Introduction

This INFORM guide focuses on two commonly used mortar types in Scotland: lime mortars and cement mortars, and the impact that the use of these materials has on stone-built structures. An overview of the physical properties of both mortar types is given, as well as an indication of their technical suitability for use with traditional stone masonry. Selecting a suitable mortar for repair works is important for the conservation of traditional buildings and for preventing masonry decay associated with the use of incompatible materials.

A brief history of mortars in Scotland

Scotland has a long tradition of building with natural, locally available materials and this has resulted in distinctive architectural styles (Fig. 1). The use of stone and lime mortar in Scottish construction stretches back to Roman times, but before lime became widely available, clay and earth mortars were common. However, a large proportion of Scotland's buildings constructed prior to 1920 used lime mortars for construction and finishing (e.g. bedding, pointing, harling and renders).

Fig. 1 *Example of stone and lime mortar construction at Fort George dating c.1769.*

The use of Ordinary Portland Cement (OPC) mortars became increasingly common from the mid-19th century. By the mid-20th century OPC was the norm for new construction, and it began to be used to repair traditional buildings that had been originally built with lime mortar. At this time the properties of the two materials were relatively little understood. Decades later, the inherent incompatibility of OPC mortar with many stone types is evident, as cases of masonry decay associated with its use have become common. The growing knowledge and understanding of the importance of stone/mortar compatibility has led to a resurgence in the use of lime mortars, particularly on traditionally constructed stone buildings.

What is mortar?

Mortar is a generic term given to workable material that can be trowelled in place and hardens in-situ. Mortar can be used for building, pointing, plastering or harling. The composition varies, but all mortars consist of three primary components:

- Binder (e.g. lime, cement, clay, earth)
- Aggregate (e.g. sand, gravel, crushed stone)
- Water

Other materials (additives) may be added to give particular properties. An understanding of the effects of the different components is required in choosing an appropriate mortar for a specific purpose.

Binders

A binder holds the mortar together, providing a supporting matrix for the aggregate grains. The type of binder used has a significant impact on the properties of a mortar, both when it is wet and when it hardens.

Lime: is produced by burning calcium carbonate (limestone, chalk, shells) at around 850ºC to produce quicklime. Historically this process was carried out throughout Scotland. Many ruinous lime kilns still standing today are evidence for this once large scale industry (Fig. 2). Quicklime is slaked with water in a vigorous reaction producing heat (Fig. 3) to produce lime putty (if excess water is added) or to form a dry powder (hydrated lime). The lime is then mixed with sand (and water in the case of dry hydrated lime) to produce a mortar. Historically it was common for quicklime to be mixed directly with sand and water to produce a 'hot mixed lime' mortar and this technique is still used by some masonry contractors.

Limes made from pure sources of calcium carbonates (e.g chalk) are typically referred to as non-hydraulic limes or 'air limes' while those made from limestones with clayey impurities are called 'Natural Hydraulic Limes' (NHLs). Modern standards classify hydraulic limes by strength, although this property is not necessarily the most important factor in choosing a lime for a mortar.

Fig. 3 *Slaking quicklime is a vigorous reaction that produces heat.*

Water absorption, or permeability and flexibility of the materials are often more significant aspects. Limes of greater hydraulicity typically have lower water absorption rates and flexibility. The range of lime binders available on the market is constantly changing. Modern materials, classed as 'hydraulic lime' or 'formulated lime' can have significant variations in lime content and may contain additives that affect their properties. When working with traditional buildings, it is generally advisable to use air limes or natural hydraulic limes as these have a proven track record in conservation work and are generally better understood.

Cement: is produced by burning impure limestone that naturally contains clay (or with added clay), to a much higher temperature than for lime production (typically 1400ºC or above). This produces hydraulic clinker particles that are ground to a powder for use as a binder. When water is added, the hydraulic particles react with it to form a network of interlocking crystals that give cement its strength, but also result in low permeability. Modern cements are classified into different types based on a number of properties including their chemical composition and strength. Historic cement mortars were typically weaker and more permeable than the OPC mortars produced today. The two materials are not always compatible; using a modern cement mortar to repair masonry built with much earlier cement mortar might not be appropriate.

