Executive Summary

Over the past three decades there has been a renewed interest in the revival of hot-lime mortars in Scotland for conservation and restoration. The Hot-lime Mortar Project of the Building Limes Forum of Ireland (BLFI) was initiated to re-introduce the use of this technology and bring it into the field of conservation in Ireland by technology transfer.

The Hot-lime Mortar Project (HLM Project) has been supported by the Office of Public Works (OPW) and Clogrennane Lime, a subsidiary of Cement Roadstone Holdings (CRH), and funded by Clogrennane Lime and the BLFI, with grants from the Department of Arts, Heritage and the Gaeltacht, and by the Heritage Council.

Other than the successful transfer technology component, the principal objective of the HLM Project is to develop guidance on the use of hot-lime mortars as used in traditional stonemasonry. Its overall aim, however, is to make modern replica mortars available using commercially produced quicklime, avoiding the expense and environmental problems associated with individual kiln burning. It is felt that this would be more practical, have wider appeal for application within built heritage, and be more useful to the average mason doing the average job.

The HLM Project is not about boutique kiln firing for specific jobs. Other than for major projects, this is not considered to be practical, economical nor realistic. It is about using commercial supplies of indigenous non-hydraulic quicklime and adapting for the modern replication of more authentic hot-lime mortars and renders, which are of compatible performance, convenient, cost effective and inexpensive**.**

Appendix N. is the recently published Historic Scotland INFORM Guide Series, *Hot-mixed Lime Mortars*, which introduces and describes hot-lime mortars.

The HLM Project has been divided into two Phases. The output of Phase I. has now been successfully completed. The principal findings being:-

i. Experience in the preparation and use of hot-lime mortars in Scotland does transfer to Ireland and materials available are compatible with slight variation.
ii. CRH - Clogrennane CaO (Quicklime) complies with EN 459 CL90 and is eminently suitable to the design of mixes and production of mortars.
iii. Basic formulations with the principles for guidelines in the design, preparation and application of mortars & renders can now be made available.
iv. Information was gathered for the production of suitable technical literature and for the adoption of best practice giving guidance on the design, preparation and use of hot-lime mortars and renders complete with base specifications and methodologies, including aftercare, as well as Health & Safety.

Phase I. also involved demonstrations and training at Drimnagh Castle and attending Conferences and Seminars.

Contrary to general belief, quicklime, calcium oxide (CaO), is not classified as a dangerous material. It is classified as a hazardous material where the risks involved in its handling and use can be readily managed. The health and safety requirements, procedures and personal protective equipment are essentially the same as for cement and other forms of lime binders. It is now also available in a granulated (kibbled) form, which is more convenient to measuring quantities and use than the traditional 'lump' or powered quicklime. The kibbled form of quicklime has already been accepted within Agriculture for field spreading and being relatively dust free satisfies health and safety considerations.

Not only are hot-lime mortars more authentic than imported mortars, they are relatively inexpensive to produce when compared with other types of lime/sand mortars, due to the low cost of the raw quicklime and the volume increase when slaked, which is typically double the original volume. In the Irish context, the availability of an indigenous lime binder is an attractive proposition, relative to relying on the import of alternative lime binders from Europe and elsewhere.

However, hot-lime mortars should not be compared directly to the more commonly specified and used Natural Hydraulic Lime (NHL): sand mixes – these can be quite different materials; each has its place within an ever expanding and changing palette of lime mortars which are commercially available. NHLs can be used as a gauging agent when designing hot-lime mortars requiring hydraulic properties.

Section 5: enumerates the advantages and benefits of using hot-lime mortars.

It is recognised that modern *Standards* may be inappropriate for historic mortars. In addition to longer term strength tests (flexural and compressive), factors such as vapour permeability, water absorption, capillarity, etc, should be measured, as all are essential in developing a fuller understanding of how hot lime mortars perform in comparison to other mortar types and mixes used in conservation and repair work.

The prime objective of Phase II. would be to continue to provide advice on formulations and use of hot-lime mortars with further testing and development of varied mixes with different sands and aggregates, including experimentation and testing with pozzolanic materials and other additives. Particular attention will be given to regional sands and aggregates including calcareous materials which dominate parts of the country.

It is envisaged that Phase II may be divided into three separate activities: -

Continuation of Phase I. Mortar Research and Development, expand range of hot-lime mortar mixes to include:

a.a. Stone types of varying porosity/with sands/aggregates (including calcareous) with NHL gauging/hybrid mortars and their development.

a.b. As foregoing with pozzolanic materials and other additives.

a.c. Brick masonry mortars

a.d. Earth mortars & vernacular mixes

i) Demonstration Workshops.

Develop and deliver Demonstration & Training Workshops for both building professionals (specifiers) and masons (practitioners) to enhance their knowledge and understanding of the use and application of hot-lime mortars and renders based on the successful Drimnagh Castle model.

ii) Research & Development.

Facilitate the possible establishment of a research project in conjunction with the OPW and TCD under the Irish Research Council IRCET Programme for post-graduate research into hot-lime mortars and renders.

Cooperate with the BLF (UK) and others in the establishment of a research to undertake a coordinated research programme for the study and development of hot-lime mortars.

Information gained be collated and disseminated by the BLFI to the wider community through a series of publications, seminars and workshops, tailored, where appropriate, to meet specific requirements.

Due to a relatively small market size and in order to achieve an economy of scale, research and development will likely need to be undertaken in conjunction with the larger UK market. The Building Limes Forum (UK) has established a special committee on Hot-Lime Mortars and has approached Historic England in the matter. Historic Scotland has also informally expressed an interest in the HLM Project. It is also possible that CADW of Wales and the Northern Ireland Environmental Agency (NIEA) will be approached. This could lead to a coordinated programme, avoiding duplication, and to sharing of procedures, findings and results.

The BLFI wishes that this report will stimulate discussion and feedback will always be welcome.

Lastly, we must acknowledge the generous funding of our sponsors without whose support the HLM Project would not have been possible. Also, for all the assistance and dedication of the many volunteers, who gave so freely of their time to furthering the HLM Project, we owe sincere thanks.

4th May 2015 HLM Project Team

SECTION 1: INTRODUCTION

The Hot Lime Mortar Project (HLM Project) is a response to the endeavour of the Building Limes Forum Ireland (BLFI) to commission a technology transfer and applied research project on hot-lime mortars and renders from Scotland to Ireland. In conjunction with Clogrennane Lime a subsidiary of Cement Roadstone Holdings (CRH) and the Office of Public Works (OPW), the BLFI has undertaken applied research for the gathering of technical information on hot-lime mortars and related for their preparation and application. As well as being funded by Clogrennane Lime, the HLM Project has been financed by the Department of Arts, Heritage and the Gaeltacht under the Government Policy on Architecture 2009-2019 Programme (GPA) and the Heritage Council, Reps 4 Farm Building (Education & Training) Scheme, with a further contribution from the Building Limes Forum Ireland.

There has been a renewed interest in the revival of hot-lime mortars in Scotland for the conservation and restoration of stonemasonry over the past three decades, with the success of these mortars increasing as practitioners gain experience in their production and use. This has followed the development of a greater understanding of the traditional materials used in our historic structures and the potential risk to these by employing incompatible materials in their conservation and preservation.

In the recently published *Building Limes in Conservation* (Ian Brocklebank, The Building Limes Forum, Donhead 2012) the introductory paragraph of an article by Dr. Alan Forster, Heriot-Watt University, Edinburgh, *HOT-LIME MORTARS A CURRENT PERSPECTIVE*, he states; *hot-lime mortars are again being used and are perceived to have advantages over cold manufactured mortars. Little is understood, however, regarding the physical and chemical performance of hot-lime mortars.* This is despite their successful use since Roman times and indeed earlier.

Currently however, hot-lime mortars are often avoided, on the basis that they are perceived to be complex and require skill in their use and aftercare, along with consideration of health and safety. Notwithstanding this, a growing number of stonemasonry contractors are now in the position of having developed in-house skills, confidence and construction techniques in order to effectively work with these materials. Contrary to general belief, quicklime is not classified as a dangerous material. It is classified as a hazardous material where the risks involved in its handling and use can be readily managed. The health and safety requirements, procedures and personal protective equipment are essentially the same as for cement and other forms of lime binders.

For the purposes of this project, *hot lime mortars* are those where quicklime, sand and water are essentially mixed together in one operation, making a ready to-use mortar. The mortar can be applied '*hot*' whilst still slaking, or can be applied '*cold'* when the slaking has finished. In the context of traditional construction, this method was (and still is) the quickest, cheapest and easiest way to make a basic mortar. The use of such mortars, historically, is believed to have been widespread. Analysis of historic mortars reveals that a significant proportion were made and used in this way. Appendix N. is the recently published Historic Scotland INFORM Guide Series, *Hot-mixed Lime Mortars*, which introduces and further describes hot-lime mortars.

Traditionally hot-lime mortars were typically made from regional or local indigenous quicklime. Currently, in the UK and Ireland, there is understood to be five commercially available sources of quicklime in lump, granulated and powdered forms which comply with the ENV459:1 standard for Building Limes, classification CL90 and all have been used in the production of hot-lime mortars. These are known as *air limes* and are non hydraulic. Hot-lime mortars are relatively inexpensive to produce when compared with other types of lime/sand mortars, due to the low cost of the raw quicklime and the volume increase when slaked which is typically double the original volume.

Hot-lime mortars should not be compared directly to the more commonly specified and used Natural Hydraulic Lime (NHL): sand mixes – these can be quite different materials and each has its place within an ever expanding and changing palette of lime mortars which are commercially available. At present there is a relatively high level of uncertainty with regards to *what* mortars should be used in *which* applications, which is leading to reticence amongst certain practitioners in the selection of lime mortars. This increases the risk of, and often results in, inappropriate materials being specified and used.

Most NHL manufacturers provide information on the performance characteristics of their materials to help practitioners' select appropriate materials for a specific job, and assist professional advisors in the preparation of basic specifications. Despite suppliers' marketing and information literature however, Historic England in association with the Building Limes Forum (UK) are undertaking a research programme which will assess the comparative performance of currently available NHLs, to fully understand the difference between the composition of each and how this affects the performance of mortars prepared from them. It is anticipated that the results will provide specifiers, professional advisors and practitioners with the tools to permit them to select appropriate binders and mortars more effectively. The HLM Project will compliment this work in which Historic England and Historic Scotland have expressed an interest.

There is no indigenous NHL produced in Ireland (nor in the UK). Those available are mainly imported from France, Germany and Portugal.

