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The effects of site practice on the physical properties of proprietary stone restoration mortar

Clare Torney [a,*], Alan M. Forster [b], Phillip F.G. Banfill [b], Ewan M. Szadurski [b]

[a] Historic Scotland Conservation Directorate, 7 South Gyle Crescent, Edinburgh EH12 9EB, United Kingdom
[b] School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh EH14 4AS, United Kingdom

HIGHLIGHTS

- Laboratory research simulates site modification of a formulated restoration mortar.
- Increased water content (120%) decreases compressive strength by ~50%.
- Increased mix time (up to 6 min) increases moisture transmission of material.
- Surface laitance reduces vapour permeance by ~13%.
- Deviation from manufactures guidelines produces unknown properties, increasing risk.

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ABSTRACT

Commercially-produced 'restoration mortars' are increasingly being used in stone masonry conservation. The convenient 'mix and go' approach of these materials is opening up the area of masonry repair to a wider, lesser skilled, consumer base. Pragmatic site practice with restoration mortars often leads to the modification of materials with the aim of providing enhanced workability, fitting with varying weather conditions and project timescales. This work aims to establish the resilience of one such proprietary restoration mortar to variations in its preparation and finishing. The properties of the material, and therefore its performance in service, are significantly influenced by variations in mixing regime, surface finish and pigmentation. Results highlight the impact of workmanship on the material's properties and the need for a thorough understanding of the product prior to specification, preparation and application.

1. Introduction

Weathering and deterioration of historic stone masonry is a worldwide problem. This situation is likely to be exacerbated by current and predicted future climate change [1], particularly associated with intensifying precipitation patterns [2–4]. Increasing rapidity of, and prevalence in, masonry degradation and the associated loss of historic building fabric is creating an urgent need for practitioners to make efficient and effective conservation decisions surrounding the repair process. A number of repair options may be considered in cases of masonry deterioration, including; natural stone replacement (indenting), consolidation of existing masonry, or 'plastic' repair with mortars [5–8]. Each of these repair approaches brings with it a number of benefits and drawbacks relating to both technical and philosophical aspects of masonry conservation [6,7].

'Restoration mortar' is a term used to describe a group of commercially produced, proprietary products specifically designed for the repair of masonry units, usually natural stone and/or brick [9,10]. These materials fall into the broader and less well defined category of 'plastic' repairs (repairs using any workable material that will adhere to a substrate and will harden after application), but should not be confused with traditionally prepared bespoke lime 'mortar' repairs. The term 'restoration mortar' does not in itself indicate a material of a specific composition. Many 'off the shelf' products are available on the market, with significantly different compositions [10]. Ideally, restoration mortars will fulfil a number of requirements relating to both technical and visual

* Corresponding author. Tel.: +44 (0) 131 334 6367.
E-mail addresses: Clare.Torney@scotland.gsi.gov.uk (C. Torney), A.M.Forster@hw.ac.uk (A.M. Forster), P.F.G.Banfill@hw.ac.uk (P.F.G. Banfill), E.Szadurski@hw.ac.uk (E.M. Szadurski).

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compatibility including: high vapour permeance and water absorption; good adhesion; and the ability to be coloured and tooled in sympathy with adjacent masonry.

The specification and application of mortars for stone repair work can be extremely complex [11]. An understanding of individual site conditions, substrate properties and aftercare requirements are all important [12–16]. Critically an assessment of the compatibility of new and old materials [11,17–19] is essential prior to the works. However, the 'case-by-case' assessment and specification approach once adopted for mortar repairs is no longer seen as practicable in all cases [20] and regrettably the aesthetics of repairs are viewed as a higher ranked measure of success than compatibility of materials. This situation is in direct contrast to the well considered approaches suggested by various authors [11,18,19].

The use of 'plastic' repair materials including restoration mortars [9] for restoration of historic masonry is increasingly common at a time when short-term cost savings are viewed by some as higher priority than longevity of repairs [21]. The emergence of proprietary 'off the shelf' restoration mortars, specifically designed for the repair of masonry in conservation projects and for the simulation of masonry in new-build situations, is likely to play a significant role in this increase in use [9]. Such prescribed products claim to offer a number of advantages over both natural stone replacement and repair using lime mortar, including: ease of preparation and application; universal suitability for a wide range of substrates; and visual 'matching' to substrate colours.