Fig. 2 *The historic lime kilns of Charlestown, Fife.*

Aggregates

Aggregates make up the bulk of a mortar mix and significantly affect the mortar's performance. Aggregates can affect the setting of a mortar, depending on their composition, and can influence air and water movement within the mortar. Sand, gravel and crushed stone are the most commonly used aggregates, particularly for lime mortars. Recycled and reused materials are increasingly used for concrete production in new build construction. Aggregates also affect mortar aesthetics, giving lime mortars (and white cement mortars) their colour. The fine grains give mortars their colour, while coarser grains add texture. The correct choice of aggregate is therefore important, particularly when undertaking patch repairs, which must be compatible both technically and visually.
Most lime mortars are made using coarse-grained sands, which contain a broad range of particle sizes (well-graded) and are angular in shape (sharp) (Fig. 4). The maximum grain size of the aggregate is dictated by the thickness of the bed or joint (or render coating) and is typically one third the joint width. For certain applications, including plaster finish coats and pointing of ashlar joints, a much finer aggregate will be required. A quartz sand with a maximum grain size of ~1 mm may be required, or for very fine joints, finely crushed chalk (whiting) can be used.

Fig. 4 *Well-graded sharp sand.*

Additives

Historically, natural additives were added to lime mortar mixes to improve their performance. 'Pozzolanic' materials such as brick dust and fly-ash promote setting; animal hair (Fig.5) was sometimes added to increase tensile strength for internal plastering and external finishes; and animal fats were used to provide a degree of weatherproofing. Modern synthetic additives are now available to enhance mortar performance. Most additives are only required in very small quantities and can be detrimental to mortar performance if not batched correctly.

Fig. 5 *Hair in a historic lime plaster. © W. Revie.*

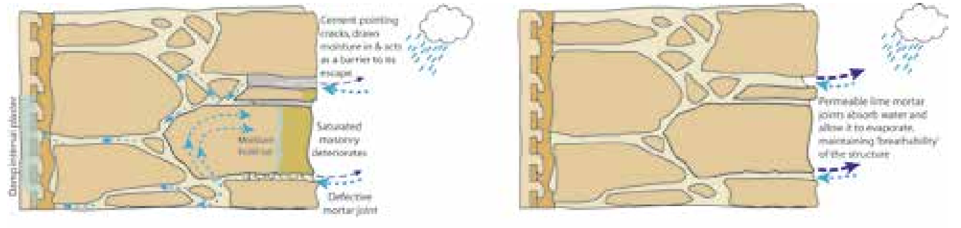

Fig. 6 *Moisture management in traditional buildings.*

Mortars in traditional buildings

Unlike modern buildings which generally rely on cavity construction and waterproof exteriors to prevent the ingress of moisture, mass masonry buildings depend on moisture management (Fig. 6). The continuous cycle of absorption and evaporation of moisture within the building fabric, sometimes referred to as 'breathing', ensures a state of balance with the surrounding environment, helping to prevent internal condensation, damp and associated building decay (Fig. 7). Mortar joints play a role in this process, protecting the external masonry by acting sacrificially, such that a correctly specified mortar will weather at a faster rate than the adjacent masonry. Mortars may therefore require periodic maintenance, i.e. repointing of joints.

In order for a mortar to perform sacrificially it should have a good degree of connected pore space through which liquid water and water vapour can move and should have sufficient flexibility to accommodate movement associated with stresses such as thermal expansion. Correctly specified lime mortars fulfil both these criteria, as do some early cement mortars. Modern cement-based mortars typically do not. In general, soft or 'weak' mortars have higher permeability and flexibility.

When impermeable mortars are used with masonry, the ability of the building to breathe is compromised. Such mortars may be used with the intention of waterproofing a building, but they are liable to shrinkage during drying, and the fine hairline cracks that form as a result can act as capillaries, drawing moisture in from the external face towards the interior of the building. The impermeable mortar prevents this moisture from evaporating, resulting in a build up of moisture behind the mortar and subsequent accelerated deterioration of the stone (Figs 8 and 9).
The use of some cements can lead to the introduction of salts to the masonry. Crystallisation of salt crystals on the surface of the stone is unsightly, while crystallisation below the surface of the stone can exert pressure on the stone causing more rapid decay.