For traditional stone masonry construction and repair, hot-lime mortars have been found by many practitioners to perform more appropriately than equivalent cold mortars, including those based on lime putty or NHL. Hot-lime mortars are generally found to be more workable, can result in increased productivity and provide cleaner work with fuller joints. Practitioners have also reported that they can be used with wet stone and sands in less favourable weather conditions, with reduced risk of slumping and leaching. In many instances they are also more authentic and cost effective. Hot-lime mortars, however, do not have as fast or predictable a set as NHLs, nor will they perform well in areas of extreme exposure or constant dampness such as the pointing of paving or work at lower levels on bridges etc. However, with the addition of a gauging of hydraulic lime or a pozzolanic additive their performance can be adapted to suit a wider range of conditions.

In effect, the HLM project will eventually result in the availability of modern replica mortars, using commercially produced quicklime instead of individual local kilns, as in the past. This will be a cost effective way of making heritage mortars more generally available, avoiding the expense and environmental problems associated with kiln burning, which can also be impractical in many instances.

There is, therefore, a need for a greater understanding of the characteristics and performance of hot-lime mortars and renders for use in the conservation and repair of historic masonry structures, and also for good practice in their use and practical advice in their application.

The Hot-lime Mortar Project of the Building Limes Forum of Ireland was therefore initiated to re-introduce the use of this technology and bring it into the field of conservation in Ireland, both to demonstrate to practitioners the ease of its production and use, and also to further the understanding of the performance of these materials.

Emphasis has been more on empirical practice of the craftsman mason than the academic, and the output leans towards the practical.

In order to achieve its main objective within a ten month time frame the HLM Project has been divided into two Phases. The output of Phase I, which has been undertaken by a focused, pragmatic yet flexible team, is the technical transfer and adoption of best practice in the specification, production of mixes and applications of hot-lime mortars and renders. Phase I. is not a research project but primarily the dissemination of knowledge and involved practical training. It is intended that Phase II. will continue this work and include experimentation with pozzolanic materials and related, as well as work with earth mortars.

This report relates to the activities and finding of Phase I. of the HLM Project with proposals for a Phase II.

Errors and omissions there will undoubtedly be, hopefully all of a relatively minor nature which will not distract from the findings of the report, and nothing that cannot be corrected in Phase II of the Project. May the report stimulate discussion and feedback will always be welcome.

The HLM Project Proposal with Terms of Reference is given in Appendix A, with the Programme of Activity in Appendix B.

SECTION 2: THE HLM PROJECT

The HLM Project is the endeavour of the Building Limes Forum Ireland in conjunction with the Office of Public Works (OPW) and Clogrennane Lime, a subsidiary of Cement Roadstone Holdings (CRH) with the BLFI Technical & Standards Committee playing a consultative role.

The principal aim of the HLM Project is to develop guidance on the use of hot-lime mortars as used in traditional stonemasonry and to establish a technology exchange between Scotland and the Republic of Ireland in this regard. This exchange is based on the practice of using hot-lime mortars in Scotland over a number of years by experienced practitioners who have demonstrated that the mortars and renders they have developed have performed well, particularly in severe environments in the West of Scotland not dissimilar to that found in parts of Ireland.

Irish members of the Team:

- Ivor McElveen, Chair Technical & Standards Committee of the BLFI
- Pat McAfee, Stonemason and Author
- Joe Connolly, Technical & Product Development Manager Clogrennane Lime Ltd
- Robert Howard, Mason, OPW National Monuments Depots, Athenry Depot
- Yvonne Doyle, Secretarial & Administration, Technical & Standards Committee BLFI

Scottish members of the Team:

- Craig Frew, Craig Frew Building Conservation Ltd.
- William Revie, Construction Materials Consultants Ltd.
- Andrew Bradley, Stonemason

The Project has been divided in to two Phases. Phase I. is as described below and Phase II, dependent on the outcome of Phase I. is as proposed in Section 12:

Phase I. activities and output of the HLM project:-

i. Evaluation of the suitability of hot-lime mortars and renders for use in the consolidation and repair of Ireland's traditional buildings, monuments and ruins.
ii. Characterisation of the performance of a range of hot-lime mortar and render mixes using commercially available Irish quicklime; Irish sourced aggregates and imported NHL's.
iii. Preparation of good practice guidance on the design, preparation and use of hot-lime mortars and renders complete with specifications and methodologies, including aftercare as well as Health & Safety.
iv. To conduct practical field trials that can be subsequently monitored to assess long term performance.

In addition to collating current knowledge and experience from within the project team, and from other individuals, companies and groups, the HLM project sought to undertake applied research to evaluate and test a (limited) range of hot-lime mortar mixes.

Four sets of test walls and sample panels were built by the OPW Stonemasons at Portumna Castle using four different hot-lime mortar mixes under the supervision of the HLM Project Team masons. Sub-samples of each mix were taken and cast into prisms and cubes for later laboratory testing. To give an indication of the properties of the mortars and assist in assessing their performance, a series of tests were selected and samples obtained from each of the mixes used in the trials. The samples were submitted to a selection of standard tests, with these repeated over a period of time to determine their properties, as the mortars aged.

Four hot-lime mortars were used, all based on non-hydraulic (air lime) binders. One a straight quicklime/sand mix, another with crushed shell included to act as seed points for carbonation, and perhaps impart a low pozzolanic property to the mix. A further two mixes were gauged with a proportion of Natural Hydraulic Lime

(NHL) of different providence which was to simulate the properties of a feebly hydraulic lime mortar, as hydraulic quicklime's are not currently available in the Republic of Ireland or in the UK.

SECTION 3: TECHNOLOGY TRANSFER: SCOTLAND & IRELAND

Hot-lime mortars, and their method of preparation were still part of standard specifications in the UK until the early 1960's. This was covered by BSI Code of Practice 121 (1951) which included a description of how to mix a mortar from quicklime. This method of mixing mortar for masonry fell out of favour early in the 20th century as Portland cement mortars became the material of choice, however, its practice with respect to plastering continued well into the 20th century.

The reintroduction of the wider use of lime mortars in the repair and conservation of historic and traditional masonry in Scotland was reawakened in the 1980's, and was championed by the Scottish Lime Centre Trust (SLCT) with the support of Historic Scotland, although this was initially based on lime putty mortars, which had limited success when used externally. NHLs became more readily available throughout the early 1990, and seemed to overcome some of the limitations of lime putty based mortars. Today, NHL based mortars predominate the market for lime mortars. In parallel however, over the past 15-20 years, hot-lime mortars have been *reintroduced* by a number of specialist masonry contractors in Scotland, and these have been used with increasing levels of confidence and success. Predominantly, these are hot-lime mortars gauged with NHL.

In Scotland and also in Ireland construction mortars and often harling (render) mortars were historically commonly based on hot-lime mixes (using both non-hydraulic and hydraulic limes). A number of comparisons can be drawn between Scotland and Ireland not only in the origin of ecclesiastical building but also in terms of geophysical features, exposed weather conditions with high levels of wind driven rain and seasonally very low temperatures with high humidity, with the rain/frost cycle being common to both in many regions. Similarly the building materials and construction techniques used in both countries have much in common, with skill and technology exchange between the two over millennia due to the itinerant nature of traditional building craftspeople, therefore the natural synergy existing between the two nations created the ideal partnership for technology transfer.

SCOTLAND

In Scotland, Calcium Carbonate is most commonly found as limestone. *The Limestones of Scotland*, by the Geological Survey of Great Britain in 1948, provides some useful references to the composition of Scottish Limestones. They 'classify' the limes which can be used for building as high-calcium, semi-hydraulic, hydraulic and magnesian. With specific reference to high-calcium (air limes), while there are some good high calcium air limes available in Scotland, there is not quantity and possibly quality as those available in England.

The foregoing supports the view that traditional Scottish building limes were generally hydraulic in nature (however feebly). This is also supported by analysis of many historic mortars, with a significant proportion of these indicated to be feebly to moderately hydraulic and also, in a number of locations, the lime binders were also found to be dolomitic, to a degree. Hydraulic properties appear to have been imparted from either the burning of impure limestone or the addition (either intentionally or unintentionally) of pozzolanic material in the aggregate and/or as fuel residue from the kiln. Irrespective of the providence of the limestone these would have tended to be feebly or in some instances, moderately hydraulic, due to the nature of the burning, utilising small kilns and low BTU fuels. This situation could have changed, however, with the advent of the larger commercial kilns and the more general use of coal at the turn of the last century.

Prior to the late 19th century much of the limestone extracted for making building mortars was obtained locally, and was commonly burnt and slaked on site, or from a local kiln, many of which were in existence for agricultural use, but these also provided materials for use as a construction mortar. In areas where limestone was scarce, alternatives were used such as earth and clay mortars. Given the diverse and complex geology of Scotland, the variation in the raw limestone would therefore have produced a wide range of mortars with differing properties, and degrees of hydraulicity. From analysis of historic Scottish mortars, the Scottish Lime Centre, and others, have suggested that the majority of mortars, particularly for bedding, and often for external harling appear to have been feebly hydraulic, and mixed and used in the form of 'hot-lime' mortars.

In the absence of commercially available hydraulic quicklime, in order to try and replicate Scotland's traditional mildly hydraulic limes more closely, the practice of gauging has been commonplace for at least the last three decades. In the case of a gauged hot-lime mortar, this involves blending predetermined proportions of quicklime (air lime) and an NHL. The function of gauging a hot-lime with an NHL is essentially to combine the working benefits of using a hot lime, with the benefits of some hydraulicity

Contemporary NHL 'gauged' hot-lime mixes are often based on equal or similar proportions of air lime (quicklime) and hydraulic lime (NHL), although the strength of NHLs and the relative proportions are infinitely variable to provide the required performance in use. Mortars should be designed to suit individual applications as the blending of mortars allows for a much wider selection of materials to be used. This is particularly important for conservation and repair work. In some instances examination and/or analysis of historic mortars may be helpful to guide the design of repair mortars, whilst in others the experience of the practitioners may be sufficient for them to replicate what they observe in the existing wall fabric.

IRELAND

Lime mortars first appeared in Ireland in the Early Medieval period, used exclusively for the construction of religious buildings, such as churches and round towers. Standing up to thirty meters tall round towers only became possible when the art of mortared masonry had been mastered. In later centuries Romanesque churches also started to appear being built by mason from Gaul who would have brought lime mortar technology with them, including the use of hot-lime mortars. With the arrival of the Normans in the 12^{th} century, accompanied by their own master masons to build their fortifications, mortar know-how from mainland Europe via England would have prevailed with a high reliance on hot-lime mortars.

