Comparative testing of hydraulic lime and OPC mortar mixes

HETHERINGTON, Steven <http://orcid.org/0000-0002-9851-8478>

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<AUTHOR> **Stephen Hetherington**

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<CONTACT> Sheffield Hallam University, Norfolk 309, City Campus, Howard Street, Sheffield S1 1WB, UK.
e-mail: s.hetherington@shu.ac.uk

<BIO> Stephen Hetherington is a senior lecturer…

at Sheffield Hallam University in the Department of the Natural and Built Environment . As Senior lecturer he is required to design and deliver lectures and tutorials on modules in Conservation Studies, Materials, Science of Materials, Building Pathology and Domestic Construction Technology.

His main core research interests are the in service performance of construction materials, namely their durability, repair and conservation. Recent external contract work has focused on the production of stone roofing slates and proprietary frost testing of historic masonry. He has also been involved in a variety of research and consultancy projects for a number of high profile clients including Hanson Brick, Blue Circle Cement (now Lefarge) English Heritage, Oxford Brookes University and The Building Research Establishment.

ABSTRACT

In recent years there has been in increasing trend towards the use of Hydraulic lime based mortars within the construction industry, especially in low rise domestic dwellings - due in part to their sustainable credentials. However, the construction industry has, until recent times, solely relied upon the use of Portland cement based mortars and the introduction of lime based mortars has added another dimension to the choice of binder and mortar specification to use. This limited comparative study is designed to clarify the relative merits of the two binder types in terms of their compressive strength, flexural strength, water absorption and porosity. The study was conducted using three different binder to aggregated designations; 1 part binder to 3 parts sand (i), 1 part binder to 6 parts sand (iii) and 1 part binder to 8 parts sand (iv). The binder designations were chosen to give a range of different mortar types that are commonly used in the industry.

Keywords:

Comparative study, Hydraulic Lime, Portland Cement, Compressive strength, Flexural Strength, Porosity,Water Absorption.

INTRODUCTION

The use of lime mortars as a viable and more sustainable alternative to Portland cement mortars has been the focus of much debate over the past few years with publications on the use of lime mortars by the NHBC 'The Use of Lime-based Mortars in New Build' (2008) and 'The Use of Lime Mortars and Renders' by the BRE (2013). Many proponents of the use of lime mortars, especially in domestic low-rise, new-build construction, claim that its sustainable credentials stem from the fact that it is burnt at a lower temperature than Portland cement, thus using less fuel. In addition, they say, the carbon dioxide liberated during the manufacturing process is re-absorbed in the process of carbonation over the life of the mortar. Other aspects of hydraulic lime mortars that make them attractive are their 'good working and handling properties, good bond to bricks and blocks, good weather tightness and good vapour permeability (ability to "breathe")'.[1] However, 'hydraulic lime mortars generally require additional care and protection during the longer curing periods'.[1]

It is perceived that Portland cement mortars do not have any of these properties, but that is not completely true. Portland cement mortars do absorb some carbon dioxide from the atmosphere and do not require extended curing periods. They also have good brick and block mortar bonds and have good compressive strength. These are the qualities that have made Portland cement so popular since its invention and patent in 1824 by Joseph Aspdin.[2]

With an extensive range of combinations of various types of mortars it is becoming increasingly hard to know what type of mortar to specify and use in what conditions, and exactly where hydraulic lime mortars and Portland cement mortars stand in comparison to each other. Additionally, are the two types of binder so vastly different or do they actually share any common characteristics? This paper will try to address these questions by testing a series of mortars using a generally accepted set of tests to determine the relative properties of each mortar type.

Compressive strength and flexural strength will be compared as it is argued that 'lime mortars behave as if they are flexible … are slower hardening and remain more flexible than cement sand mortars'.[3] Other parameters that will also be considered are water absorption and porosity, as it is generally stated that lime mortars exhibit a more 'breathable' nature than their cement-based counterparts, and that they are more porous and allow humidity and moisture to freely move in and out of the masonry. Subsequently they are deemed to be more sympathetic to the surrounding materials. From this information, an indication of the likely in-service performance of the different mortars can be obtained.

