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The Design and Use of Repair Mortars for Historical Masonry in Australia

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Abstract For the first 150 years of European settlement in Australia, masonry buildings were constructed largely using the techniques brought from Europe (particularly Great Britain) by the immigrants. Lime for mortar was made by shell burning until limestone deposits were worked from the mid 19th century. Contamination of the source and the wood–fired burning process ensured that the resulting lime was at least feebly hydraulic, as shown by testing. As in so many parts of the world, lime in mortar was displaced by Portland cement after World War II. Even the available Australian Codes lost sight of the role of lime and became quite misleading in giving guidance to users. As heritage restoration became important from the 1970s, there was increasing interest in lime, but architects and engineers had no guidance and made many mistakes which are still being perpetuated. Following experience in masonry conservation in buildings dating from the 1790s onwards, the author has been instrumental in developing a synthetic hydraulic lime mortar which is now being used successfully throughout Australia.

1 Introduction

1.1 Lime mortar use in Australia

The first European masonry buildings in Australia were built in the 1790s using bricks made in clamp kilns. Lime was made by burning shells gathered from aboriginal “middens” (waste dumps), but large quantities of this material were not available due to kiln shortages and deficiencies, and many early buildings were almost entirely built with soil bedding and even had soil plaster with the little lime available used for lime–wash paint to give some durability. As the colony developed, kilns were set up in many places along river and harbour foreshores,
but it was not until the mid 19th century that limestone deposits were first used for a more consistent supply of lime. These deposits, unfortunately, were generally well away from settlements and easy transport, and the use of lime from shells was continued for some time [1].

Many lime mortars found in older buildings, particularly those from the many built in the late 19th century, such as inner city terrace houses, are now found to be a powder which falls from the joints when the outer crust has broken. This observation has led to many architects and engineers, even those with some conservation experience, gaining a distorted impression of the quality of all lime mortar. On the other hand, very sound mortars were made from the earliest times when knowledgeable people were employed, particularly on government works.

A possible explanation for the poor mortar of the late 19th century has been found in the reporting of a customs duty dispute in which the New South Wales (NSW) colonial government classified imported New Zealand hydraulic lime as Portland cement and levied the same duty on it [2]. This would have been a disincentive to the local industry using hydraulic lime and the increasingly pure “fat” limes made from the local limestone deposits would have made poor mortar without use of pozzolan.

1.2 Current practice

Since the middle of the 20th century Portland cement has taken over as the cementing agent in almost all mortar; lime, if used at all, is usually in the form of hard–burnt dry slaked material, which adds little to the mix apart from workability. The situation has been exacerbated by a lack of understanding on the part of the Australian Masonry Code committee [3], which has effectively banned lime for new work in any mix “weaker” than 1 part lime: 2 parts cement: 3 parts sand; the issue is further confused by simply referring to the “Limes in building” code [4] and not distinguishing dry slaked lime from lime putty from quicklime, etc. in volume batched mixes. Further problems are caused by the Code not designating sand grading requirements, which results in unworkable mixes made from single–sized sands, which are then made workable by the bricklayer using additives ranging from household detergent to fireclay.

The situation in conservation works is little better, particularly when the conservation specialist’s back is turned.
2 Research on early lime mortars

2.1 Examples

The properties of some of the early lime mortars have been investigated in detail and it is useful to set out the findings. The two samples used for illustration purposes are a c.1840 mortar used for construction of a stone reservoir and an 1859 mortar used for a brick–arch railway bridge.

2.2 c.1840 mortar

A reservoir wall and adjacent “cattle tank” were built around 1840 at Campbelltown, near Sydney, using convict labour gangs. Sandstone was quarried nearby and lime was sourced from shells. Samples of the original mortar were subjected to analysis using a scanning electron microscope (SEM) and X-ray diffraction (XRD). Fig. 1 shows the mortar in place and Figs. 2 and 3 show the SEM results, including spot energy dispersive spectrographs indicating the compositions.