All of the documentary evidence in England points towards hot-mixing, as do medieval illustrations of building practice that survive. The greater ease of mixing mortars with quicklime and their undoubtedly enhanced utility and workability, providing maximum efficiency with minimum effort, suggests that masons would have preferred using hot-limes, and some still do.

While there has been research into the composition of medieval mortars in Ireland, notably by Dr. Jason Bolton, their actual structure and the process by which they were produced and the implications in terms of expertise and site management may not yet have been fully explored.

Research to date appears to have concentrated more on NHLs and lime putties. It further appears that past research on historic mortars was more inclined to focus on quantitative analysis and related chemistry rather than on structure and actual manufacture. In some instances there seems to have been an inclination towards an assumption that the mortar mixes were made from lime putties, and sometimes with additives. Indeed, it is speculated that the use of lime putties for *exterior* work erroneously arose from the re-use of lime mortars and renders based on the methodology and techniques applied in *interior* work by plasterers, being the only methodology to generally survive to the present day. This method was simply adopted without question and applied to exterior work and often with a lot of hardship and sometimes with dire consequences. With the arrival of bagged NHL, a practical and workable solution to using lime mortars and renders was made available. It appears for the most part that hot-lime mortars were either missed or simply ignored in this process.

We do have verified tests and samples of hot-lime mortars from Irish structures undertaken by our Scottish colleagues. The OPW have also undertaken work in this area. Most importantly, we are able to better replicate historic mortars, including their properties, by using modern quicklime in hot-lime mixes. But, in short, while hot-lime mortars are now more generally recognised, there seems to be little academic work available to draw on. We would hope, however, to have a significant archaeological input into Phase II accompanied by academic study, with research supported by a literary search, site investigations and laboratory testing and development.

Appendix C. Extract from *The Builder's Complete Guide*, by C.F.Pattington, 1825, describing the making of hot-lime mortars etc

SECTION 4: HOT LIME MORTARS: MATERIALS & DEFINITIONS

Building lime is a manufactured, rather than a naturally occurring material. It is produced by heating limestone to alter it into a material which readily breaks down to form the binder component of a mortar.

The basic manufacture process involves *burning* (or rather heating/calcining) *calcium carbonate ($CaCO_3$)*, commonly in the form of limestone, chalk or shell in a kiln at around 700-900°C, at which temperature carbon dioxide is pressurised from the raw material, forming *calcium oxide (CaO)*, or quicklime (sometimes also referred to as lump-lime or shell-lime, or mother lime). When the *calcium oxide* (quicklime) is combined with water (referred to as the slaking process), it reacts, sometimes violently, breaking down to form *calcium hydroxide ($Ca(OH)_2$)* (slaked lime or just 'lime'). Where there is an excess of water added the formation becomes lime Putty.

The limes which are currently available through specialist lime mortar suppliers and, increasingly, through some general builders' merchants, are primarily sold in the form of hydrated limes and are mostly Natural Hydraulic Limes (NHLs). These are manufactured from hydraulic quicklime. The other form most commonly available is ordinary hydrated lime produced from non-hydraulic quicklime that has been watered, or hydrated, to create calcium hydroxide ($Ca(OH)_2$). This is either available as dry hydrated (powdered) lime or, with an excess of water added, as lime putty. Sand and other types of aggregates can be later added to NHLs and Putty lime, with sufficient water, to make a mortar. These are prepared as cold mortars.

Non-Hydraulic lime hydrate, often referred to as 'bagged lime' or 'builder's lime' should seldom be used on its own in the preparation of a mortar. Its main purpose in mortar is as a plasticiser added to cement/sand mortars to improve their workability and cohesion.

Quicklime, calcium oxide (CaO), can now also be made available in a granulated (kibbled) form which is more convenient to measure quantities and use than the traditional 'lump' quicklime.

Transition of lime from limestone to hydrate with 'lumped' quicklime in the centre.

Dust reduced granulated quicklime for ease in handling and controlling. One Euro coin shown for grain size comparison.

Historically there were two basic forms of mortars used in construction that today we have termed as either '*Hot Lime Mixes*' or '*Hot Slaked Lime Mixes'*. Both are prepared in a wholly different way. Essentially for a hot-lime mix the fresh quicklime, sand and water are mixed together in one operation to make a ready-to-use mortar. In the context of traditional construction, this method was (and remains) the quickest, cheapest and easiest way to make a basic mortar. The mortar can be applied 'hot' whilst still slaking, or once it has cooled

after slaking has finished. These mixes were traditionally used 'hot' for bedding rubble stonemasonry, grouting wall cores and sometimes external harling and render coatings.
The foregoing is quite different to a hot slaked lime mix, or what is more commonly termed '*sand slaked'* mortars where quicklime is placed and watered to slake within the covering of a damp, 'as-raised', sand. Once slaked the dry-hydrated lime and the now dried and sterilised sand, from the heat generated, is thoroughly mixed together and then 'screened' to remove larger, unwanted particles of under-burned or over-burned lime and larger aggregates which is beneficial for high-quality brickwork, rendering, and base coats of internal plastering mortars. For internal brick walling and backing-up behind face brickwork the mix is left 'un-screened'. Next, sufficient water is added to the dry mix to make mortar and placed to one side to 'bank' and mature as a heap covered over to keep off the weather and help retain moisture. This 'banking' process is both critical and essential to allow all particles of quicklime surviving the initial slaking to hydrate through reaction with moisture from the damp, banked, mortar. All lime inclusions after this phase are no longer quicklime and act as aggregates. It has been suggested that banking also allows lime to caustically etch the sand grains, significantly enhancing the binder/aggregate bond, whilst the putty formed within the mix enhances the plasticity and workability of the final mortar. These mixes were traditionally used for brickwork, rendering and base coat plasters, though not generally on very fine quality work.

It is considered that up to some 90% of mortars used in the past in exterior applications, up to the 19th century and into the early decades of the 20th, was possibly from a variety of hot-lime mixes. Therefore, its use today in repairs and renovation is most likely to be a more authentic replication of the original mortar.

Given that lime mortars were used in most forms of solid masonry wall construction, this represents a considerable proportion of our existing housing stock and public buildings.

Techniques have now been developed as to how to determine if a historic or traditional mortar had been made with quicklime as the binder, as opposed to lime putty; and if quicklime, was the mortar mixed and used as a 'Hot-Lime' mortar.

The identification of 'hot-lime' mortars is described in Appendix G.

SECTION 5: HOT LIME MORTARS: ADVANTAGES & BENEFITS

The advantages and benefits of hot-lime mortars are recognised by those who use them through choice, but these are not particularly well documented. Limited academic research has been carried out on the subject, much of which has not been widely disseminated to specifiers and users.

The recurring features of hot-lime mortars which have been identified, through academic research, includes; the expansion of lime between the stones or brick to improve the bond between them (Margalha G, 2011); the improved bond between the aggregate and binder as a result of etching of the surface of the aggregate grains (Jedrzejewska, 1967); and use of the hot mixing method to produce high strength and durable lime mortars (Callebaut et. al. 2000).

Whilst the advantages and benefits of hot-lime mortars will be different, depending on the specific application, an essential part of the HLM Project was to record how hot-lime mortars were perceived by those who use them. Observations and comments from the project team stonemasons and OPW stonemasons during the construction of the wall sections and sample panels at Portumna Castle, on the 8th to 9th July 2014, were recorded and are summarised below.

The use of hot-lime mortars;

- Produced cleaner work with no runs of mortar down the face of the work
- Produced solid, full joints and a better quality of work
- Allowed the wall to be built higher than normal without leaks occurring down the face of the work and mortar squeezing out through overhead weight
- Increased production
- Prevented slumping of joints which then have to be tidied up
- Prevented leaching of lime from the mortar leading to weaker mix at the face of the work
- Potential for use in colder weather (notwithstanding the requirement for protection and curing)

Also, in situations where the stones and sand are wet;

- Allow wet stones to be laid and stabilised without their subsequent movement; a common problem with most mortars that are used cold.
- Very wet sand could be used without adverse effects on the final consistency of the mix due to the massive absorption of water by the quicklime and loss of some of the excess moisture due to the heat generated.

The advantages and benefits of hot vs. cold use of *hot mixed* mortars will also depend on the particular application. Essentially the hotter the mortar, the greater the slaking reaction (and therefore expansion of the mortar) will be at any given time. Mortars used *hot* will therefore expand to a greater degree *in-situ* and will also stiffen and lose moisture more rapidly, which may be an advantage when building with impervious stones and/or when working in colder weather. The enhanced contact and bond created between the sand and lime, imparted by the heat generation and high alkalinity should remain whether or not the mortar is used whilst still hot or allowed to cool. It has been suggested that mortars applied *hot* will develop a different pore structure to those allowed to cool; although this has been observed and confirmed in the study of comparative mortars in thin section, this area requires further research.

One of the principal benefits in using hot-mixed lime mortars can be found in the ergonomics. The mason goes straight from the quicklime to the mortar, to the structure, adding water and sand/aggregate along the way. It is simple and quick. By comparison other process, such as lime putty, are more complicated and took longer to prepare, slowing down the process, involving storage and a waiting time, and obviously added to the cost. There was also a problem storing quicklime and transport was expensive and troublesome.

In the Irish context, the availability of an indigenous lime binder is an attractive proposition, relative to relying on the import of alternative lime binders from Europe and elsewhere. The recent availability of a consistent and granulated/kibbled product which meets the requirements of ENV459:1 as a CL90 building lime has made this indigenous material viable for use (in whole, or in part when gauged with an NHL) as a lime binder.

With the availability of a constant and a standardised supply of indigenous quicklime, the making of hot lime mortars is now more economical, relative to other forms of lime mortar, due to both the cost of the raw material and the increase in volume of the quicklime (typically reckoned to double for an air lime, depending on aggregate used and other factors) when slaked to make a mortar. The carbon footprint of the works undertaken is also significantly lower once the costs of manufacture and transportation are considered, along with the ease of their use in construction and the longevity of this traditional material as demonstrated from historic evidence. Therefore, the overall impact of their use is significantly positive, both financially and environmentally.

Advantages are further discussed in Section 11:

SECTION 6: HOT LIME MORTARS: STANDARDS

Building Limes for use in conservation work have either been based on non-hydraulic lime, hydraulic lime and for a period of time cement/lime/sand mixes. The standards that apply to the binders are as follows:

Lime binders BS EN 459 – This covers Non-hydraulic lime (CL – Calcium Limes and DL - Dolomitic Lime grades), Natural Hydraulic Lime (NHL), Hydraulic Lime (HL) and Formulated Limes (FL).