The 'just add water' convenience of restoration mortars undoubtedly makes them attractive to less-skilled workers who might not otherwise attempt to carry out masonry repair work. These products also have favourable qualities for specifiers who lack the knowledge, experience and/or confidence to use the more complex traditional bespoke mixes tailored to the individual project; restoration mortars simplify specification by obviating the assessment and selection of suitable binders and aggregates for each repair project. This is somewhat at odds with the skills required for conservation of historic masonry structures where increasing technical understanding of materials characterisation and performance has developed [22]. The potential decrease in skills levels associated with the widened target consumer base of these products is a cause for concern. It is unclear what impact variations in workmanship will have on the material's performance as a higher number of inexperienced operatives utilise the materials. Whereas strict manufacturer's guidelines on the appropriate use of products and step-by-step instructions on their preparation and application might be seen as a route to ensure success, this is not necessarily the case. Site practice is often influenced by time and financial constraints, as well as weather and workmanship, and variations undoubtedly impact upon the materials' ultimate physical properties. The growing availability of such products from specialist builders' merchants and general trade suppliers is also stimulating the market. The potential consequence of these trends is the accumulation of latent defects, with future adverse effects on the built heritage.

Proprietary restoration mortars for masonry repair [10] and commercially produced pre-mixed 'lime-based' repair products for pointing/bedding [20] can significantly differ in their composition and physical properties. Variations in curing regime and aftercare of lime-based mortars can lead to further significant variations in materials' properties and their success rates [22–25]. The objective of the present work is to investigate the impact of variations in site practice (i.e. mix regime modification and workmanship variations) upon the properties and performance of a proprietary restoration mortar. The resilience of a material to modification in site practice is key to the overall robustness of any specification.

1.1. Restoration mortar

Commercially available restoration mortars are typically dry packaged (anhydrous) materials consisting of binder, aggregate and, in some cases, other fillers in predetermined ratios. Such products are optimised during manufacture and are similar in form to some ready-mixed mortars utilised for other functions such as pointing, bedding [20] and rendering. This pre-batching is assumed to reduce the risk of failure associated with drying shrinkage and inaccurate proportions [9], as well as providing 'just add water' convenience. It must be emphasised that some products require mixing of multiple dry components prior to addition of water. Additionally, some restoration mortars may be 'formulated', containing a number of natural or synthetic additives that may or may not be declared by the manufacturer. These additives aim to enhance the fresh properties and/or the hardened properties [23], for example by entraining air (Fig. 1).

A previous study of two commercial restoration mortars highlighted significant differences in physical properties [10] that have also been observed between ready-made lime mortars for other applications [20]. One material was found to be essentially a natural hydraulic lime mortar, and the other a formulated hydraulic lime–cement hybrid mix [10]. The hydraulic lime restoration mortar offers no obvious technical advantages over a site blended mortar mix apart from the convenience of pre-batched components which eliminates the need for careful batching by the end-user. Although the manufacturer provides detailed guidance on appropriate background preparation and application of the mortar, little technical advice was provided on how best to mix the material (i.e. water content and mixing duration) at the time of purchase in 2012. It can be assumed that the 'best practice' guidelines that apply to hydraulic lime mortars in general (e.g. [16,23,26]) are applicable to this restoration mortar. The properties of hydraulic lime mortars are relatively well understood and the impact of workmanship and site practice on their properties has been dealt with in other studies [23,26].

The present study focuses on a single lime–cement hybrid restoration mortar 'Lithomex', a material produced by Chaux et Enduits St. Astier (CESA, France), based on a St. Astier natural hydraulic lime binder. Lithomex is supplied with detailed guidelines on its use and mixing regime [27,28]. We explore the impact on technical performance of deviation from these guidelines, giving mortars of different water content, mixing duration and pigmentation, and also the impact of surface finish.

2. Materials and methods

Unpigmented Lithomex and pre-pigmented Lithomex were obtained from a local supplier and stored in airtight containers until ready for use. Manufacturer's data [27] indicates that the material consists of the following components (expressed as percentage of binder): calcium hydroxide $\leqslant$20%; hydraulic binder (Portland cement) $\leqslant$20%; filler (vermiculite) $\leqslant$5%. In addition, previous research has established that Lithomex also contains fine grained quartz and calcite aggregate and talc filler [10].

The manufacturer's preparation guidelines state that the materials should be mixed (mechanically or by hand) for between three and five minutes, with a water content of 4.5–5.5 L of water per 25 kg of dry material (giving a water/solid ratio of 0.18–0.22). The test programme extended these two ranges and, in addition, assessed the effect of surface finish, specifically the presence of laitance, on the hardened properties of the material. Laitance is a surface coating, 'skin' or 'scum' that forms when fine lime particles held in suspension migrate to the outer surface of the wet material when the surface is being trowelled smooth [29]. This is believed to hinder the vapour permeability of lime-based materials [30], and negatively impact upon the substrate beneath by causing accelerated masonry decay associated with entrapment of moisture.

2.1. Specimen preparation

Specimens were prepared as 40 mm $\times$ 40 mm $\times$ 160 mm rectangular prisms; mortar was mixed using a Hobart 5 L bench top paddle mixer, and cast in polystyrene moulds. These specimens were utilised for determination of carbonation depth, water absorption and compressive strength. Cast cylindrical mortar discs,