings:
  i. Lime from any chalk, including grey chalk, that might give a feebly hydraulic set, or
  ii. Lime from a relatively pure white chalk that is probably a 'fat' lime, meaning it can carry a higher proportion of sand (i.e. 1:3 or higher).

Grey chalk and feebly hydraulic lime

Across large parts of the southern, eastern and north-eastern counties of England, such as Bedfordshire, Berkshire, Buckinghamshire, Dorset, Hampshire, Kent, Lincolnshire, Norfolk, Suffolk, Sussex and Yorkshire, runs the huge seam of chalk laid down during the Cretaceous Period, 145–66 million years ago. The bedrock geology of what is termed the 'Chalk Group' all along this seam is quite complex, with beds of relatively pure sources of calcium carbonate – known as 'white chalk' – which produce air lime, and beds of 'grey chalk', which contains variable amounts of clay or shale lenses and yields varying levels of hydraulic lime.

Although air lime produced from calcining white chalk was used in some bricklaying mortars, it was particularly favoured by plasterers as the principal binder in their mortars. The grey chalk beds, such as those formerly worked at Totternhoe, Bedfordshire, are part of a bed that runs down to the south coast and extends northwards up to the Wash, with outcrops as far north as Grimsby and Scarborough. Where available, this source of chalk was always the first choice for the binder in the majority of bricklayers' mortars.

It is important to note that the expert quarrymen working the Chalk Group beds were also experienced in identifying the most appropriate chalk for particular uses, whether for agriculture or construction, within the rock strata. There was high demand for feebly hydraulic lime, which was specified frequently for bricklaying mortars on traditionally built masonry within all of the

Fig. 1 (Below) Totternhoe Lime Works in Bedfordshire in the late 1980s.