Portland Cements BS EN 197: Composition, specifications and conformity criteria for common cements.

The above are production standards employed to control the consistency of binders from a wide range of producers and do not, on their own, provide information as to the properties of a mortar for use in masonry or renders. They are considered and used as Production Standards.

Currently, there are understood to be five commercially available sources of quicklime in the UK and Ireland which comply with the EN 459:1 standard for Building Limes. They comply with Classification CL90, which is essentially the same standard which commercially produced lime putty falls within.

The perceived pre-occupation with mortar (compressive) strength is simply a consequence of the BS EN 459 hydraulic lime classifications of (minimum) 2, 3.5 and 5 N/mm^2 (MPa) @ 28 days within each of the designated categories (NHL/ HL/ FL), and is also a carry-over from the designations used in the Standards for Cement mortars and concretes. For traditional masonry construction, and use for repair of historic and traditional buildings and structures, high compressive strengths are rarely necessary or desirable. In traditional masonry buildings and structures the support of the structures relied heavily on the stone to stone contact with mortar providing the filler between stones to even out the plane of contact, to reduce risk of point contacts, to provide a level bed for coursing and to fill the interstices within the masonry acting as a barrier to wind and water penetration. Therefore, typically the compressive strength of the mortars used historically were low, mortars with strengths of in the region of 1N/mm^2 (MPa) were not uncommon, hence the attempt to reintroduce the *Grey limes* in the south East of England with the proposal for the inclusion of an NHL1 into BS EN 459. Similarly the feebly hydraulic limes found in Scottish buildings and ruins are also likely to have been of relatively low strength initially, given their chemistry/mineralogy. Although given the occurrence of dissolution and re-precipitation that is apparent in many samples examined the ultimate (aged) strengths are likely to be higher, found on some samples tested to be in the range 2 to 4 N/mm^2.

The standards that cover mortars for use in construction are: -

BS 5628 Code of Practice for use of Masonry

BS EN 998 Specification for Mortar for Masonry

Both of the above standards cover adequately the areas for which they are intended. BS 5628 sets out durability requirements for Natural Hydraulic Lime Mortars and provides guidance on the grades to be used for particular durability designations. In addition BS 5628: Part 3: 2001 makes an allowance for the more gradual strength development of hydraulic lime in comparison with Portland cement, where the mortar standard strength values are measured at 91 days in lieu of the 28 Day strength stipulated for Portland cement mortars. However, neither this standard or BS EN 998 include options to use non-hydraulic air limes or hot- lime mortars (gauged or straight), which are the basis of a high proportion of the mortars used historically in stone masonry buildings and structures, where the binder was commonly an indigenous lime prepared from the burning of local limestone, and occasionally shell. The strength classifications for HLD (Hydraulic Lime Designation) mixes, however, should be achievable with gauged mixes for mortar durability classes 3-4(1N/mm^2 @ 91 days). It should also be possible, with experimentation, to design hot-lime mortars for higher durability classes, though these may require the addition of pozzolans, which gives the mortar hydraulic properties. This may be deemed necessary to meet the criteria quoted for the higher classes.

Traditional mortars ranged in their hydraulicity from non-hydraulic to eminently hydraulic dependent on the proportion of impurities in the limestone and the method of burning (fuel type, temperature, duration, etc,).

Therefore it would be expected that the properties of the mortars employed in bedding mortars, renders and plasters in traditional and historic structures would be equally variable in their properties and performance and not fit neatly into the classifications given in modern standards.

A number of suppliers of ready mixed mortars using NHL binders offer to supply mortars that comply with BS EN 5628 with respect to the durability designations, typically HLM5 - Class ii (5N/mm^2 at 91 days) made with NHL 5 grade lime, HLM2.5 – Class iii (2.5N/mm^2 at 91 days) based on a NHL 3.5 grade lime and HLM1 – Class iv (1N/mm^2 at 91 days). However, as all of these NHL binders continue to gain strength beyond this period, the ultimate strength may reach a significantly higher figure. It is important to design a mortar for its final strength which may be at in two years or even longer.

There is no specified data for the requirement for non-hydraulic lime mortars, used in the form of Hot-lime Mortars, and there is no documented information, or very little, to give guidance on their performance or provide data against which they can be compared. British Standard CP121: 1951 Code of Practice for Masonry gave guidance on the use of Quicklime for the preparation of putty lime and the slaking of hydraulic lime for use in masonry mortar; however it offered no physical values against which the mortar properties could be measured. Guidance however can be obtained from the English Heritage publication *Series Practical Building Conservation Mortars Renders and Plaster, Properties of Replacement Mortars.*

Ultimately, the design of mortars for the repair and conservation of historic/traditional buildings and structures requires an understanding of the materials used, on a project by project basis, and to some degree knowledge of local skills employed at the time of construction. With the selection of binders and aggregates for use in conservation works based on the availability of suitable materials and knowledge of their properties and the skills availably for their application in the works, may require that the mixes be tempered to accommodate the skills of the artisans involved in the work.

Ideally any mortar being used in conservation work should employ a binder that has sufficient free lime to provide a workable mix at as low a water content as is practical with the sands being used, i.e. it should provide sufficient paste to both fill voids in the sand grading (typically 33%), function as a lubricant, between sand grains, aid compaction and assist with adhesion to the masonry. There should be sufficient excess lime to be available for reaction with hydraulic components present in the binder (naturally present or added as a gauging) and any reaction with potentially reactive aggregates or added pozzolans in the mix, and to provide lime (CaO) for use in autogenous healing of cracks that may form due to movement in the structure. There should, ideally, however not be an over excess that could result in leaching and staining of masonry, particularly if effective curing does not occur due to poor aftercare.

It has been found advantageous by experienced practitioners in the use of hot-lime mortars to employ granular (kibbled) quicklime for site mixing, both for the ease of gauging and the reduced risk of the hazard presented by wind action on mixing when fine powdered quicklime is used. The use of kibbled quick lime also reduces the potential for balling of the dry lime powder when added to wet sands, which can result in small inclusions of potentially very reactive lime being entrapped within the mortar. Although there are some practitioners who use powdered lime with good success, it is recommended that unless very experienced with hot-limes, granular material should only be considered. Granular limes should ideally not contain a high proportion of fines, as this will affect the density of the material and impact on the yield of binder per unit volume.

The most important factor for consideration in the design of a hot-lime mortar is its compatibility with the mortar in the masonry to which it is being applied. It should be designed to be weaker, marginally, and more permeable than the existing to minimise the risk of accelerated decay or deterioration of the existing masonry fabric. To achieve this, the original fabric needs to be examined by an experienced professional or practitioner to ascertain the condition of the masonry (mortar and stone/brick) and the mortar itself, with the condition of the building/structure/ruin assessed along with its environmental exposure to arrive at the desired properties of the repair/conservation mortars. Where there is any doubt as to the properties of the existing mortar it may be necessary to extract samples and submit these to a more detailed examination and analysis to provide the data necessary to direct the design.

Failure to assess adequately the existing mortars and prevailing conditions can prove detrimental to the original fabric as if the mortars used are incompatible, they may alter the properties of the masonry, thus resulting in reduced durability, accelerated decay in the original fabric, or reduce the effectiveness of the new materials thereby reducing their service life.

As noted in Section 10: as well as Compressive and Flexural Strengths, tests were undertaken on the project test mortars for Density, Water Absorption, Porosity and Depth of Carbonation, all of which are not covered within the current Standards regime for which Standards should be established. Of particular relevance is the permeability of a lime mortar, which is associated with porosity, as this is arguably one of the most critical features of lime mortars as applied to solid wall construction.

BS 7913:2013 Guide to the conservation of historic buildings provides 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 (BS7913) is applicable to historic buildings with and without statutory protection"*

BS7913 also makes specific reference to materials selection and mortars:

- *"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"*

To conclude, it is recognised that modern *standards* may be inappropriate for historic buildings, whether protected or not. The considered application of experience and knowledge is essential. The specific requirements of each and every historic building or structure must be considered on a case by case basis.

Alternate testing regimes and other National Standards, including ASTM (American) are discussed in *Building with Lime,* by Stafford Holmes & Michael Wingate, (1997: Intermediate Technology Publications ISBN 1 85339 384 3).

SECTION 7: HOT LIME MORTAR: MIX DESIGN

From the examination and analyses of mortar samples taken from historic structures and ruins it has been found that a significant proportion of the mortars used in masonry construction in Scotland and Ireland were based on hot-limes (quicklimes) with those commonly found in historic mortar having proportions in the region of 2 parts lime to 3 parts aggregate by volume, or even richer. This appears to have been achieved by mixing 1 part quicklime to 3 parts aggregate (given the volume increase of quicklime when slaked). However, mixes that appeared to have performed successfully over time were also found to range from proportions much richer than 1:1, with mixes as rich as 1.0:0.5 and occasionally leaner than 1:3, albeit the latter is more rare in traditional masonry, unless there is also evidence to suggest that the mortar had been leached.

Aggregates found in historic mortars show very little resemblance to those stipulated for mortars and renders in the current EU Standards, and, therefore, where mortars are being designed for conservation and restoration works the aggregates should, wherever possible, be selected, or blended, to be as close as possible to the existing, if the mortars are to be replicated as closely as possible. There will of course be some instances where selecting closely matching aggregates is not desirable. The aggregate type and grading is as important in the performance of a mortar as the selection of the binder, as the aggregate forms a significant proportion of the materials present.

Traditional hot-lime mortars have proved to be incredibly durable with many examples dating back hundreds, if not thousands of years. There are endless examples of traditional buildings and structures, hundreds of years old and still surviving with original mortars, renders and plasters intact. Therefore, to enable us to specify and use durable, appropriate mortars we need to accept that hot-lime mortars play a significant role within the palette of lime mortar types available to us today. We do need to understand more about these traditional materials, how they were manufactured and used, and in doing so, both in Scotland and Ireland, we will better protect and preserve our cultural heritage.

The success of lime based works is largely determined by two main factors; the availability and use of appropriate craft skills, and appropriate materials and also mixes appropriate for location and well considered weathering details sympathetic to the use of lime binders. Other issues may also be relevant, to greater or lesser degrees, such as building design and detailing. Mortars have developed and been adapted over thousands of years to deal with local environmental conditions – therefore, careful consideration must be given to the appropriate design of repair mortars.

It is important that an understanding is gained of any historic building or structure before undertaking any work. The function or purpose of any repair mortars must be established as *matching* the original mortar may not always be appropriate. A roofed residential building, for example, will have different conservation and repair requirements to an un-roofed standing ruin.

