

# The whole and the parts: Can lime coatings enhance the drying of salt laden materials?



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## HIGHLIGHTS

- Lime coatings can enhance drying with pure water but with salt solutions their effect is variable.
- With salts, the drying kinetics is slower, more irregular and shows higher dispersion.
- Also, with salts, the drying kinetics may diverge for specimens of a same material subjected to similar conditions.
- The variations in drying kinetics are in agreement with shifts in the salt decay patterns.
- Salts amplify the effects of material heterogeneity.

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## ABSTRACT

Lime coatings are frequent in the architectural heritage. Previous research has shown that they can accelerate the drying of porous materials, such as stone and mortars, which could help control the endemic problems of dampness of these constructions. Here, we investigate the effect lime coatings have when soluble salts are present. The work is based on evaporative drying tests performed on one lime coating applied on five substrate materials contaminated with solutions of NaCl or Na<sub>2</sub>SO<sub>4</sub>. Conclusions could be drawn about: (i) the behaviour of the coating; (ii) the salt decay process. It was observed that the coating can, in few cases, still enhance drying when salts are present. However, in comparison to pure water, the drying kinetics is slower, more irregular and shows higher dispersion. Also, it sometimes diverges among specimens of the same material subjected to similar experimental conditions. These chaotic variations are in agreement with the decay patterns and suggest that soluble salts amplify the effects of the natural heterogeneity of porous materials.

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## 1. Introduction

Lime coatings were used on architectural surfaces since time immemorial. They can be observed in interiors and exteriors of buildings, most currently over lime plasters but sometimes directly on stone elements [1]. The most typical are limewashes, liquid dispersions of lime in water applied by brush, but thicker lime coatings, applied by brush or with a trowel, were also used.

After the industrial revolution, lime coatings started being progressively replaced by synthetic coatings such as acrylic or vinyl emulsion paints. The latter, however, eventually proved to be unsuitable for historical buildings. For example, they often worsened dampness problems, most typically increasing the height of

capillary rise. Indeed, since they have lower vapour permeability than the original lime coatings, water has to rise further up in the wall to restore flow equilibrium [2].

To reinvent and renew the use of lime in conservation has been considered of great interest in the last decades due to its good compatibility with the original materials [3–5]. Compatibility encompasses the functional reasons mentioned above, related to the presence of water. Indeed, it is generally recognized today that traditional lime coatings, namely limewashes, are able to improve the performance of masonry walls in relation to water. This is attributed to their ability to encourage run-off (because they smooth the surface), thereby reducing water penetration while maintaining a high evaporation rate due to their high vapour permeability. It is also, at times, pointed out the role that the hydrophilic characteristics of lime coatings can play in this context. When the moisture content in the material is high, hydrophilic coatings allow the

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positioning of the evaporation front at the outer surface of the material, i.e., the establishing of Stage I conditions (Fig. 1). In contrast, for hydrophobic coatings, the front is always beneath the coating, independently of how high the moisture content is. This corresponds to Stage II conditions, and, consequently, to lower evaporation rates.

However, the effect of traditional lime coatings can go even farther; these coatings, not only do they not hinder drying but might even accelerate it, as recently shown by Brito and Diaz Gonçalves [6]. These authors observed that materials such as lime mortar and natural stones dried faster when covered with a traditional lime coating than when they were uncoated. The difference was particularly important during Stage I, i.e., at the higher moisture contents, when the evaporation front is located at the surface and, thus, the drying rate is constant (Fig. 1). This effect is not related to a high vapour permeability of the lime coating because in Stage I moisture is transported as liquid to the surface. It was attributed to a larger effective surface of evaporation, i.e. a larger dimension of the evaporative surface in the coating (in comparison to that of the uncoated substrate material). This idea is based on the work of Tournier et al. [7] to calculate the effective surface of evaporation of rocks. The fundamental cause is that the complex pore networks of porous building materials give rise to evaporating surfaces with irregular morphology, in which the surface area may exceed that of the projected surface. Therefore, depending on their internal structure, some materials can generate larger effective surfaces of evaporation than others, suggesting that a coating could be used to enhance drying. This hypothesis is consistent with the fact, observed by Brito and Diaz Gonçalves [6] and previously by Tournier et al. [7], that the Stage I drying rate can be higher for some materials than for a free water surface simultaneously tested as reference.