PRODUCTION OF LIME AND PORTLAND CEMENT

Lime takes various different forms. 'Lime' is a general term and covers:

<LIST>

- non-hydraulic lime (lime putty);
- dolomitic lime (obtained from magnesium carbonate);
- hydrated builder's lime;
- naturally hydraulic lime.

<END LIST>

The use of the word 'lime' as a general term covering all these different forms can be somewhat confusing. However, they all contain calcium hydroxide $Ca(OH)_2$ with the exception of the dolomitic lime, which contains magnesium hydroxide. They are all obtained from the calcining of limestone or chalk (calcium carbonate), heated to approximately 900– 1,000°C.

The classification of naturally hydraulic limes isis based on the level of clay impurities that the limes contain. The clay is hydraulically active and indicates that the binder will set under water and in wet conditions (as will Portland cement). Limes with lower clay levels (thus with higher purity content) are termed 'feebly hydraulic', those of moderate initial clay content are 'moderately hydraulic' and those with even higher clay content are 'eminently hydraulic'.[4] These labels describe the three different strengths, and a number suffix denotes the compressive strength of each lime inN/mm^2, for example,:NHL 5 (eminently hydraulic), NHL 3.5 (moderately hydraulic) and NHL 2 (feebly hydraulic). However, it is unclear how these materials compare with Portland cement mortars. How does a 1:6 cement/sand mortar compare to a 1:6 hydraulic lime mortar as far as compressive strength, flexural strength, porosity and water absorption are concerned?

THE WORKABILITY TEST

Material and sample preparation

Both the hydraulic lime and the Portland cement mortars are produced in accordance with BS 4551: 1998. This standard has been withdrawn and is no longer current, but contains a mortar- mixing procedure that provides a known volume of mortar and ensures that all the mortar mixes are produced in a consistent way and will, therefore, ensure that each set of samples produced will be consistent in its performance.

One test that can be employed to gauge the consistency of each mortar is a workability test. The workability test chosen for this purpose is a test known as the 'dropping ball test' (DB) as set out in BS 4551: 2005. Although this test will ensure that the workability of each mortar will meet a predetermined level of consistency, thus providing a common reference point that each mortar can be gauged against, 'mortar mixes prepared in the laboratory should have [their]consistency adjusted to a penetration of 10+ or - 0.5mm'.[5] The workability of each mortar is an important factor, and ensuring that all the mortars have the same workability means that direct comparisons can be made between them.

Three Portland cement mortar mix specifications will be used, mixed according to the following ratios by mass 1 part cement: 3 parts sand; 1 part cement: 6 parts sand; and 1 part cement: 8 parts sand. These will be compared with the respective mortar mixes produced using NHL 5 (naturally hydraulic lime). The proportions described above will be manufactured using the same sand that conforms to BS 1200: 1996, and use prescribed mortars in which the proportions are stated, as opposed to designed mortars in which compressive strength is used (BS EN 998-2: 2003).

A set of three cubes (50mm^3) and three prisms (100mm*25mm*25mm) will be produced for each mix type so that a comparison of the compressive and flexural strength of each can be obtained. The production of the cubes will be done in accordance with BS 4551: 2005, although the actual testing is in accordance with BS EN 1015-11: 1999. Some of the material used for obtaining the flexural strengths will then be used to determine the porosity and water absorption, as these are pertinent parameters that are related to the performance of mortar. These tests will be based on BS EN 772-4: 1998.

Curing regime

All the samples will be cured under polythene tenting to maintain an 80 per cent relative humidity. The normal curing conditions for Portland cement mortars is stated in BS EN 1015-11: 1999 where the samples are placed in 'storage chambers, capable of maintaining a temperature of 20°C ± 2°C and a relative humidity of 95% ± 5% or 65% ± 5%'[5]. They are to be cured in these conditions for 28 days as the Portland cement mortars will have reached 95 per cent of their compressive strength by this time.