Repair mortars must be fit for purpose – they must perform adequately in use, they must have sufficient workability for the task in hand, and they must be compatible with the original and any surviving historic fabric. Judgement based on experience and skill is often required in order to make appropriate decisions and manage any conflicting requirements.

In most cases, however, the starting point for selecting an appropriate mortar mix is an understanding of the original mortar. This understanding may come from interpretation by an experienced craftsperson or consultant, or may require a more detailed analysis by an appropriate laboratory.

When designing mortar mixes for use in conservation and repair works the following issues should be considered:

- Workability – Lime improves the plasticity and workability of mortar and imparts a high degree of cohesiveness to the mortar, thereby making it easier to work, with it spreading easily off the trowel and adhering to the stone/brick. Therefore, the aim of the designed mix should be to have adequate binder to ensure that it will have these properties.

- Water retention - Non-hydraulic lime based mortars have higher water retention than cement and NHL binders, ensuring that the mortar has an extended workable plastic time than other mortars. It also has improved cohesion and due to the resultant higher porosity of the hardened mortar encourages carbonation and improves vapour permeability. Water retention within the mix also aids placing when working in drying conditions and working with high absorption masonry, though it should be protected from over wetting when working in wet weather, as should all fresh mortar work.

- Mortar strength - The use of air lime (non-hydraulic lime) mortar mixes reduces the compressive strength of the hardened mortar compared to NHL mortars, but in situations where structural movement is a possibility, which is likely in most masonry structures, air lime mortars can better accommodate this movement than stronger cement and NHL based mortars. The rate in strength gain of an air lime mortar, even when gauged with an NHL, is also much slower and ultimately lower than with mortars made with other binders. It must always be borne in mind that the strength of the mortar should be no greater than that currently within the historic fabric, unless this is required for specific reasons.

- Freeze-thaw resistance - Cured lime mortars generally have a good resistance to freeze-thaw. Their connected pore structure and good vapour permeability encourage moisture within the mortar to evaporate, drying the mortar. Without moisture, ice cannot form, so the freeze-thaw resistance of mortars in a relatively dry state is good. Mortars in a relatively wet (or saturated) state will be at greatest risk of freeze-thaw failure, although such risks can be managed by protecting new mortars against unwanted conditions. Hot lime mortars, when used hot, stiffen quickly, loosing moisture more rapidly than other mortar types.

- Vapour Permeability - the vapour permeability of mortars improves with increasing lime content, therefore a mortar having high lime content can act as a *wick*, to encourage water vapour to vent from the wall fabric enabling the structure to effectively *breathe*. In the case of *hot-lime* mortars the added impact of air entrainment from the action of steam during the mixing process tends to increase this property in the mortar. Where possible the vapour permeability of the new mortars should be as great, or greater, than that in the existing wall fabric.

- Autogenous Healing - The presence of excess lime available in hot-lime mortar mixes ensures that there is sufficient free binder available should cracks develop in the mortar. The combination of lime and the percolating waters react and release calcium hydroxide (Portlandite) into the crack paths. This will then be available for reaction with atmospheric carbon dioxide helping to seal the cracks with the formation of calcium carbonate. The mix should, therefore, be designed to ensure that the mortar contains an excess of lime, and not less than in the original mortar.

The above features can all still be achieved with NHL gauged hot-lime mortars.

Scottish and Irish mortars in particular must be designed to withstand relatively high levels of climatic exposure, as would be expected in northern maritime countries. Wide temperature ranges, very wet conditions and severe wind loading are all common. The development of any specification must be based on an assessment and evaluation of the specific building and its location and environmental exposure. Geographical location, climatic conditions, topography, coastal or inland location, temperature range, driving rain and wind indices must all be considered when specifying appropriate materials. This applies to any mortar mix, not just hot-limes.

At specification stage, requirements for curing and the levels of achievable protection should be taken into account. Caution is, however, required to ensure that stronger mortars are not used in place of inadequate protection or curing regimes.

Modern non-hydraulic lime (air lime) hot mixes are typically based on ratios of around 1 part quicklime: 3-4 parts sand by volume, giving a final mix of 1 part lime: 1.5-2 parts sand by volume, after slaking. When using quicklime as a mortar component, always bear in mind the volume increase (typically double for an air lime) that arise on completion of slaking. The volume increase of slaked quicklime is simple to determine if not already known. Clearly this can vary due to particle sizes and related voids. Real accuracy (for laboratory testing) can only be achieved by batch mixes by weight (mass).

NHL gauged hot-lime mixes are commonly based on equal proportions of quicklime and NHL (for ease of batching), although the ratio can, and should, be varied to suit a particular application. A mix comprising 1 part quicklime: 1 part NHL3.5: 6 parts sand, by volume, will give a final mix of 1 part lime: 2 parts sand, after slaking (on the basis that the quicklime doubles in volume when slaked).

Gauging of a typical NHL3.5 into an equal proportion of quicklime will give a very feebly hydraulic lime. If, for example, the free lime content of an NHL3.5 is 25%, the above gauged mix will give an overall free lime content of 75%. Gauging of a strong NHL5 into an equal proportion of quicklime will still give an overall free lime content of greater than any current NHL2 on the market. Where a mortar with a low free lime content is desirable, hot mixes (whether gauged or not) may not be appropriate.

It is possible to replicate many of the properties of a traditional non-hydraulic or feebly hydraulic hot-lime mortar, using currently available materials, but difficult (if not impossible) to replicate the properties of a stronger moderately or eminently hydraulic hot-lime mortar, given the current availability of quicklime only as a non-hydraulic (air) lime, and the dilution factor involved in gauging hot mixes with NHL. It is intended that this aspect, with the use of pozzolans, will be studied further during the proposed Phase II of the HLM Project.

Caution should also be taken in the design of a gauged mix to ensure that the properties of the gauging binder are understood. It is also advisable to adjust the grade of NHL to be used rather than reduce the content of a stronger grade, where weaker mortars are required. This is a function of the effects of dilution, and this will be evaluated further within the scope of Phase II.

The following hot-lime mixes were trialled and tested:

Mix No. 1 - Quicklime/sand at 1:4 by volume
Mix No. 2 - Quicklime/sand at 1:4 + 10% Oyster shell by volume of lime
Mix No. 3 - Quicklime/ NHL3.5 (St. Astier)/sand at 1:1:6 by volume
Mix No. 4 - Quicklime/ NHL3.5 (SOCLI Roundtower White)/sand at 1:1:6 by volume

The purpose of trialling and testing these mixes was to establish a baseline for some typical hot-lime mixes. The basic properties of these mixes are set out below (see Section 10: for further explanation and interpretation). These mixes should not be interpreted as recommended specifications, but comparison of the test results below may help assess their suitability and compatibility. It is proposed that an expanded range of hot-lime mixes, subject to a more comprehensive range of tests, will form part of Phase II of the HLM Project.

Table: 1: Summary of mortar testing results

Mix	No. 1	No. 2	No. 3	No. 4
Components	Quicklime/ Sand	Quicklime/ Sand + 10 % Shell	Quicklime/ NHL3.5 (St.Astier)/ Sand	Quicklime/ NHL3.5 (Roundtower)/San d
Mix proportions	1:4	1+(10%):4	1:1:6	1:1:6
Mean Physical Properties of Mortar at test (35 to 180 days)				
Apparent Density (kg/m^3)	1770	1780	1800	1720
As tested Moisture Content (%)	12.9	12.6	12.5	10.7
Real Density (kg/m^3)	2660	2680	2620	2660
Water absorption (%)	14.3	16.2	13.7	15.2
Open Porosity (%)	31.4	30.7	30.0	31.4
Total Porosity (%)	33.5	33.5	30.9	33.0
Saturation Coefficient	0.83	0.79	0.82	0.86
Compressive Strength (N/mm^2)				
35 days	0.3	0.3	0.5	1.1
91 days	0.4	0.5	1.1	1.2
180 days	0.6	0.6	1.7	2.5
Flexural Strength (N/mm^2)				
35 days	0.30	0.21	0.12	0.69
91 days	0.47	0.49	0.65	0.53
180 days	0.50	0.58	0.76	1.12

Clearly, there is a need for good specifications and an understanding of the materials to be used, along with the application of good-practice by experienced practitioners in the application of these mortars, but guidelines in the preparation of specifications for base mixes can now be drawn up.

SECTION 8: PREPARATION & USE OF HOT LIME MORTARS

Practitioners using hot lime mortars have developed their own preferred methods for batching and mixing such mortars. The end use of the mortar, along with the quantities of mortar required, will often dictate which method of preparation is the most appropriate. This section sets out basic processes for the most commonly used methods of hot lime mortar preparation, based on the use of granulated or kibbled quicklime.

As with working with all mortars appropriate PPE should be worn at all times. (Please see Section 9: and Appendices E & F).

The first method is to mix the sand and the quicklime together first in a dry state (Hot-lime Mix). Then add water and mix thoroughly. In this method the mortar can be used while still hot which has certain advantages or it can be allowed to cool, be stored and used later.

The second method involves the quicklime and aggregate being mixed together then set aside to allow the quicklime to slake by taking up moisture from the sand and from the air (Hot Slaked Mix). This process may take several days to slake fully, during which time a large amount of heat will be generated, drying the sand. The quicklime will breakdown to a powder effectively creating a dry premixed mortar which can be passed through a sieve or thrown through a screen to remove any un-burnt/overburnt lime, then either stored covered with tarpaulins for later use or have water added and be knocked up to provide a workable mortar.

The practice of mixing the aggregate and quicklime then adding water to produce a workable mortar which can be used immediately, while still hot, or allowed to cool and fatten up, is the method that is described below, utilising different equipment and techniques.

Hand mixing

Hand mixing can be carried out successfully to produce quite large quantities of mortar due to the relative ease of hot mixing. A suitable clean, level mixing area should be prepared, either a concrete pad or plywood sheet. The aggregate and quicklime should be measured by volume in a suitable container and placed in a pile in the centre of the board then mixed dry by tuning over with shovels or drawing and chopping with a hoe. It may be necessary to add a small quantity of water at this stage to get the reaction underway if the aggregate is particularly dry. As the quicklime starts to slake the mixture should continue to be turned over to ensure the aggregate and lime are thoroughly mixed. The slaking will have generated a lot of heat and the quicklime will have broken down to a powder (hydrate). Additional water can now be added and the mixing continued until the mortar is of the required consistency. It is usually worthwhile mixing the mortar a little wetter than required as the slaking will continue after mixing and the mortar will initially stiffen up quite quickly. Should a large quantity of mortar be required another pile of quicklime and aggregate can be set up whilst the first one is breaking down and a production line system set up, this is often preferable to mixing a large quantity of mortar in one batch and will be dependent of site conditions/requirements.