Fig. 7 *Problems caused inside buildings by using impermeable mortar on the exterior.*

Fig. 8 *Pointing with hard cement can cause masonry to deteriorate at an accelerated rate.*

As well as the technical issues associated with incompatibility of materials, the use of cement mortar with traditional stonework can produce poor aesthetic results (Fig. 10). The often dull grey finish of cement mortars and renders is often a poor match for the colours and textures that are achievable using lime mortars. A range of different styles are used for finishing modern cement pointed joints, many of which were not used traditionally (Fig. 11). Recessed and strap pointing can lead to the pooling of water on the stone and should be avoided.

Fig. 9 *Deterioration of masonry around cement mortar joints.*

Fig. 10 *Unsightly cement pointing.*

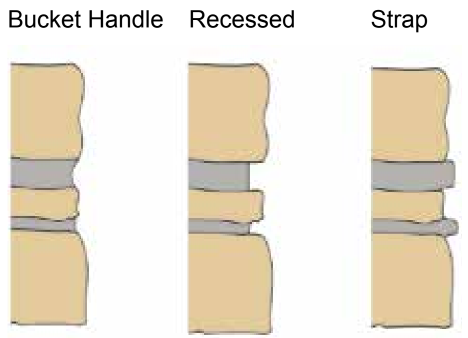

Fig. 11 *Pointing styles typically associated with modern cement mortars.*

Choosing a suitable mortar

Where repairs are to be carried out, the most effective approach usually involves the use of materials and techniques that were employed in the original construction. This logic applies to both lime and cement mortars, for original cement mortars are often just as worthy of conservation as lime mortars. However, due to the widespread use of replacement cement mortars over the past 70 years, care should be taken to establish what is actually original (Fig. 12).

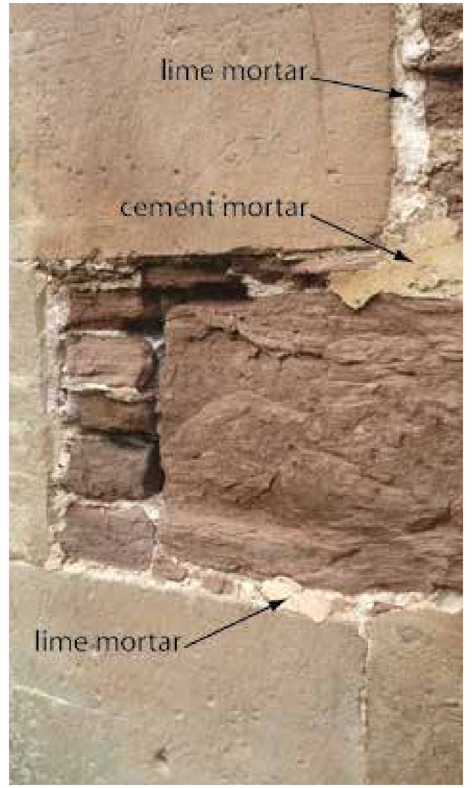

Fig. 12 *Detachment of failed cement pointing reveals original lime mortar beneath.*

Where failed mortars require replacement, evaluation of their function is required. The masonry condition, prevailing climatic conditions, and visual appearance (texture and colour) should all be considered. Analysis of the existing mortar can assist in matching, to help maintain the visual integrity of the structure where patch repairs are carried out. Detailed analysis of the original mortar can provide an indication of the original mix proportions (providing the mortar is not excessively weathered). However, simply replicating the mix may not always be the best course of action, especially if the requirements of the mortar have changed, for example repointing of wallheads on a once roofed, but now ruinous, structure.

Selection of an appropriate repair mortar can be a complex process, and the skills of an experienced buildings consultant may be required. An initial investment in getting the right specification for materials and application will ensure better performance in the longer term, and save on future maintenance and repair costs.

Conclusion

Both lime and cement mortars can perform well when used appropriately. In the majority of cases, lime mortar will be required for the repair of traditionally built masonry structures. The use of incompatible mortars can lead to accelerated masonry decay and damp problems. An appropriately skilled buildings consultant or stonemason should be involved in the specification of repair materials from an early stage in any conservation works to ensure that the right materials are used, preventing avoidable masonry decay and associated problems.