However, hydraulic lime appears to need longer. 'Compressive strength of lime base mortars are usually quoted at 91 days rather than 28 … lime based mortars will typically have reached half its 91 day strength by 28 days'.[6] As the samples are being produced to obtain a direct comparison of the various merits of each mortar system, a shorter curing period would be an advantage in the production of dwellings, as time is, in effect, money. The length of curing time for the hydraulic samples of 91 days can cause problems with the 'build rate being perceived to be very slow with lime mortars', and it is therefore proposed that a curing time of 28 days be used as this is a recognised curing time for mortar.[6] Indeed, it could be argued that the compressive strength of the samples should be done at an earlier age as mortars are often required to cope with the demands of loading well before the recognised 28-day-strengths prescribed by the British standards.

Water content of the mixes

The amount of water added to each mix is controlled to provide a set of mortars of similar workability. Water added to each of the mixes is recorded and the series of 'dropping ball' determinations is taken to ensure that the mixes conform to the standards specified. Mortar mix water content and dropping ball readings are then tabulated and graphed to illustrate the conformity and consistency of the mortars being produced. This can be seen in Table 1 and Table 2 below, and in the graph of the mean and standard deviations in Figure 3.

Figure 1: Dropping ball equipment for measuring workability

Figure 2: A typical mortar mix 1:3

Table 1: The amount of water added to each mortar mix to achieve the required workability dropping ball (DB in mm)

Mortar mix	Water added to mix (ml)	DB 1	DB 2	DB 3	Average DB	Standard dev
Cement/sand C1:3	1,480 ml	10.4	10.6	10.2	10.4	0.2
Cement/sand C1:6	1,400 ml	11	11.5	10.9	11.13	0.32
Cement/sand C1:8	1,400 ml	11.8	12.2	12.5	12.16	0.35
Lime /sand L1:3	1,520 ml	10.4	10.8	10.1	10.43	0.35
Lime /sand L1:6	1,450 ml	12.9	12	12.7	12.53	0.47
Lime /sand L1:8	1,400 ml	10.4	9.6	10.8	10.26	0.61

Table 2: Dropping ball results

	C1:3	C1:6	C1:8	L1:3	L1:6	L1:8
+1 sd	10.6mm	11.3mm	12.5mm	10.7mm	13.0mm	10.8mm
-1 sd	10.2mm	10.8mm	11.8mm	10mm	12.0mm	9.6mm
Average	10.4mm	11.1mm	12.16mm	10.4mm	12.5mm	10.2mm
Standard dev	0.2mm	0.3mm	0.3mm	0.36mm	0.5mm	0.6mm