Principal Limestone Formations in England and Wales south of Catterick

Based on information from the IGS Geological Survey

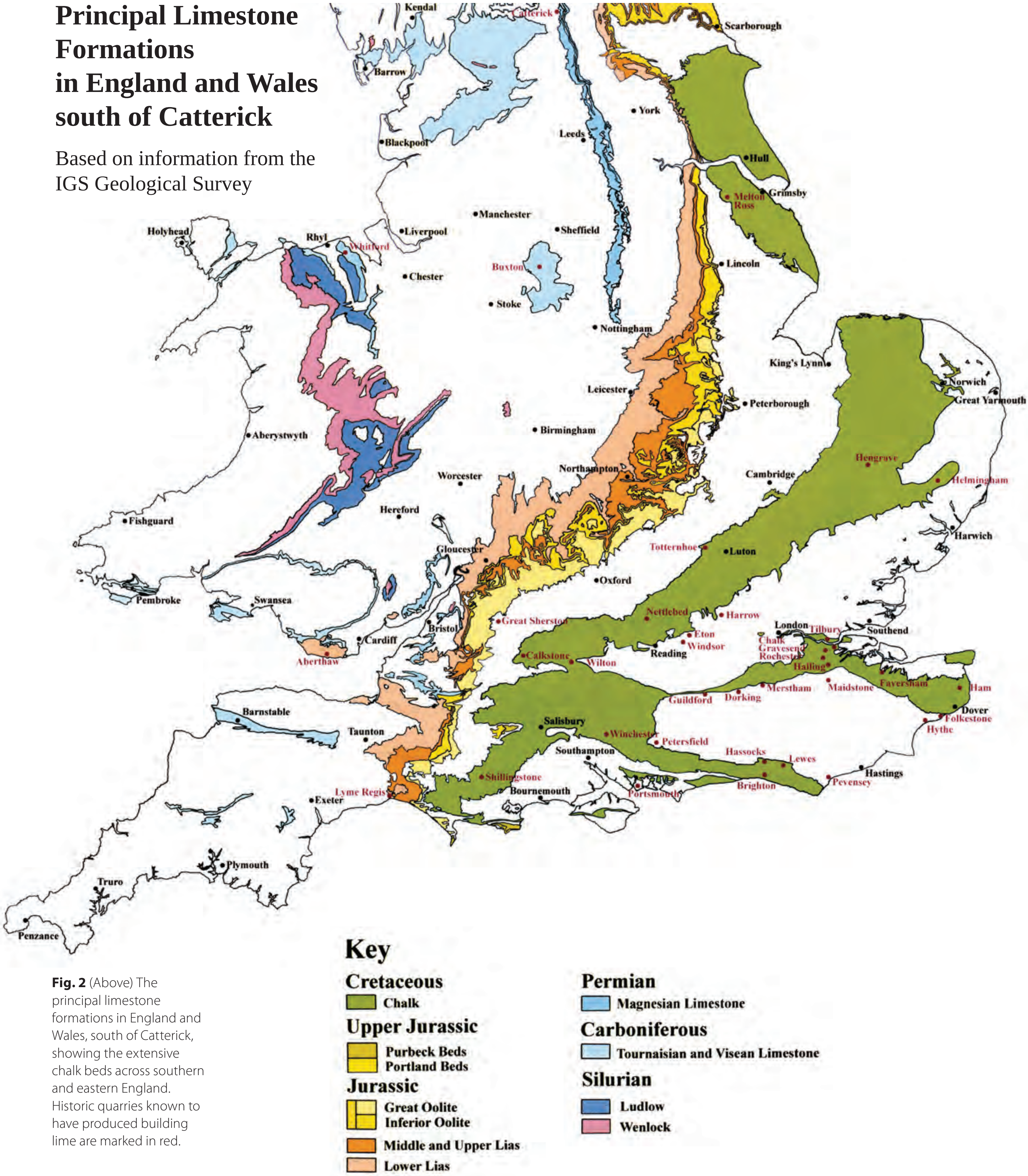

Fig. 2 (Above) The principal limestone formations in England and Wales, south of Catterick, showing the extensive chalk beds across southern and eastern England. Historic quarries known to have produced building lime are marked in red.

aforementioned counties, including London, right up to World War II.[3] With regard to producing building limes, quarrymen exploited good beds of grey chalk, which they knew would furnish feebly hydraulic lime, and other strata from the Blue Lias formation, which would yield a stronger range of moderately hydraulic limes.

Of crucial significance was the work of the highly skilled and experienced lime burners in their assessment of the quarried grey chalk to determine how best to fire it – the appropriate temperature and residence time in the kiln – to produce a consistent hydraulic quicklime.

Historic references refer to the importance of using quicklime fresh from firing, because the longer it is left, the greater the danger that it will begin to react with the ambient humidity, thus causing it to fall to a powder, or 'air slake', which all but destroys its potential as a binder. Such material was termed 'fallen lime', and its use as a binder was expressly forbidden in all bricklaying specifications; these typically stressed the importance of ordering fresh quicklime as BHP, or 'Best Hand Picked', from the kiln. Of interest: although grey chalk fires light buff, it slakes to become a delightful creamy colour.

Among the last domestic producers of feebly hydraulic lime was Totternhoe Lime Works, which worked the grey chalk of the Dunstable Downs and ceased production in 1993. Some smaller scale production of a low-end feebly hydraulic lime from the grey chalk at Shillingstone, Dorset, stopped several years later. In 2002, following the unfortunate withdrawal of BS:890, grey chalk and other slightly hydraulic limes were omitted from the new standard.

In recognition of the significant national need for reintroduction of this historic source of building lime, sterling efforts were made from 2006 by Singleton Birch to revive domestic production of feebly hydraulic lime at its Melton Ross site in north Lincolnshire, using a local source of grey chalk near Caistor. It was to be marketed as an NHL 1. Such material was, and remains, a much-needed addition to the palette of building limes. However, due to a bizarre interpretation of the rules of the new standard – EN 459 – it was not permitted that classification, and regrettably production of the lime ceased. There is now no formal classification or definition of NHL 1 in the European Standards. We have no domestic hydraulic lime production within the UK and are entirely dependent on imports. Perhaps, in light of Brexit, a case can be made for developing a standard to support production and use of grey chalk limes in the UK.

Properties of mortar for traditional thick-walled brickwork

Generally, most building stones utilised for stonemasonry are large and heavy, whereas standard bricks are relatively small units and light in weight. Consequently, the design of a bricklaying mortar plays a very significant part in helping to achieve structural integrity and stability when building standard domestic structures. The main properties sought in a mortar for brickwork are:

- Workability: comes cleanly off the trowel and spreads easily, reducing fatigue
- Cohesion: holds together when being worked
- Good adhesion: adheres completely and durably to the bricks

Fig. 3 (Left) The limekilns at Totternhoe in the 1930s.

- Stiffening rate: stiffens sufficiently fast to allow a good build rate
- Set: sets throughout the full width of the walling
- Strength: sufficient, but no stronger than the bricks
- Flexibility: able to cope with movement and deformation
- Durability: fully hardened, it resists extremes of weather and pollution
- Weatherproof: resistant to rain penetration
- Good aesthetics: depending on bond and joint thickness, the mortar typically represents between 15 and 30% of the wall face.