XRD results have been found of minimal use as the calcite and silica peaks tend to hide the smaller peaks of components critical to classification; this may not be a problem if the work was done in a laboratory with a good database of similar materials by an operator versed in mortar materials.
The principal finding has been that the mortars have significant quantities of calcium silicate hydrate (C-S-H) crystals indicating hydraulicity. Of interest has been that the long thin “birds nest” crystals are, in fact, tubular and the bore of the tube was able to be measured as 0.5 µm.

2.3 1859 railway bridge mortar

This was the first mortar for which the author was able to obtain an analysis and, as well as the SEM results, a chemical analysis was undertaken showing that
the mortar had 12% clay mineral content and so was “feebly hydraulic” under the Vicat classification [5].

The quality of this mortar throughout the joint had first been demonstrated when a pair of bricks was removed from the structure for analysis. When these bricks were prised apart, the fracture occurred in the face of a brick, not at the joint, indicating the strong bond obtained. It was this example which led the author into investigating old lime mortars, as it clearly showed that they were not all as poor as those frequently found in buildings.

Test results to date have not been able to show whether the mortar was made from lime which was deliberately or accidentally hydraulic and no documents have been found which can assist this determination; petrographic examination might help, but has not been fundable within the project budgets.

2.4 Other results

The need to repair and strengthen a number of 19th and early 20th century railway structures has required determination of the flexural properties of the brickwork. Whilst the Australian masonry code [6] does not allow the mobilisation of tensile strength under gravity and live loading, it does under intermittent loads from wind and earthquake actions. To determine the flexural strength of existing brickwork, cores have been taken and the cylinders tested under four-point bending. Characteristic flexural strengths in excess of 1 MPa have been determined, with individual cylinder bending tests exceeding 6 MPa flexural tensile strength: the maximum flexural tensile strength allowed under the code [7] for modern mortars is 1 MPa.

2.5 The problem of sand

Early mortar makers living near the coast had unlimited supplies of beach and dune sands, but these tended to be neither sharp nor well graded. Observations suggest that coarser particles, giving better sand grading, were introduced by using crushed shell, either unburnt material from the kiln or deliberately added separately as seen by the lack of signs of burning on some fragments.

In the modern masonry industry, poor sand grading has continued as noted above. Another problem found in conservation practice is that sand is chosen often for its colour, not its physical properties.

Rediscovering the importance of sand grading and interpreting the writings of such as authors as Vitruvius [8] and Palladio [9], together with 19th and early 20th century writers on this subject, has been an important part of the author’s journey.
3 Replacement mortars

3.1 Design criteria

The design criteria used for replacement mortars in buildings have nominated an adequate, but not too strong, compressive strength and permeability greater than the bricks or stone. The latter requirement, which is critical to limiting salt damage, has been the most neglected and hardest to achieve. Most unfortunately, many practitioners have ignored both requirements with mixes made from powdered slaked lime, white or off–white cement for appearance and single sized dune sands; workability agents or even clay are often added. The resulting mortars have given none of the key properties, but they seem to look satisfactory, at least for sufficient time for the continuing problems not to be ascribed to the faulty work.

3.2 The first new mortar

The 1827 church in Port Macquarie, NSW, about 300 km north of Sydney, was built with convict labour using sandstock bricks made from local clays and fired in clamp kilns. The author was engaged for major conservation works on the masonry in 2002.

The first requirement was to design a suitable mortar for repointing the brickwork which was of suitable strength (i.e. not too strong) and with permeability greater than or equal to the bricks. The church is very close to the coast and salt damage was widespread, particularly where Portland cement–based mortars had been used for past repair work. Severe damage had also been caused by an ill–fated attempt to control rising damp by cement rendering the outside of the walls to window sill level: not only were the bricks damaged and had to be reversed or replaced, but the trapped moisture caused severe damage to the internal timber panelling.

The mortar design was based on aged lime putty, graded sharp sand and a blast–furnace slag pozzolan at 5% of the lime by volume.