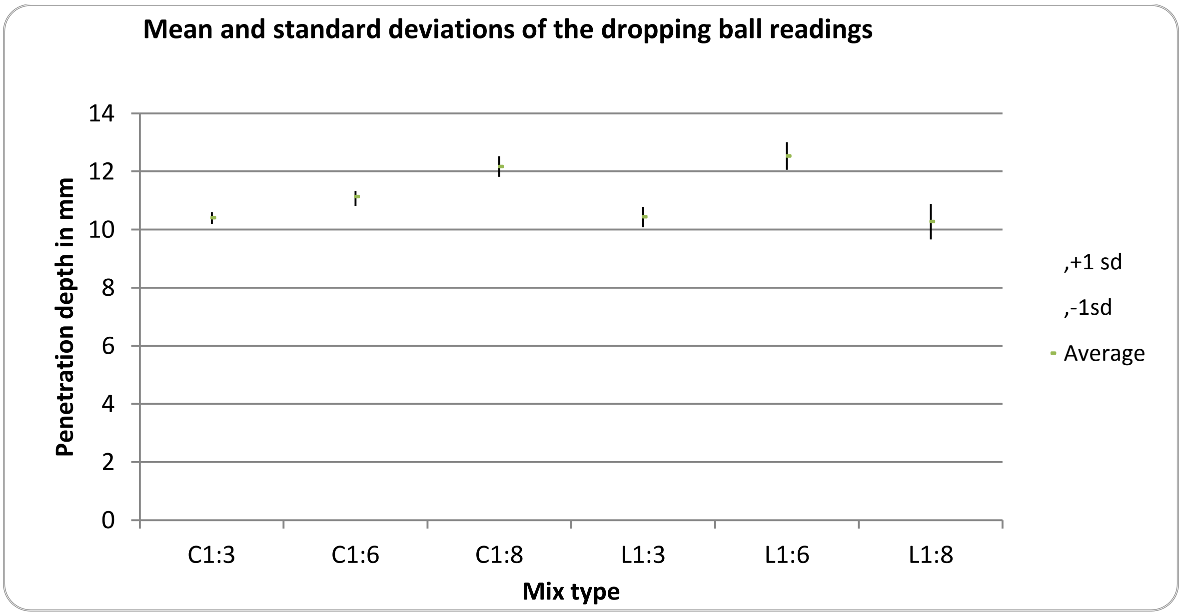

Figure 3: Mean and standard deviations for the dropping ball test

Each mortar mix then has a series of cubes and prisms produced so that the compressive and flexural strengths of each mortar can be obtained. These are made in accordance with the relevant standard. Figure 4 shows a set of cubes being produced.

Figure 4: ~~Five~~ test cubes being prepared

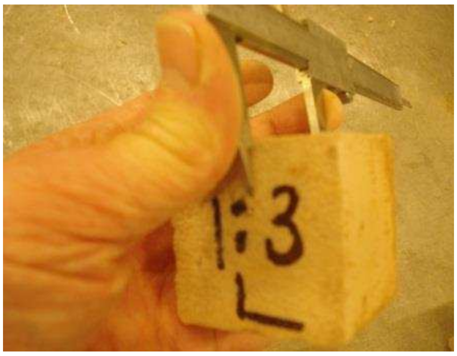

Figure 5: Measurement of cube dimensions using vernier callipers

Compressive and flexural strength of the mortars

The cubes produced are subsequently tested in accordance with the relevant standard after 28 days' curing. The mortar cubes are subject to compressive loading while the prisms are subject to three-point flexural bending.

A graphical representation of the performance of the cubes and prisms can be seen in Figure 6 and Figure 7 where both cubes and prisms express similar trends, with the exception of the 1:3 cement binder mortars, which display a far larger compressive and flexural strength than the rest of the samples.

However, it would appear from the results of the flexural tests displayed in the graph in Figure 7 that a 1:8 cement/sand mortar expresses similar flexural strengths to a 1:3 lime mortar. This does not, however, mean that the flexural capacity of the cement/sand mortars, i.e. its capacity to bend/flex prior to failure, is the same as its respective lime mortar, as this parameter was not measured, merely that the load required to induce failure is similar.