Bricklayers have always sought to achieve these criteria through their selection of the appropriate binder and aggregate.

What types of lime did bricklayers prefer?

An examination of the written works on brickwork at the end of the 17th century up to World War II, when widespread use of lime mortars for building virtually ended, reveals constant references to the opinion that pure white chalk was considered an inferior stone to make air lime binders for bricklayers' mortars. Greystone lime, generally understood to refer to feebly hydraulic lime that not only had plenty of workability but also possessed the all-important internal set that bricklayers required and slowly hardened by carbonation, was definitely deemed the superior binder.

An insight into the practice of 17th-century craftsmen, regarding lime used for bricklaying mortar, can be gauged from Joseph Moxon, who was advised by Venturus Mandey, an influential master bricklayer to the City of London: 'There are two sorts, one made of Stone, which is the strongest, and the other of Chalk, being burnt in a kilne.'[4] Moxon continued: 'The lime that is made of Soft Stone, or Chalk, is useful for Plastering of Seelings and Walls within Doors, or on the inside of Houses, and that made of hard Stone, is fit for Structures, or Buildings, and Plastering without Doors [Outside].' This opinion is restated in a manual by Richard Neve, published in 1703.[5]

Adam Hammond, operating in London and discussing the same subject during the 19th century, advocated the use of the feebly hydraulic limes obtained from the grey chalk seams of Dorking, Surrey, and Halling, Kent. He dismissed air lime as a binder for brickwork, stating: 'Chalk lime is seldom used in London for outside work, because it sets [hardens] so slowly, and in damp places never sets [hardens] at all. But it is used to a great extent for plastering inside where there is no dampness.'[6]

By the end of the 19th century, these concerns were still held, as evidenced in Charles F. Mitchell's *Building Construction – Advanced Course* (1893), which emphasised: 'Pure lime mortar built in thick walls never hardens nor sets, but crumbles to a friable powder. For this reason pure lime should be avoided for constructional work.' Discussing hydraulic limes, he stated: '...[they] do not depend on external agencies for their setting properties; they are liable to set in the centre of thick walls and under water. This renders them valuable for all constructional work.'[7]

Writing in the 1930s, William Frost commented that for brickwork: 'Lime is still the chief component of mortars in general, although cement [OPC] is being more largely used in important building operations.' He remarked: 'Pure, fat or rich limes are generally used for internal walls, plastering and repair work. They have little strength.' And concluded: 'Hydraulic lime, such as Dorking grey lime, is a moderate hydraulic lime and is used extensively in London and the provinces for the making of mortar.'[8]

By the mid 20th century, by which time traditional lime-based mortars for thick-walled construction were fast being replaced by stronger OPC-based mortars for use on thin-walled masonry designed by structural engineers, William Blaber – writing solely on brickwork – made the following observations: 'Rich limes...are entirely dependent on external agents for setting [hardening]. They are chiefly used for interior plasterers' work... Hydraulic limes contain certain proportions of impurities, which during calcification combine with the lime and endow it with the valuable property of setting under water or without external agents... The principal limes used in making mortar for constructional work are of the Greystone variety...' He concluded: 'Pure lime mortars built into thick walls never harden on the interior. The crystallisation of the exterior of the joint when set prevents access of carbon dioxide to the inside of the wall. For this reason, pure lime mortars should not be used for constructional work, only those which are not entirely dependent on external agents.'[9]

How did historic bricklayers build brickwork if they only had air lime binder?

Where the local source of limestone was relatively pure and the only binder for brickwork was air lime (although there would have been some slight beneficial hydraulic action through contamination of the quicklime within the kiln from the ashes of the wood or coal fuel), the usual way to overcome the lack of set of air lime, and its ultimate lower strength as a hardened mortar, was simply to widen the overall width of the brick walls. This increased their dead load, which in turn helped to better resist the expected level of compressive and, particularly, tensile loading.

By the 17th century, as knowledge of the use of natural pozzolana and artificial pozzolans arrived from Europe, it became possible to add some types of these materials into lime-based mortars to provide a degree of hydraulic set. However, this was not common practice in standard domestic brick construction. The revival of the use of pozzolanic materials in masonry was influenced by the Renaissance and the slow transfer of classical material knowledge and craft practices from Italy to England, largely via the Netherlands. Dutch trass, a pyroclastic material used in the masonry of dams, harbours and canals in the Low Countries, was imported into Ireland to be gauged with the lime mortar in the building of the vast brick walls of Jigginstown House, County Kildare, in the 1630s, under the direction of master brickmason John Allen. The use of trass was deemed necessary to enable the air lime mortar to gain a good hydraulic set in the notoriously damp climate of Ireland, and to help the tall brick masonry gain compressive and tensile strength as quickly as possible in order to be able to withstand the inclement weather, particularly the high winds.