It should be noted that thorough mixing of any lime mortars requires the mortar to be compacted and beaten rather than just turned over; this can be done with the back of a shovel or the flat of the hoe being used to ram the mortar during the mixing process.

Machine Mixing

A forced action mixer, such as a rotary pan paddle mixer or mortar mill, are the preferred type of mixers for the mixing of any lime mortars as the action of the blades, paddles or roller chop, turn and compact the mortar producing a more homogenous mix than a standard drum mixer. The dry ingredients should be added to the mixer and the mixer run to start the slaking process (as in the hand mixing procedure) before the water is added, once the mortar is well combined and is quite wet it is sometimes worthwhile stopping the mixer to allow the mortar to fully slake before running up again to finally mix the mortar.

Hand held paddle mixers (single or preferably double whisks) can also be used for mixing smaller quantities of hot-lime mortars in suitable buckets or containers.

Standard site drum mixers are not recommended for mixing hot lime mortars as the mix will tend to stiffen and dry at the back of the drum. Mixing initially requires extra water to fold and turn the mix, which will increases the risk of splashing of the hot mortar from the drum. However where site drum mixers are used, the following guidance may be helpful;

If using a standard site drum mixer the water needs to be added first then followed with half of the aggregate, then three quarters quicklime, then the rest of the aggregate, this is done to prevent the mortar stiffening up and drying at the back of the drum, the remaining quicklime can then be added to adjust the mortar to prevent it being too wet. Great care is needed when using a drum mixer as the mortar has to remain wet enough to fold and turn within the drum without splashing hot-lime mortar out of the drum. These mixers require very careful operation to produce good quality mortars as they have to be run for longer than a mill as the blades do not offer any compaction and only turn the mortar over. Some operatives set the mixer drum to sit slightly closer to horizontal than is used for normal mixing to ensure the mortar turns over and falls, compacting the mix, care should be exercised if doing this as again it will encourage splashing.

It must be stressed that with any form of site mortar preparation and use, adequate PPE must be worn at all times.

Mixing with Additives

The addition of pozzolans or the gauging of hot-lime mortars with dry hydraulic limes can be carried out both to reduce the initial setting time of the mortar and to impart a hydraulic property to the set mortar. It should be noted, however, that when mixing any mortars the rule should be that only dry ingredients are mixed together dry, or only wet ingredients should be added to wet materials. Should it be necessary to add a dry powder to a wet mix the mixing will be more difficult to achieve and the fine dry ingredients added will tend to 'ball-up' rather than mix evenly through the mortar. It has also been noted that the heat generated during slaking will accelerate the set of hydraulic limes (i.e. NHL's used in gauging) and some pozzolans, therefore, care must be exercised if these are added at the dry stage. It is usually better to mix the dry gauging ingredients as a wet putty at a similar consistency to the mortar and add after the initial heat from the slaking has dissipated. This applies both to the gauging of both hand mixed and machine mixed mortars, but not always for earth stabilisation where experience has shown that mixing all soil and other inclusions including water together, first into a well wetted mix and then adding the powdered quicklime as a last operation produces good results.

In situations where an acceleration of the stiffening of gauged mixes are desired due to low ambient temperatures, or where working with large or wet stones, the benefit of early gauging, in hot-lime mortars, can be achieved by adding the gauging along with the quicklime, in which case the gauging can be added as a powder, with reduced risk of balling or separation.

An alternative mixing procedure, which would be dependent on site conditions and management organisation, is given in Appendix H.

It will be noted that the foregoing mixing methods are generally for the preparation of masonry mortars, which include pointing and external renders. Different practices and methodologies are used in the preparation of mortars for brickwork and plasters, which are intended to be covered in Phase II of the HLM Project.

SECTION 9: USE OF QUICKILME: HEALTH & SAFETY

All limes are classified as hazardous materials, but no more than cements. In solution lime has highly alkaline qualities and acts as an irritant. Likewise, quicklime is a hazardous rather than a dangerous material, however it is also hot when slaked and has the potential to burn. As with any building material, you must assess any risks and take precautions to reduce these risks.

Precaution must always be taken and appropriate PPE (Personal Protective Equipment) worn while using lime. The PPE required for working with quicklime is the same as the PPE required for working with other forms of lime and cement. Special attention, however, should be given to eye protection at all times.

More detailed Health & Safety information is provided in Appendices E & F.

REACH

REACH is a European Union regulation concerning the Registration, Evaluation, Authorisation & Restriction of Chemicals. An important part of chemical safety is clear information about any hazardous properties of a substance. The classification of different chemicals according to their characteristics follows an established system, which is reflected in REACH.

REACH adopts and builds on the previous system for passing information – the Safety Data Sheet. This should accompany materials down through the supply chain, providing the information users need to ensure chemicals are safely managed. Covering quicklime, is a sizeable document consisting of two parts; the traditional "MSDS" section and a second Appendix of Exposure Scenarios. It is common sense to have both of these documents on site and for your H&S personnel to be familiar with them. The same applies to all chemicals registered under REACH.

As a chemical user, if you take a chemical (CaO) and add a second chemical (H_2O) you get a third chemical ($Ca(OH)_2$). By this reasoning, you would normally register as a chemical manufacturer. However, Annex V of the REACH Directive sets out exemptions to the rules, within which the site manufacture of hot-lime mortars falls (Entry 3). The hot-lime mortar, incorporating hydrated lime, is not formed solely from quicklime. Rather, it is mixed with sand, water and possibly NHL or other additives in a mortar preparation prior to the end use. As the final product is mortar, rather than a specific chemical, means that it is exempted from the registration process.

Please see Appendices E & F for further information on Lime Safety and a Safety Guide in the making of mortars with quicklime.

SECTION 10: SUMMARY OF HLM TESTING PROGRAMME & RESULTS

At present there are no prescribed requirements for hot-lime mortars, but a measure of their properties is essential to permit specifiers and engineers to gain confidence in the materials with which they are working. Therefore, as part of the trials carried out at Portumna Castle in July 2014 a number of samples were obtained from each mix used for the purpose of submitting these to a testing programme to ascertain their basic properties. The tests used at this stage were limited in number and range and it is proposed that a more extensive Phase II would follow. This would include a more detailed programme of analysis and testing of the hot-lime mortars, to include both non-hydraulic mixes and gauged mixes to provide better guidance for future specifiers and masons alike.

To facilitate the sampling and testing, in a real building situation, four sample walls were constructed approx 1.8m long X 0.6m wide X 0.9m high built off blockwork bases. Four different hot-lime mortar mixes were-produced in standard site drum mixers, two of these mixes were gauged NHL that was first mixed to a putty by hand prior to adding to the already mixed hot-lime. The walls were constructed against an existing boundary wall in random limestone rubble with brick quoins at the free end. The pointing was finished flush with the stonework, pressed back and beaten with a stiff bristle brush to compact the joints and expose the aggregate in the mortar. Following the completion of the sample walls Liscannor flagstones were bedded on top of the wall to act as a capping and

One of the hot lime mortar mixes ready for use.

Construction of wall sections

Preparing the harling test panels *Pointing of the rubble wall panels.*

prevent water ingress. In addition to the sample walls, panels of pointing and harling were also prepared on the existing boundary wall using the same mortar mixes.

The sample walls and panels allow the performance of the four-mortar mixes to be observed in a real building situation and compared with the results of the laboratory analysis being carried out on the mortar samples taken during the mixing of the mortars. The production of the samples also allowed the masons to comment on the mixing and use of the hot-lime mortars.

Four mortars were used, all based on non-hydraulic (air lime) binders, with the presence of shell included in one mix to act as seed points for carbonation, and perhaps impart a low pozzolanic property to the mix. Whilst in another two of the four mixes selected the binders were gauged with a proportion of NHL of different providence. This was to simulate properties of a feebly hydraulic lime mortar, as hydraulic quicklimes are not, at this time, commercially available.

The mixes used in the trials were as follows:

Mix No. 1 - Quicklime/sand at 1:4 by volume

Mix No. 2 - Quicklime/sand at 1:4 + 10% Oyster shell by volume of lime

Mix No. 3 - Quicklime/ NHL3.5 (St. Astier)/sand at 1:1:6 by volume

Mix No. 4 - Quicklime/ NHL3.5 (SOCLI - Roundtower White)/sand at 1:1:6 by volume

Two different sources of NHL3.5 were used in the trials as these were the most commonly used by masonry contractors and to also establish for comparison purposes if there were differences in performance of the gauged mortars produced.

As discussed in Section 6: there is no criteria specified against which these mortars could be assessed to determine compliance or otherwise. Similarly there has been no accumulation of data recording the physical properties of gauged and non-hydraulic mortars used in traditional masonry. Therefore, to give an indication of the properties of the mortars and assist in assessing their performance a series of tests were selected and samples obtained from each of the mixes used in the trials.

The samples were submitted to a selection of standard tests, with these repeated over a period of time to determine their properties as the mortars aged. It was acknowledged at the outset that non-hydraulic lime mortars do not reach their optimum strength in 28 days, the age normally used for assessing compliance of cementitious mortars (EN998) and hydraulic lime binders (EN459) and, therefore, measurement of the mortar properties were to be extended and made at a range of ages, including 35 days (in lieu of 28 days), 91days, 6, 12 and 24 months.

There are currently compliance requirement for lime binders and these are given in EN459: 2010: Part 1 “Building Lime – Definitions, Specifications and Conformity Criteria”, and Part 2 “Building Limes – Test

Methods", and for mortars and Renders, in EN 998:2010 Part 1 "Specification for Mortar for Masonry – Rendering and Plastering Mortar", and Part 2 "Specification for Mortar for Masonry – Masonry Mortar". With the tests of physical properties of the mortar being in general accordance to that stipulated in EN998 and EN1015 "Methods of Test for mortar for Masonry" Part 11 "Determination of Flexural and Compressive Strength of hardened mortar". However, at present none of these standards stipulate requirements that can be applied to mortars made from non-hydraulic lime mortars, or gauged lime mortars.