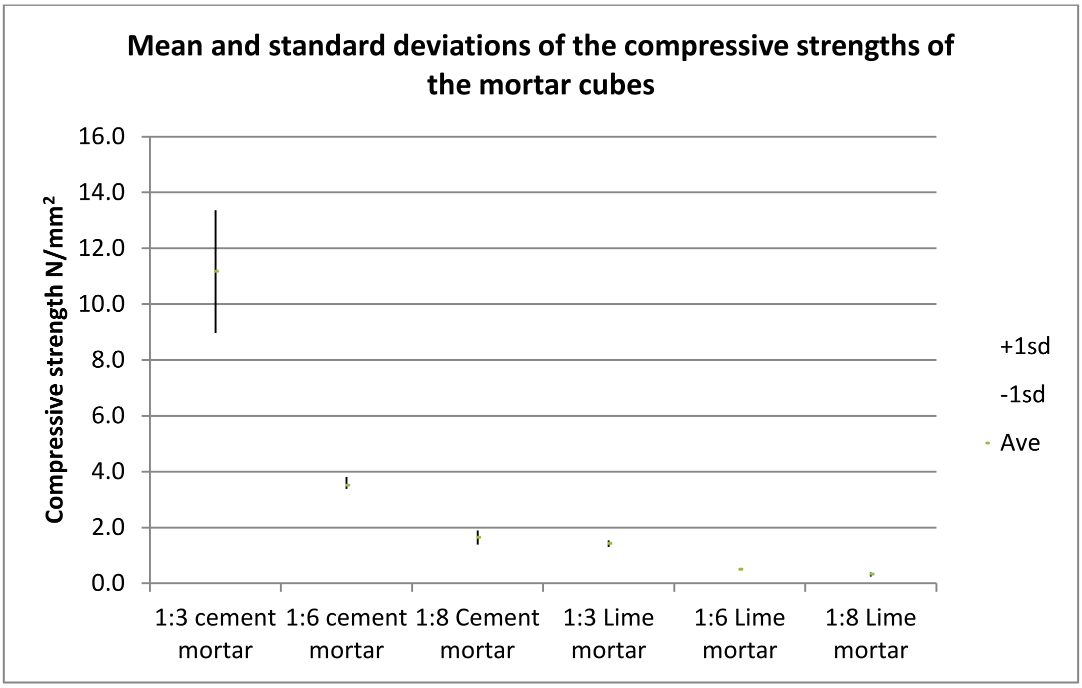

Figure 6: Compressive strengths of the mortar cubes (mean and standard deviations)

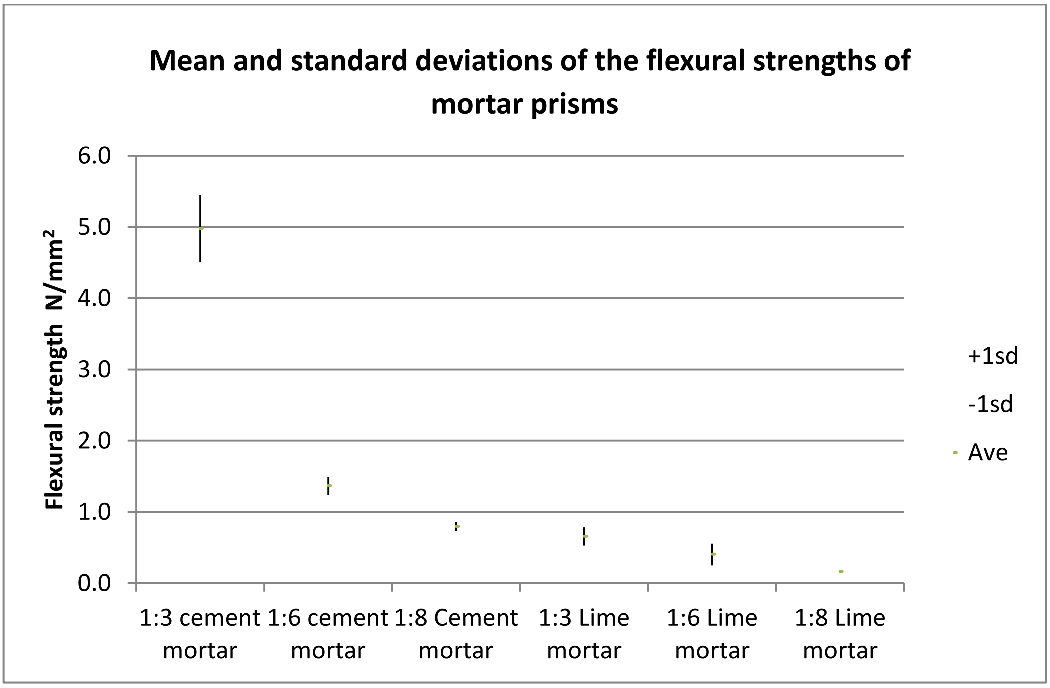

Figure 7: Flexural strengths of the mortar prisms (mean and standard deviations)