The rise of moderately and eminently hydraulic lime

Although there were exceptions, the main use of the stronger classes of hydraulic lime (moderately and eminently hydraulic limes) within masonry mortars largely dates from the changing constructional demands seen from the 18th century onwards. These were popularised through the works of civil engineer John Smeaton and his experiments with locating, testing and successfully utilising Blue Lias lime on the rebuilding of the Eddystone Lighthouse (1756–59), off the coast of Plymouth. He and other engineers made extensive use of lime from the Blue Lias formation, which yielded both moderately and eminently hydraulic limes. These stronger classes of hydraulic lime were suited to the demands of the Industrial Revolution – for the construction of large commercial buildings such as warehouses, factories and mills housing machinery – as well as the civil, marine and military engineering requirements of a growing British Empire.

Preparation of bricklayers' mortar

Traditionally, mortar making was considered a vital skill. It demanded sound knowledge, meaningful experience and a pragmatic understanding of the variations within the local sources of limestone and aggregates, and of how best to utilise them to produce quality mortars, plasters and stuccos to suit the craftsmen and the intended purpose. However, the ubiquitous use of terms such as 'pug' and 'muck' has served to demean mortar and its importance, which has led to the misguided belief that nowadays any unskilled operative can be tasked with preparing a mortar mix. They cannot; it is an important part of the overall finished brickwork. Preparing mortar was never a job for a general labourer, which is why we read of master mortar makers in historic accounts.

Slaking lime to putty

Although slaking lime to putty was undoubtedly a method that could be used for small building projects, it was both impractical and unnecessary where large quantities of lime mortar were required daily by gangs of bricklayers on bigger construction sites. Generally, lime putty was mostly reserved for maturing (absolutely vital to prevent late slaking, causing pitting in the finished work), screening through a fine mesh

Fig. 4 (Left) Erected during the late 1630s and measuring 448 feet (136.5 m) long, Jigginstown House, Naas, County Kildare, was one of the largest buildings in Ireland at the time. It also featured one of the earliest uses of brick. The mass-walled, polychromatic brickwork of red- and buff-coloured bricks was built using a lime-rich mortar based on air lime and gauged with Dutch trass, which provided the necessary strong hydraulic set that the tall and wide masonry – and the notoriously damp Irish climate – demanded.

Fig. 5 (Above) Chicheley Hall, near Milton Keynes, Buckinghamshire. This red brick, Baroque-style country house was built between 1719 and 1723 and has a facade of ashlared gauged brickwork.

Fig. 6 (Right) The upper storeys of the house (above the platt band) were constructed using fine red rubbing bricks with narrow joints of feebly hydraulic lime putty and fine silica sand, or 'fine stuff', contrasting with the wider jointed brickwork of the lower storey, laid in a hot-mixed feebly hydraulic lime mortar.

to remove oversized inclusions, and mixing with sand for the 'fine stuff' applied by plasterers on the floating coats of internal plaster. For brickwork, putty was used by brickmasons for setting gauged brickwork, where the special rubbing bricks were worked to fine degrees of accuracy so that they could be dip-laid with joints of approximately 1 mm thick; even then, the preferred binder was greystone feebly hydraulic lime for their matured fine stuff. Putty was never used hot and fresh.

Sand slaking lime to a dry hydrate for a hot-mixed lime mortar

Elaborating on the brief description given earlier, sand slaking was undertaken as follows. A volume of quicklime, traditionally in the form of small lumps the size of nutmegs (ground or fine granular lime is not traditional for air lime or feebly hydraulic lime, but rather a more recent practice), was added within a ring created in the centre of the measured volume of sand. The common ratio was 1:3 quicklime: aggregate.[10] That said, other ratios were sometimes recorded in historic texts for bricklaying mortars. If different ratios were utilised they usually related to other areas of the building – particularly internal brickwork, such as 'backing-up' facework, partition walls and party walls – where bricklayers felt they could save on the amount of lime binder. Alternatively, other ratios might have been used with sand that demanded a different lime content, such as fine soft sand that required a higher lime binder content to produce a workable, durable mortar. When utilising a well-graded aggregate at a ratio of 1:3, the resultant mortar mix was traditionally termed 'coarse stuff', whereas with an aggregate of finer, regular-sized grains, the mortar was referred to as 'fine stuff'.