Contacts and further reading

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The Society for the Protection of Ancient Buildings (Scotland)
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INFORM: Repointing Ashlar Masonry, Historic Scotland (2013)

Practical Building Conservation Series: Mortars, Renders and Plasters, English Heritage (2011)

Short Guide 6: Lime Mortars In Traditional Buildings, Historic Scotland (2014)

Short Guide 9: Maintaining Your Home, Historic Scotland (2014)

TAN 1: Preparation and Use of Lime Mortars, Historic Scotland (2005)

Historic Environment Scotland's INFORM Guide and Short Guide series contain further information on the conservation and maintenance of traditional buildings. These publications are free and available from our technical conservation website, address above. Alternatively, you can contact us on technicaleducation@hes.scot for these or any other publication enquiries.

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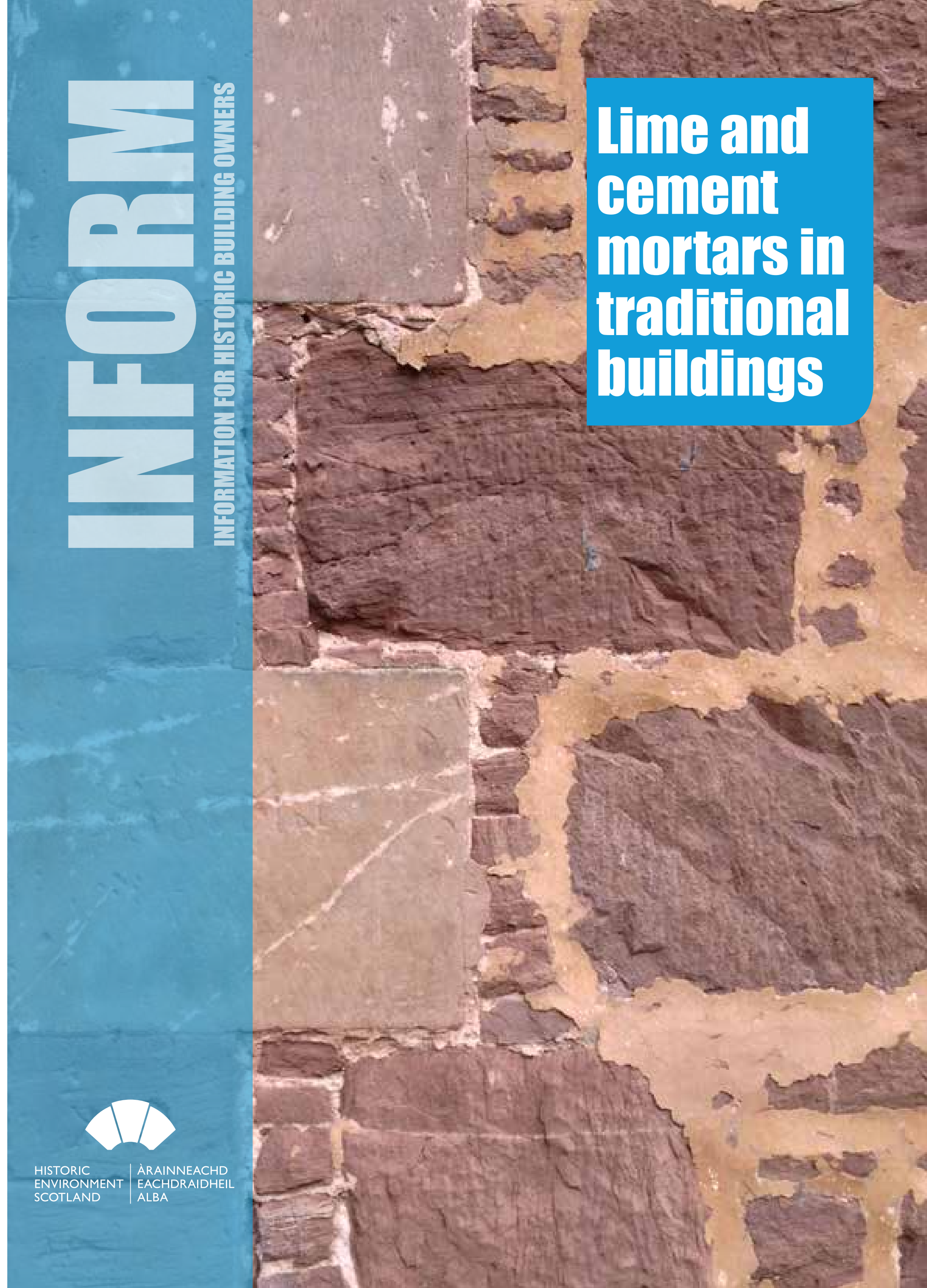

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