Taking standard size mould samples. *Cataloguing for testing procedure.*

BS EN 1015-11 details the method of measuring the strength of mortar following a specified curing condition, in order to permit assessment of its performance in service. And although the methods detailed in this standard were employed in the measurement of the flexural and compressive strength, the curing and testing regime adopted as part of this programme deviated from that stipulated in BS EN 1015 to permit the measurement of the mortars basic properties cured, as near as practical, to that achieved in the service environment. To achieve this a selection of mortar specimens were cast from a range of the batches made from each mix, with the specimens cast as standard prisms for the measurement of flexural strength and compressive strength as per EN1015-11 and EN459, however, the curing regime was modified to permit the specimens to be cured at the trial site to ensure that the specimens were exposed to the same conditions as the test panels constructed at Portumna.

In addition to the 160mm x 40 x 40mm prisms for strength tests a number of 40mm cubes were also cast along with a 100mm x 100mm x 50mm prism and a 150mm cube. The specimens were to be used to measure the following properties of the mortar from each mix:

- Flexural Strength,
- Compressive strength,
- Density (Real and Apparent),
- Water Absorption (Total),
- Porosity
- Depth of Carbonation, determined by Phenolphthalein Indicator solution applied to freshly cut surfaces at each age of test.

In addition a petrographic thin section was prepared from an example of each mortar, both from the prepared samples and from a piece of mortar obtained from the site works, for evaluation of the mortars condition

The results of the tests and analysis carried out, including the petrographic examination of thin sections made from both the laboratory samples and samples obtained from the site panels, have all shown that carbonation of the binder is not yet complete and in the case of the NHL gauged mixes, the hydraulic components continue to develop and gain strength (as expected in both cases), therefore their ultimate properties have yet to be determined. The proposed 6, 12 and 24 month tests will augment the existing (up to 180 day) results and provide a clearer picture of how these materials will perform in their cured and hardened state.

The results to date have confirmed the hypothesis that air lime mortars originally gain *strength* from loss of excess moisture and the early development of their structure. It also confirmed that finely divided calcium carbonate, in the form of limestone, in the binder, in the aggregate or as an additive (crushed shell) act as seed points for the development of carbonation within the body of the mortar. The foregoing, together with invasive carbonation from the diffusion of environmental carbon dioxide into the mortar through its outer surfaces is low as shown in the samples examined, see below. However, the contribution, and development, of carbonation from both sources appear to contribute to the development of the mortar's crystalline structure and hence its durability.

Depth of Carbonation (Phenolphthalein Test) depths in mm

Site Measurements

Mix	Pointing	Harl	Wall Panel
1	Nil to 10	4 to 6	Nil to 5
2	20 to full depth	6	Nil to <1.0
3	9	8 to 10	Nil to <1.0
4	4 to 8	4 to 6	Nil to <1.0

Laboratory Measurements on site samples & cube specimen

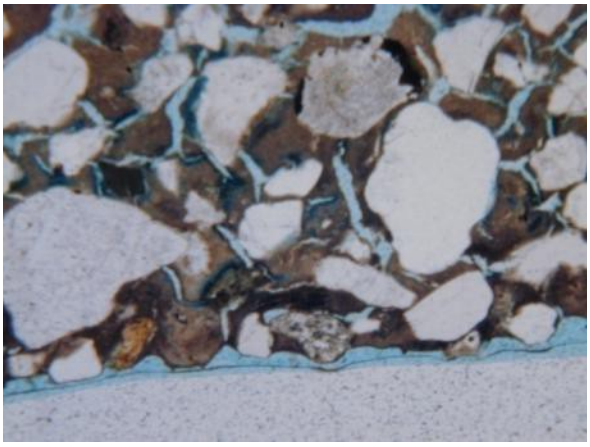
Mix	Pointing	Harl	Wall Panel	Cube Sample
1	Surface <1.0	2.2 to 6.0	Nil to 5.4	0.2 to 1.3
2	8.4 to full depth	Nil to 5.2	Nil	0.2 to 2.1
3	4.0 to 8.1	Surface <1.0	Nil to 3.0	0.4 to 2.2
4	patchy to 3.8	Surface <1.0	Nil to <1.0	0.3 to 1.8

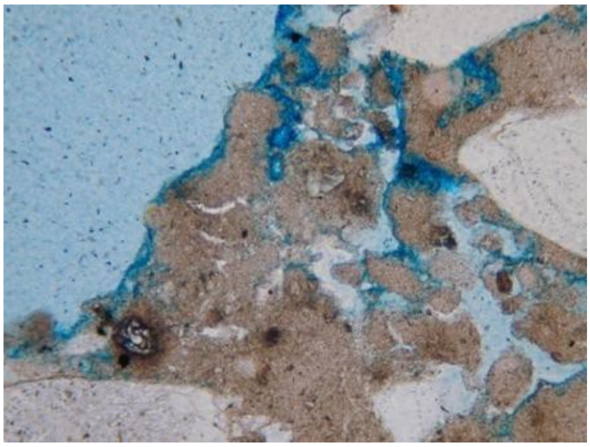
The study of the mortars have shown that they have all behaved in a similar manner, i.e. typical of that observed in high calcium limes (non-hydraulic lime mortars), with the initial stiffening being due to drying of the paste with the associated development of very fine early drying shrinkage cracks randomly distributed throughout the mortar. These form a network of micro-cracks, resulting in a mortar demonstrating high microporosity, with well-connected channel ways. This indicates that the mortar is both porous and permeable with high vapour permeability. The porosity as determined from modal analysis was found to be similar to that determined by direct measurement, albeit slightly lower, as the micropores that will be present are below the resolution of the microscope. This high vapour diffusion capacity will contribute to the drying of the masonry fabric and minimise the risk of disruption due to prolonged saturation and thereby also reduce the risk of frost associated deterioration.

The impact of a gauging with hydraulic lime has been twofold; provided early stiffening to the mortar as placed, and a higher early strength. The latter also tended to develop further to impart a higher strength to the mortar, which appears to be still developing in the samples tested. The 6 month test has been successfully completed and the 12 and 24 month tests are yet to be carried out. These will confirm if this will develop further or whether the contribution from the hydraulic component has been exhausted, see following summary.

The study of the mortar in thin section, at 90 days, confirmed that most, but not all, of the clinker in the NHL's added had hydrated, which may infer that some strength development may yet occur. The following examples show the structure of the mortar and show the development of the channel way and pore structure, which is typical of that observed in air lime mortars.

Further examination and analysis will be carried out on the specimens as they age and the mortar carbonates, however, to date the properties of the mortars as determined from the programme of testing and examination carried out would tend to support the observations from the practitioners familiar with using these materials and the masons involved in the Portumna Trials.





Long term performance, however needs to be assessed on the trial panels and site stored specimens, to assist in obtaining a greater understanding of the performance and apparent durability of these forms of lime mortars. That said however, it must be recognised that these types of mortar have been around for many centuries, performing well in existing historic structures. The basic form of the material is essentially the same, but the raw material sources and methods of manufacture have changed – it is important to understand how both traditional mortars and their modern counterparts perform and why.

It is hoped that the mechanisms involved in both determining the properties of existing traditional mortars and those designed for use in their conservation and restoration will be studied further in the proposed Phase II of the HLM Project.

Table 2: Summary of results of the testing programme for each of the 4 mixes.

Mix	No. 1	No. 2	No. 3	No. 4
Components	**Quicklime/ Sand**	**Quicklime/ Sand + 10 % Shell**	**Quicklime/ NHL3.5 (St.Astier)/ Sand**	**Quicklime/ NHL3.5 (Roundtower)/Sand**
Mix proportions	1:4	1+(10%):4	1:1:6	1:1:6
Physical Properties of the Mortar				
Apparent Density (kg/m^3)	1770	1780	1800	1720
As tested Moisture Content (%)	12.9	12.6	12.5	10.7
Real Density (kg/m^3)	2660	2680	2620	2660
Water absorption (%)	14.3	16.2	13.7	15.2
Open Porosity (%)	31.4	30.7	30.0	31.4
Total Porosity (%)	33.5	33.5	30.9	33.0
Saturation Coefficient	0.83	0.79	0.82	0.86
Compressive Strength (N/mm^2)				
35 days	0.3	0.3	0.5	1.1
91 days	0.4	0.5	1.1	1.2
180 days (6 months)	0.6	0.6	1.7	2.5
12 month	TBC	TBC	TBC	TBC

24 month	TBC	TBC	TBC	TBC
Flexural Strength (N/mm^2)				
35 days	0.30	0.21	0.12	0.69
91 days	0.47	0.49	0.65	0.53
180 days (6 months)	0.50	0.58	0.76	1.12
12 month	TBC	TBC	TBC	TBC
24 month	TBC	TBC	TBC	TBC

Fig. 1: Compressive strength development

Fig. 2: Flexural strength development

The conclusions that can be drawn from the early age results are that they are largely as expected, with the gauged mixes giving strengths in line with that which could be expected from a feebly hydraulic lime, whereas, the non-gauged mixes are again typical of the properties (fabric and strength) that have been indicated to be inherent in high calcium lime mortars found in traditional structures. Clearly there have been some challenges in applying some of the modern standard tests to mortars that we know do not gain strength quickly; therefore, the early compressive and flexural strength tests can only provide limited information on the long term performance of these mortars. However, given that they were intended to provide a measure of the mortars physical properties that were to be assessed against the performance of the test walls and panels *in situ*, this is being achieved, with the continued monitoring and testing intended to further contribute to the understanding of these materials and their performance.

The longer term (12 and 24 month) tests are therefore an essential part of this exercise, and their results in combination with the long term evaluation of the test walls and panels at Portumna will contribute to our understanding of the potential uses of hot lime mortars under service conditions. The results of this programme may also assist in understanding the apparent successful use of these mortars, in a range of applications, over the previous two to three decades, both in Scotland and in Ireland.

This Phase 1 project was, however, limited in scope, timeframe and budget, and the range of tests was therefore limited, but the early outcome demonstrate that it has been both valuable and informative, in terms of developing the Phase II the project. In which it will be essential to expand the testing programme to consider mortar performance in use, which is of great relevance for specifiers and practitioners alike. In addition to longer term strength tests (flexural and compressive), factors such as vapour permeability, water absorption, capillarity, etc will be measured as all are essential in developing a fuller understanding of how hot lime mortars perform, not only in isolation, but also comparatively, with other mortar types and mixes used in conservation and repair work.