Due to modern industrialised production methods, quicklime granules and powdered quicklime are now in use rather than the traditional lump lime. The difference in bulk density of the different forms needs to be taken into account when proportioning mixes, particularly when measuring by volume.

To ensure a good sand slake, it is essential that an established measure of water to suit the type and volume of quicklime is used. This is poured evenly over the entire quantity of quicklime, and the sand is drawn quickly over it to enclose. Within this dome of sand, the quicklime reacts with the water in an exothermic reaction as it slakes. It breaks down to a crude dry-hydrated lime and increases in volume. The speed of reaction, evolution of heat and increase in final volume of the slaked lime are dependent on the type and class of lime. During slaking, a typical feebly hydraulic lime from grey chalk quicklime will double in volume, so that the initial 1:3 ratio will often be found to have created a final mortar mix with at least a 1:1.5 ratio. In other words, the ratio of lime to sand is doubled. The more hydraulic the lime, the slower it will slake, the lower the temperatures generated and the smaller the increase in volume. A pure air lime, however, always increases in temperature the fastest during slaking and increases the most in volume.

The time required for the quicklime to fully slake within the sand depends on the overall volume of mortar being made. In small-scale demonstrations – in which a wheelbarrow full of mortar might be used – an hour might be sufficient. However, insufficient heat would be gained to create the kind of breakdown seen when using bigger volumes, such as a cubic metre or yard. Larger volumes naturally create more heat and therefore slake more readily and rapidly. Essentially, the effectiveness of the slaking action is reflected in the speed with which the enclosing dome of damp sand changes colour and lightens as its natural moisture content dries out with the heat.

Fig. 7 (Far left) The measure of sand is formed into a ring and the appropriate volume of quicklime is placed in the middle.

Fig. 8 (Left) The correct amount of water is poured over the quicklime.

Fig. 9 (Far left) The sand is drawn quickly over the quicklime to cover it fully as slaking starts.

Fig. 10 (Left) As slaking continues the lime expands, creating fissures in the covering sand. It is tamped down with the back of a shovel to keep in the heat.

Screening and punching the dry-mixed material

Once slaking is deemed complete, the dry-hydrated lime and enclosing dried sand are mixed thoroughly by turning them over three times to ensure that both materials become fully integrated. During dry mixing, the aggregate also acts as an abrasive that helps to break down the small lumps of lime that might appear solid yet easily crumble into powder to the touch. The resultant dry-mixed mortar is usually 'screened' by being shovelled up and 'punched' (thrown) through a large inclined screen of a suitably sized steel mesh. This process helps to remove all oversized inclusions that might later interfere with precision bricklaying with accurate bed and cross joints.

W. B. McKay's remarks on the traditional practice of screening the mortar emphasise how using unscreened mortar whilst hot would never suit traditionally built brickwork: 'If slaked nodules (small round lumps) were mixed with the mortar and built into the joints of a wall, delayed slaking might cause much damage to the brickwork. Hence, in order to remove any unslaked particles, it is necessary to pass the lime after slaking through a screen and only that which has passed through the screen is made into mortar.'[11]

This practice was particularly important when small-scale lime burning was the norm and the inclusion of some poorly burnt lime was to be expected. Today, mechanical production results in reliable, evenly burnt quicklime, which may well eliminate the need for screening at this stage.

All screened mortars for bricklayers were termed 'front mortars', denoting that they were best quality. They were traditionally used for the outer face brickwork, or the facades. It is important to note, however, that not all bricklaying mortars were screened, particularly if they were intended to be used for footing courses, internal walling or 'backing-up' brickwork (brickwork behind the facework). Although these unscreened mortars appear rather crude, with an obvious greater amount of larger sized lime (and sand) inclusions, this must not be seen as evidence that they were used

Fig. 11 (Above) When the lime has finished slaking, it is turned with the shovel to mix it with the dry sand; this starts to break down some of the lumps of lime and aggregate.

Fig. 12 (Right) The dry-mixed material is 'punched' through a mesh screen.

Fig. 13 (Below right) Once passed through the screen, the material contains no lumps and can be used for laying facing bricks.

hot. Like all bricklaying mortars, unscreened mortars would still have been mixed with water and left to bank (mature) for a period of time before being knocked-up (reworked) and used.