To determine permeability matching, samples of bricks were cored to produce 38 mm x 13 mm discs and mortar samples were made up to the same dimensions. The samples were mounted using resin in PVC tube and tested with water using a controlled pressure differential of 20 kPa: permeability (in m²) was then determined from the volumetric flow rate using a form of Darcy’s law (see Figs. 4 and 5).
The initial test, of what was thought to be a reasonable mortar design, resulted in a mortar having a permeability 1/10th of that of the bricks, showing how wrong one can be if testing is not undertaken. A suitable mortar was found after adjusting mix proportions and sand grading.

The undertaking of this test was a valuable part of the mix development process and showed that a mortar mixed using all the criteria normally recommended did not necessarily produce the desired result.

### 3.3 The next phase in development of synthetic hydraulic lime mortars

Further study of the literature and old specifications made it clear that there was a clear distinction between the practices followed by plasterers and masons in their use of lime: stories of plasterers’ aged supplies of lime putty had been generally interpreted as applying to masons also, and this confusion also seems to have been common in other English–speaking countries until work undertaken by members of the Building Limes Forum was better known [10]. Study of 19th century
specifications in Australia also indicated that quicklime (sometimes referred to as rock– or stone–lime) was the normal material for masonry, that it was to be used with the “hot” lime process and that “fat” lime was not desirable for masonry, as illustrated in a typical specification used in Australia in the early 20th century [11]. This latter requirement appears, however, not to have been followed because of the general unavailability of hydraulic limes in Australia.

Manufacturers of lime in Australia produce more than 90% of their product for uses other than masonry. In most cases purity is required and reactivity is not an issue for buyers when the product is to be used for such industries as chemical manufacture and water treatment, where the bulk of sales are made. There is, however, one non–mortar use where reactivity is important and that is the stabilisation of clay soils in road construction: at least two production plants (in the whole of eastern Australia) are known to make soft–burnt lime thanks to the requirements of road construction. The lime is available in granulated form, rather than the coarser particles of traditional rock lime: the smaller particles give a material with a greater bulk density, which needs to be accounted for in the mix design.

Having found suitable sources of quicklime, it was necessary to determine the best available pozzolan. The blast furnace slag used in the early mixes was only available in bulk quantities and with little control over quality. Brick dust from demolished buildings was not available in sufficient quantities from older buildings with low–fired bricks. Metakaolin was determined to be the best choice and, although imported, had consistent quality. Sand was specified in accordance with the grading in the British code [12], and some washed, coarse river sand, produced for compacted paver bedding, was found to comply with the requirements without further treatment.

Mixes have been made successfully for different structures with lime:sand proportions of between 1:3 and 1:4, by volume, and with metakaolin pozzolan added at between 5% and 15% by volume of lime.

Strength testing of the mortars has given further problems as the first cubes moulded and placed in a laboratory “fog” room failed to gain any strength from carbonation, due to saturation resisting the diffusion of carbon dioxide. The most recent test results have been obtained by placing the cubes prior to testing in a chamber controlled at 70% relative humidity and 20°C, as nominated for the testing of “historic” mortars by the ASTM method [13].

4 Where to from here?

There is still resistance to the use of properly formulated lime mortars in Australia, not just for new works but for conservation of historical buildings. For example, one of the major specifiers of conservation works on 19th century sandstone in government and other buildings in Sydney is still recommending a
mix by volume of one part Portland cement: 1 part dry slaked lime: 6 parts sand, and with no sand grading requirements. At the time of writing the author was engaged in what appeared to be an unwinnable dispute with this group over adopting lime mortar, and the elimination of epoxy fastenings, for the replacement of a sandstone cladding on a major public building.

Industry may be less resistant and a major manufacturer of lime which is already producing the best “soft burnt” material is interested in making progress with the manufacture of hydraulic lime as it may help the “ticking of green boxes” in its corporate profile.

5 Conclusions

The struggle to bring Australia up to “world’s best practice” (a term loved by politicians), in its use of lime mortar has started, but has a long way to go before all involved can be convinced that modern Portland cement is not an appropriate material for use in historical masonry. The author has made a start and now the resulting “hot lime” mixes are being used in projects throughout Australia.

6 References

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5. Vicat LJ (1837) Treatise on Calcareous Mortars, Trans. Smith
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