The water absorption and porosity of the mortars

A series of tests is then carried out to compare the porosity and water absorption to establish if lime mortars are indeed more porous and, in turn, more breathable. Samples of broken prisms that had been used to find the flexural strengths of the respective mortars will be employed in these tests. The procedure adopted for testing the mortar samples is based on a top pan weighing method, in which the initial dry mass of each sample is taken. The method is based on BS EN 772-21: 2011. The samples are either left to soak for 24 hours or, as in this case, vacuum saturated. The samples are then suspended in water with a reading taken of the mass of water displaced. The samples then have their saturated mass determined and from these three masses — the dry mass, the suspended mass and saturated mass — the percentage porosity and percentage water absorption of each sample can be determined.

The results indicate that the lime-based mortars have a more open, porous structure in comparison with their cement-based counterparts (as can be seen in Table 3). It is worth noting that the same trend seems to be observed with the 1:3 lime-based mortar, which has a similar water absorption to the 1:8 cement-based mortar (as is the case for the compressive and flexural strengths). Note that the 1:8 lime-based mortars do not express a great difference from the 1:6 lime mortars. This is due to the readings for these samples not being as accurate as the other samples because of the friable nature of this lime mortar; the samples break up when they are subjected to the test procedure.

Table 3: Porosity and water absorption of mortar (in %)

Porosity and water absorption						
	C1:3	C1:6	C1:8	L1:3	L1:6	L1:8
Porosity	35.38	37.39	38.21	38.50	40.14	40.30
Water absorption	21.30	23.35	24.20	24.11	25.69	25.88

CONCLUSION

Although the test regimes applied here have been restricted to a few parameters, namely compressive strength, flexural strength, water absorption and porosity, it can be deduced from the results exhibited by the different test regimes that the 1:3 lime/sand mortar performs very closely to the 1:8 cement/sand mortar in every aspect of the tests carried out. That being the case it can, therefore, be said that the use of a reduced amount of cement within a mortar mix would produce a mortar with similar characteristics to a mortar with a high proportion of hydraulic lime.

This can then be taken further by looking in more detail at the qualities required by mortars. One quality that is desirable in a mortar is its breathability and it has long been established that lime mortars express breathability, ie, its ability to regulate moisture migration to and from the surrounding air and masonry. This ability has been partly attributed to the mortar's porosity because the 1:8 cement/sand mortar expresses similar porosity to 1:3.

Lime/sand mortar has a similar breathability . Other factors that are important are compressive and flexural strength, and here again it can be seen from the results obtained in these tests that the two mortars highlighted express similar performance to each other.

This paper could then postulate that this might also be the case for the bond strength performance of these two mortar systems, namely the 1:3 lime/sand and the 1:8 cement/sand, and the subsequent effects that this might have on the water penetration of the masonry structure. Links are often drawn between bond strength and water penetration.

In essence the tests conducted here suggest that a reduction in the amount of Portland cement binder being used to produce a usable and viable mortar (1:8) is similar to using a mortar that contains a high proportion of hydraulic lime binder (1:3). This paper acknowledges that the choice of binder is based sometimes on more than its mere performance characteristics and in the case of hydraulic lime this can be its compatibility with the building units and continuity with the original materials, especially in the conservation arena. Although as stated previously this paper does not set out to compare the sustainable credentials of one hydraulic binder over another. However, it could be said that the results expressed here do suggest that a reduction in the amount of Portland cement binder being used might be another alternative to using higher proportions of hydraulic lime binder. It could be argued that using less Portland cement binder within a mortar mix would mean that fewer raw materials would need to be won, thus conserving our natural resources and ultimately releasing less carbon dioxide as a result. This may be a very simplistic view and would need further and more detailed calculations. However, it is something that needs to be considered and debated if the construction industry is to embrace an holistic approach to the question of sustainability.

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