The ability to minimize the effects of dampness is of supreme importance in conservation. Indeed, moisture is one of the main causes of degradation of the porous building materials that constitute most of our architectural heritage, such as stone, mortars or ceramics. It can lead to aesthetical alteration (owing to dampness, efflorescence or biological colonization, for example) or structural/aesthetical alteration (due to the occurrence of subflorescence which fractures the porous material, or to the decrease in mechanical resistance when the material is wet). Moisture may also worsen indoor environmental conditions, either by itself or due to the decay processes it promotes.

In the architectural heritage, though, water is seldom present by itself. Salts from diverse origins exist currently, which migrate as solutions in the pore network of the materials. These salts give rise to intriguing decay processes which are among the most destructive and frequent of those related to the presence of water in porous building materials [8,9]. The degradation occurs generally within evaporative drying processes, during which the salts crystallize on the surface, as efflorescence, or within the pores, as subflorescence. Efflorescence and subflorescence cause problems in terms of the aesthetics and integrity of the material. Further, they

may also affect the underlying drying process, adding to the effect that the salts already have in the thermodynamic properties of the liquid. This happens because efflorescence may block the material pores and subflorescence disrupt the material, thereby altering the vapour flow [10,11].

The work presented here is aimed at verifying the performance, in relation to drying, of one lime coating applied on substrates contaminated with either sodium chloride or sodium sulphate. It appears as a development of the mentioned study of Brito and Diaz Gonçalves [6], in which the performance of the same lime coating was evaluated regarding pure water. The current work is based also on evaporative drying experiments carried out on the same five substrates and lime coating. However, one solution of sodium chloride (NaCl) and another of sodium sulphate ( $\text{Na}_2\text{SO}_4$ ) were used here instead of pure water. The general goal was to find out whether the lime coating could still accelerate the drying rate in the presence of salt. This implied answering the following questions:

- A. How does the drying kinetics vary when we have a salt solution instead of pure water?
- B. What are the differences between the two salts, in terms of drying kinetics and decay patterns?
- C. How does the coating change the decay patterns?
- D. How does the coating change the drying kinetics?

The work is of an experimental kind and does not follow an exclusively reductionist approach. It is based on a topological analysis of quantitative experimental data, graphically expressed by the drying curves, and of qualitative experimental data, expressed by images of the salt decay patterns. It was performed within the DRYMASS research project, which is aimed at advancing the state-of-the-art on the drying of porous building materials, taking into account the effects of soluble salts.

## 2. Materials

### 2.1. Substrates

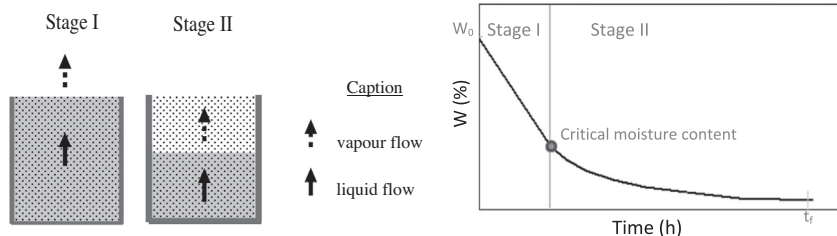
Five substrate materials currently encountered in the architectural heritage and with different porosity were used (Table 1).

Small cubes with around 24 mm edge were prepared from these materials. The lime mortar was prepared following standard EN 1015-2 [12]. The mortar cubes were then moulded and cured as described in [13], i.e., following as close as possible standard EN 1015-11 [14]. The stone cubes were cut from larger blocks.

The four lateral faces of the cubes were sealed with an epoxy resin. Then, the top and bottom faces were gently sandpapered to remove dirt (except in the cases of the mortar and Bentheimer sandstone which easily disaggregate). Finally, the cubes were subjected to an ultra-sound cleaning (a Branson 1200 ultrasonic cleaner was used).

### 2.2. Coating

An artisanal lime coating was applied on the top surface of the mortar and stone cubes. The lime paste was obtained by blending hydrated commercial lime powder with water in a standard mechanical mixer [16]. The lime was first mixed with



**Fig. 1.** Drying stages (left) and typical evaporation curve (right) of a porous material drying from saturation. Stage I occurs when the moisture content is high enough to sustain a saturated condition at the surface. Stage II starts when this moisture content is no longer sufficient to produce a liquid flow able to compensate the evaporative demand. During Stage I, the drying rate is constant and corresponds to the slope of the initial straight line segment in the evaporation curve.

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