SECTION 11: HLM PROJECT: PHASE I CONCLUSIONS

The prime objective of the HLM Project Phase I. of transferring know-how and experience in the use of hot-lime mortars in Scotland to Ireland can be considered successful. In particular the materials available in Ireland are compatible with slight variation to that of Scotland. In summary:-

- v. Experience in the preparation and use of hot-lime mortars in Scotland does transfer to Ireland and materials available are compatible with slight variation.
- vi. CRH - Clogrennane CaO (Quicklime) complies with EN 459 CL90 and is eminently suitable to the design of mixes and production of mortars.
- vii. Basic formulations with the principles for guides in the design, preparation and application of mortars & renders can now be made available.
- viii. Information was gathered for the production of suitable technical literature and for the adoption of best practice giving guidance on the design, preparation and use of hot-lime mortars and renders complete with base specifications and methodologies, including aftercare, as well as Health & Safety.
- ix. In cognisance of the foregoing, text for the publication of literature can now be provided.

At this stage the formulations for hot-lime mortars are basic, but can be refined with knowledge and experience. In reality, hot-lime mortars and renders are gaining acceptance as a preferred choice by an increasing number of masons, and are developing their own *momentum.* Masons are even experimenting with various trial formulations, some of which emanate from tradition. Ancillary projects such as the re-building of the Lime Kiln at Russborough House and the construction of the Medieval Mortar Mill at the Irish National Heritage Park (Appendix K) has contributed to this movement. Sample testimonials are given in Appendix L.

It must be acknowledged that some masonry contractors and individual masons have been using hot-lime mortars for over 30 years within Scotland and the UK, using lump, powdered and kibbled forms of quicklime, which is supplied by a variety of producers in. 25 kg bagged versions of both powdered and kibbled quicklime are now being sold through builders' providers in parts of the UK.

While the choice of the form of quicklime to be used for a specific job will depend on the preference of the mason, a standardised and uniform kibbled quicklime now available in Ireland is advantageous. Kibbled quicklime has already been accepted within Agriculture for field spreading and being relatively dust free satisfies health and safety considerations. It could be considered to be less hazardous than other forms of powered limes.

The advantages of hot-lime mortars are enumerated in Section 5. Being indigenous they are obviously more authentic than mortars based on imported limes. They can also be more cost effective offering significant economic advantages being less expensive by a factor of up to a fifth when compared to imported hydraulic limes, depending on quantities and packaging, with further cost savings in its both usage and productivity.

In response to the HLM Project the Building Limes Forum (BLF) in the UK has set up a committee to liaise with Historic England (formerly English Heritage) and Historic Scotland both of whom have expressed an interest in the Project. Historic Scotland has recently issued an INFORM guide to *Hot-mixed Lime Mortars* in conjunction with the BLF (Please see Appendix N).

The BLF is holding a major Hot-lime Mortar Workshop in York on the 14th & 15th May 2015 at which the HLM Project team will be participating. It is being supported by Historic England.

In Heritage Week, the BLFI will be holding a Hot-lime Demonstration event at the Irish National Heritage Park, Wexford. It is also intended to hold a number of Demonstration Workshops at Drimnagh during the course of 2015, the first one being on the 4th June.

Other initiatives and activities from which the HLM Project has benefited:

Nigel Copsey: Stonemason - Experience & work with Hot-Mixed Lime Mortars & Paper to *3rd HMC 2013, Glasgow* etc
Stafford Holmes: Architect and author – Work with lime kilns, expertise on limes - the Pakistan Housing Project & others

Pat McAfee: Stonemason and author – Experience in the USA and elsewhere in the design and use of hot-lime mortars
Chris Pennock: Stonemason - Project at Nidaros Cathedral Workshops, Trondheim, Norway.

SECTION 12: HLM PROJECT: PHASE II PROPOSALS

Other than transfer technology, the objective of Phase I. was essentially dissemination of knowledge and practical training.

The prime objective of Phase II. would be to continue to provide advice on formulations and use of hot-lime mortars with further testing and development of varied mixes with different sands and aggregates, including experimentation and testing with pozzolanic materials and other additives. Particular attention will be given to regional sands and aggregates including calcareous materials which dominate parts of the country. As the overall aim of the HLM Project is to make modern replica mortars available using commercially produced quicklime, avoiding the expense and environmental problems associated with individual kiln burning, an emphasis will be placed on the foregoing.

It is intended that Earth Mortars would also be researched in association with others.

Demonstration and Training Workshops would continue to be held at Drimnagh Castle and elsewhere.

In order to more thoroughly achieve the foregoing, a literature search would have to be undertaken collating all currently available information and compiling this into a useable format, in order to provide a database upon which future research can be based. It is essential that we understand what mortars were used, how they were made, what materials were used and why they performed in the way they have.

In short, if we are attempting to replicate we must know more about what we are trying to replicate.

In designing base replicating mortars it is not proposed to burn and test local limes as this could be highly problematic and certainly costly. Testing of regional aggregates, pozzolanic materials and other additives will be undertaken with the existing commercial quicklime supplier, and adjusting as required in order to achieve compatible performance, replicating the characteristics of the original mortar. It is felt that the latter would be more practical and have wider appeal for application in the conservation industry, and more useful to the average mason doing the average job.

The following proposals are not to be interpreted as being prescriptive and are for the consideration of the Executive and the Technical & Standards Committees of the BLFI. They will possibly be also the subject of discussion with the BLF.

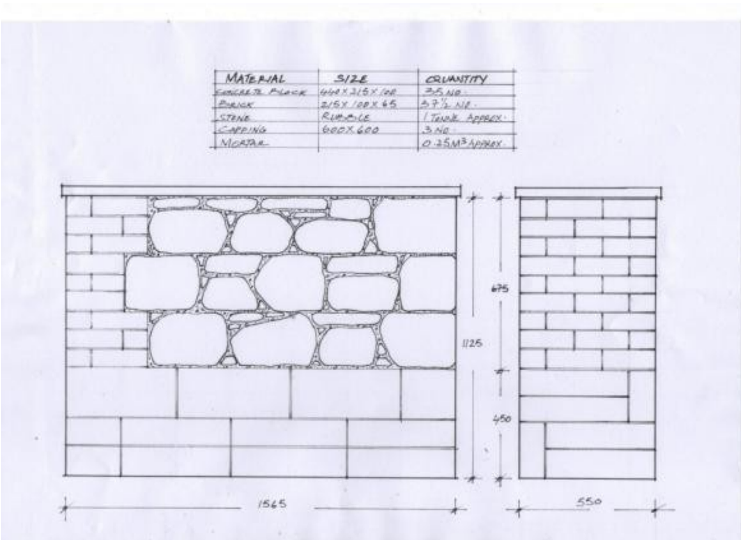
For consideration, it could be envisaged that the Programme will be divided into three separate activities: -

i) Continuation of Phase I. Mortar Research and Development, expand range of hot-lime mortar mixes to include:

   a. Stone types of varying porosity/with sands/aggregates (including calcareous) with NHL gauging/hybrid mortars and their development.
   b. As foregoing with pozzolanic materials and other additives.
   c. Brick masonry mortars
   d. Earth mortars & vernacular mixes

It is anticipated that the building of the test walls and testing would be undertaken jointly by the OPW and members of the BLFI. The OPW testing will be on its in-house projects utilising the laboratory at Athenry. It is intended that either individual projects or masonry test walls and panels would be built voluntary by BLFI Members for testing separately. Both will adopt the same procedure as for Phase I, The walls to be built will be to the design and specification as shown below. Records would be kept and a data base would be compiled on the limes, aggregates and mixes used.

The longer term (12 and 24 month) tests associated with the test walls and panels at Portumna, constructed during Phase I, will have to be completed. These will be an essential part of this exercise, and their results in will contribute to our understanding of the potential uses of hot lime mortars under service conditions.



ii) Demonstration Workshops.

Develop and deliver Demonstration & Training Workshops for both building professionals (specifiers) and masons (practitioners) to enhance their knowledge and understanding in the use and application of hot-lime mortars and renders based on the successful Drimnagh Castle model, establishing Drimnagh as a central training location.

iii) Research & Development.

Facilitate the possible establishment of a research project in conjunction with the OPW and TCD under the Irish Research Council IRCET Programme for post-graduate research into hot-lime mortars and renders which will include both archaeological and academic laboratory research for the identification of historic and development of replica mortars.

This may also involve the use of an experimental kiln not dissimilar to the experimental Lime Kilns established near the Scottish Lime Centre Trust and others previous. It is also understood that the Institute of Theoretical and Applied Mechanics, Academy of Sciences of Czech Republic, is currently working in this area.

iv) Also:

a. Assist in the possible development of Standards and a Code of Practice with Heriot-Watt University, Edinburgh, should such an intended project proceed.
b. Attendance at meeting and events within the UK and elsewhere as well as liaison work with Historic England, Historic Scotland, CADW and the NIEA to further the knowledge and development of hot-lime mortars.
c. Publish literature.

v) Information gained be collated and disseminated by the BLFI to the wider community, through a series of publications, seminars and workshops, tailored, where appropriate, to meet specific requirements.

All the foregoing will be subjected to funding.

Lastly, the Central Statistics Office records that the imports of hydraulic lime was 2,080 tonnes for 2014 with a value of €527,000.00. [CSO: CN 25223000: Hydraulic lime, excluding pure calcium oxide and calcium hydroxide]. Due to the small size of the market extensive research and development may not be immediately sustainable from a strictly commercial viewpoint. Although with the reduction in costs by using hot-lime mortars and with a possible increase in its use, market growth could be anticipated. It is understood that the figure for imported hydraulic limes was in excess of 3,000 tonnes prior to the recession.

In order to achieve an economy of scale, however, research and development will likely need to be undertaken in conjunction with the larger UK market. In short, Phase II is too large a project for too small a market if confined to Ireland, but realistic if adopted and undertaken in cooperation with BLF for the UK. The Building Limes Forum (UK) has established a special committee on Hot-Lime Mortars and has approached Historic England. Historic Scotland has informally expressed an interest in the HLM Project and will possibly enter into talks with the OPW. It is also likely that CADW of Wales and the Northern Ireland Environmental Agency (NIEA) will be approached. This could lead to a coordinated programme avoiding duplication and in the sharing of procedures, findings and results, compiling a data base of common and mutually beneficial information.

Lead Consultants

Craig Frew, Frew Conservation

Ivor McElveen, Chair – Technical & Standards Committee
Building Limes Forum Ireland

Ivor McElveen Associates

Supported by

William Revie, Construction Materials Consultants Ltd
Pat McAfee, Stonemason and Author
Joe Connolly, Technical & Product Development Manager Clogrennane Lime Ltd
Robert Howard, Stonemason, OPW National Monuments Athenry Depot
Andrew Bradley, Stonemason

Yvonne Doyle, Secretarial & Administration, Technical & Standards Committee BLFI

4th May 2015