Adding water to the dry-mixed material

Once the slaked lime and aggregate have been dry mixed and fully integrated – whether screened or unscreened – water is added to create a mortar. Mixing a mortar by hand involves creating a large hollowed-out ring within the centre of the mix and pouring in the clean potable water. A long-handled larry (similar to a drag hoe) is used to circle continually around the heap while drawing the inside face of the dry-mixed mortar into the pool of water. The water is topped up as necessary, until all of the mix is sufficiently moistened. Then, to finish to the desired consistency, shovels are employed with vigorous turning-over, chopping and beating actions in order to truly work up the lime content and consolidate the mortar. Moxon emphasised the benefits of this historic practice, stating: '...beat all your Mortar with a Beater 3 or 4 times over before you use it; for thereby you break all the Knots of Lime that go through the Sieve, and incorporate the Sand and Lime well together, and the Air which the Beater forces into the Mortar at every Stroak, conduces very much to the strength thereof.'[12]

On the larger sites, mortar mills (occasionally operated manually but more commonly driven by horse and then, later, powered by steam, diesel and more recently electricity) were used from the 17th century. However, these were expensive compared to manual labour, so a large number of site mortars were still being mixed by hand in the 20th century. This is evidenced in a builder's price book of 1932 by John T. Rea, who remarked in reference to machine-made mortar: 'The lime and sand should be mixed at least once dry before putting in [the mill], and without preliminary slaking for ground lime. A mill is economical for over 10 y. C. [7 m^3] per day.'[13]

Once mixed, the mortar is left to bank and then covered with suitable waterproof sheeting to both retain the moisture and keep off inclement weather. Historically, hides were used hair-side down, because the alkalinity helped to remove the hairs, which aided local tanners. It is possible that this is how the benefits of hair as a reinforcement in mortar were discovered.

The importance of banking a lime-based mortar for brickwork

Banking a lime-based mortar for bricklaying is critical. It is a vital phase because it ensures that any residual quicklime left over from the initial slaking phase has time, in the presence of moisture, to slake so that there cannot be any blistering, pitting or popping of the lime binder in the mortar once it is used. All small inclusions of lime that are visible within a mortar after the banking phase are particles of either under-burnt or over-burnt material, which simply play a role as additional aggregate. Banking also brings other benefits: it facilitates the caustic lime to etch onto and have a greatly improved connection to the aggregate. This is something that was particularly significant when aggregates were used 'as raised' from the pit, and not fully washed and largely free of dirt and dust as they are today when cold-mixed mortars are the norm. In addition, the banking phase facilitates a closer union between the lime and aggregate and allows the mortar to 'fatten up', which greatly increases its overall workability as well as its cohesiveness. This was a much-lauded feature of the greystone feebly hydraulic limes.

What is the storage time of a banked mortar?

Although it is a common belief that only mortars based on pure air lime (non-hydraulic) binders can be banked, this is not so because coarse stuff and fine stuff made from true feebly hydraulic limes from grey chalk can be banked for two or three days, as emphasised by Moxon, and few bricklayers' mortars are banked longer. However, only air lime mortars are capable of increased periods of banking, particularly favoured by plasterers.

Feebly hydraulic lime from grey chalk can be slaked and stored for several weeks as putty to be used later for setting gauged brickwork (mixed with fine silica sand and never used neat). Banked coarse stuff or fine stuff from feebly hydraulic lime, despite beginning to stiffen, has much of the workability of air lime mortar once sufficiently knocked up, yet will go on to achieve a perfectly adequate internal chemical set that allows the built brickwork to progress with growing strength – exactly what bricklayers require of their bedding mortars.

Knocking-up banked lime mortar

Knocking-up a banked mortar (air lime or feebly hydraulic lime), in order to return it to a highly workable condition suitable for laying bricks, remains a vitally important traditional practice. When it is executed correctly, the benefits in helping to achieve a first-class mortar are enormous.

Moxon confirmed this ability to rework a mortar based on a feebly hydraulic lime binder from grey chalk when he stressed: 'If I might advise anyone that is minded to build well, or to use strong Morter for Repairs, I would have them beat the Morter well, and let it lie 2 or 3 Days and then beat it again when tis to be used.'[14]

A matured mortar held in the banker will stiffen, particularly if it is hydraulic, but this must not be taken as an indication that it requires additional mixing water nor, if a feebly hydraulic lime binder has been used, as an indication of irreversible setting (like that of an OPC binder, which must never be reworked). It most certainly can be knocked up and will be all the better for it, providing this occurs within a few days of it first being banked. All lime mortars are water-retentive, so the belief that a stiffened appearance means the banked mortar has begun to dry out and needs additional water to reach the desired consistency is almost always misplaced. Simply cutting out the amount of mortar needed and reworking it, as described previously, for ten minutes, will usually return it to a highly workable condition without the addition of water. If, however, after ten minutes it has not achieved the desired condition then – and only then – a very small amount of water can be added and the mortar reworked for a further ten minutes. Adding water that is not required will always result in a mortar that will crack upon drying.

All lime mortars, and particularly those made by the hot-mixed method, improve if compressed, which is why Moxon refers to 'beating'; and is why roll-pan mixers are so very good for mixing lime mortars. Large mortar whisks can be very useful in this respect, although the action is somewhat different. In essence, the aggressive mixing actions of both types of mixer cause all of the many residual small lumps of slaked lime to break down, which increases the degree of contact between binder and aggregate, creating a more cohesive, full-bodied mortar. Whisking also helps by entraining air into the mortar.

Hot-mixed lime mortar or hot lime mortar?

Sand-slaked mortar

The traditional process of sand slaking generates a great deal of heat, so the result may be termed a hot-mixed mortar. Once the heat has subsided (signalling the slaking and resultant expansion are complete) and the slaked lime and sand have been fully mixed together, 'punched' through a screen to remove oversized particles and mixed with water to make a mortar, the mortar is by then cold. Sand-slaked mortar is not a hot lime mortar; it is a hot-mixed lime mortar.

Hot lime mortar

To make a hot lime mortar, the same initial procedure is followed. However, once water is added over the quicklime, it is mixed straightaway, while still slaking, into a full mortar – for immediate use while still hot. This type of mortar is particularly useful where speed of construction is important for thick stone walling and repointing hard impermeable stones, as well as in exposed conditions.

Hot lime mortars are not generally suitable for brickwork. This is because an assembly of smaller and lighter masonry units (compared to most stone) is unable to cope properly with residual expansion, particularly on core filling. However, there is evidence to suggest that hot lime mortar was sometimes employed for quickly laying widespread footing courses of foundation brickwork. Occasionally, it was also used in winter to combat cold conditions.

Modern lime and modern construction

Are modern air limes unsuitable for constructional brickwork?

Modern air limes present a problem for constructional brickwork because they are wholly unlike their historic counterparts from a commercial perspective. Sales to the construction and conservation sectors are really quite insignificant – around 1% – and the lime industry views the sources of 95%+ calcium carbonate as a premier material, primarily for producing chemical limes (not building limes) for major industries, such as steel, paper, leather and cosmetics, as well as for water purification, soil stabilisation and agricultural purposes.

Furthermore, these high-calcium lime sources of feedstocks are usually fired within ultra-clean conditions in highly efficient and computer-controlled kilns. Most use gas as the main fuel, which means the resultant quicklime contains no ash residue or contamination from the wood or coal fuels in traditional kilns, which imparted pozzolanic properties. Consequently, the lime is reliant solely on carbonation to harden and gain strength. Lastly, in order to prolong the shelf life of quicklime, it is given a hard burn during the later stages of firing, which was not traditional practice with lime burners and also affects reactivity, preparation and performance.

Despite this, a hot-mixed lime mortar from a modern air lime can be utilised for some individual brick replacements and repointing. It can be used in parts of the country where an original sand-slaked and matured mortar for laying the brickwork of a historic domestic building was based on either an air lime or a feebly hydraulic lime, and where the climate is fairly benign, with a low driving-rain index. It cannot, however, be used for rebuilding major structural brickwork of mass walls, or for remedial brickwork executed in persistently wet locations in positions exposed to the harsher aspects of the elements, such as copings, wall heads, parapet walls and chimney stacks.[15]

Natural hydraulic limes

The revival of interest in hydraulic limes presented problems for structural engineers, not least because they could not calculate strengths and performance criteria around the old unquantified terms 'feebly', 'moderately' and 'eminently' hydraulic. Consequently, natural hydraulic limes (NHLs) were classified under EN 459 by stated minimum compressive strengths in N/mm^2, within an ascending order of NHL 2, NHL 3.5 and NHL 5. It is important to note that these classes do not equate to the historic classifications. However, broad generalisations are not constructive because there are many differences within the mineralogical types and behaviour in use and many reasons behind the varying short- and long-term strength gains within all three classes of NHLs, and across the differing brands. Moreover, without doubt their current technical data have long been in need of updating and unifying.

Ironically, because OPC is an artificial material made by blending and calcining limestone and clay sources, during modern OPC production daily scientific testing is always undertaken to determine any mineralogical differences. This is vital in order to make appropriate adjustments to the calcining conditions within the kiln to achieve the desired consistency of finished product. Yet, because NHLs are obtained from naturally occurring limestones, companies do not see the need to test them. Although this might be acceptable when mining along a consistent stratum of limestone, most producers utilise blasting. This technique removes the full height of a quarry face, which can include several different rock strata. As the weeks and months pass, material of varying mineralogy is removed, which inevitably leads to widely differing performances of the resultant calcined and hydrated NHL within the same brand. Daily testing, like in the OPC industry, would enable manufacturers to identify all variations and to take appropriate actions to achieve a consistent product.

Modern cavity-walled brickwork and lime-based mortars

Although it is possible to erect new cavity-walled brick-built properties (with certain design adjustments and specified daily height limitations on brick- and blockwork) using traditional lime-based mortars, these will always be designed around structural calculations based on the use of NHL binders, and particularly NHL 3.5 and NHL 5. The weakest class, NHL 2, is deemed to be insufficiently strong for this type of masonry.[16] This automatically rules out traditional lime-based mortars based on an air lime binder, including those made by hot mixing.

Gauged mortars

It has been historic practice to sometimes combine a hot-mixed lime mortar from quicklime with an appropriate class of hydraulic lime (today an NHL) to produce what is termed a 'gauged mortar'. Alternatively, one can gauge into a lime-based mortar some form of natural pyroclastic (volcanic) material or certain artificially fired materials – pulverised fuel ash or ground low-fired high-silica-bearing bricks, for example – as pozzolanic additives to provide or enhance a hydraulic set. However, some types of pozzolan need to be used with caution, particularly on domestic masonry construction, as they can also impart rigidity and density into the mortar. This is not ideal because the joints are the conduits through which the walls breathe.

Conclusion

Over the years, the dedication of members of the Building Limes Forum to undertaking accurate research and disseminating their knowledge, skills and experience has helped to ensure that the lime revival continues to move forward and become ever broader in its subject areas. As Stafford Holmes stated: 'References to the wide range of building limes, including grey chalk lime, and their chemical composition and appropriate application have been given in numerous textbooks until quite recently, and historically by Smeaton (1793), Vicat (1837) and Cowper (1927). It is clear from these and many other records that grey chalk lime and other slightly hydraulic limes are an important part of the wide spectrum of building limes traditionally produced and extensively used in Britain.'[17]

From a rather limited standpoint at the start of the lime revival, which focused on air lime slaked to putty and mixed with well-graded aggregate for mortars and plasters, a wider perspective has been embraced gradually. There is now greater recognition of the many different types of historic hydraulic lime, natural cement and early Portland cement, as well as the numerous types of sand, crushed limestone and subsoil that were used by the wet trades within their mortars, plasters and renders. This understanding is part of the ongoing reintroduction of traditional materials for mortars, plasters and renders – the use of which had all but died out thanks to the emphasis on modern OPC-based mortars after World War II. It has served to provide all who are engaged within the heritage sector (and indeed the more discerning clients and professionals within the new-build sector) with a much-needed wider range of traditional materials to work with.

Although it is natural that some people will prefer certain materials and craft-specific techniques to others, it is important that this preference does not tip over into generalisation and, as a result, misinformation. With renewed interest in hot-mixed mortars, there is a need to distinguish the specific requirements of plasterers, stonemasons and bricklayers. It is also worth remembering that the ultra-pure chemical quicklimes available today are not remotely like the historic feebly hydraulic limes, so are neither authentic nor appropriate for the vast majority of standard constructional brickwork.

Linked to the revival of interest in hot-mixed mortars, there is an undercurrent that implies that the popular uses of NHLs within repair mortars are somehow now inappropriate. Undoubtedly, there are problems with the current set-up for the production and classification of modern hydraulic limes, and so it is timely and to be welcomed that important research projects continue to investigate the existing ranges and types of NHLs on the market.

The successful role hydraulic limes played historically as principal binders in mortars for traditionally constructed brickwork up until the mid 20th century should be acknowledged, as should the fact that they still have a crucial part to play in the lime revival. Yet there is a pressing need to re-examine the method of NHL production and current classifications according to EN 459. The outcomes of the various studies should be noted in order to make the necessary modifications to realign the stated strengths to those of the three historic classifications. It is necessary to do everything possible to avoid the potential for wholly divisive 'pro' and 'anti' lobbies developing within the lime revival, as that would be both unhelpful and regretful.

All the traditional materials, craft practices and subtle nuances of skills in preparing and using mortars, on both traditionally constructed and modern brickwork, must always be fully and scientifically researched and practically explored. When proven, they can then be accepted and utilised where appropriate by applying the same suitability of purpose criteria that our forefathers wholly understood and practised so successfully in centuries past.

Endnotes

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