ASSESSMENT OF DESALINATION MORTARS AND POULTICES FOR HISTORIC MASONRY: THE EU PROJECT “DESALINATION”

Fulvio Zezza*

University IUAV of Venice, Faculty of Architecture
Convento delle Terese - Dorsoduro 2206, 30123 Venezia - Italia

Keywords: Desalination, Salt damage, Poultice, Non Destructive Technique

ABSTRACT

Salt damage is widespread and intense in Europe where the environmental conditions favour, and locally widen, the decay processes of masonry caused by sea flooding, rising damp, marine aerosol and water condensation. The question how to intervene and act represents a technical and scientific side of the problem and also an economic reality of common interest not only to the European countries.

Salt decay processes are amongst the most recurrent and severe causes of damage to cultural heritage buildings. Application of poultices is generally performed to preserve these objects while retaining as much as possible of their original materials. The EU project Desalination (Assessment of desalination mortars and poultices for historic masonry, 2006-2009) aims to develop a straightforward methodology for optimising the selection and the assessment of the performance of desalination poultice systems.

Central scientific and technical objectives are gaining a better understanding of salt transport mechanism between a salt laden substrate and a material applied on top and to assess possibilities and limitations of desalination treatments. The research methodology developed in the Project is based on Non Destructive Techniques (NDT) analyses, Nuclear Magnetic Resonance (NMR) and laboratory tests to determine the assessment of the state of conservation and the assessment of treatments of desalination systems. Test methods have been developed for the determination of rheological/mechanical properties and to assess the effectiveness of poultice. The outcomes obtained give practical information to support architects, heritage authorities, conservators, owners and scientists to plan the best restoration intervention.

INTRODUCTION

The European Project Desalination aims to actualize the complex interrelationship in poultice systems between a salt laden substrate and a poultice applied on top. The salt laden masonries require knowledge and remedial measures to mitigate the weathering processes: lots of uncertainties still remains about the efficiency of salt extraction and location of salt remaining after treatment as well as the variable outcome of such interventions. Many aspects of poultice’s working principle are not clarified and the behaviour of the substrates, as nature, must be taken into account within the poultice/substrate system [1-2-3].

The core of the project is the assessment of desalination systems on wall and finishes in monumental buildings and their impact on these monuments (Fig.1-2).

The research consists of two main steps devoted, the former, to gain insight into the current working practice and materials selection and, the latter, to increase the scientific knowledge in poultice systems. At first, an international survey, comprehensive of a short online survey targeted at a large audience (17 multiple-choice-questions whit the possibility to record personal comments) and of in-depth interviews with conservation specialists, was developed to determine the working practice currently used on field of desalination treatment, as pre-treatment adopted, application

* To whom all correspondence should be addressed.
methods, type and frequency of any pre- and post-treatment assessments [4].

The second step, instead, was focused on substrates characterization (NDT methodology), analyses of the poultice-substrate relationship (laboratory test) and of the transport mechanism during desalination (nuclear magnetic resonance NMR-scanner) [5].

**Figure 1:** Desalination Project: aims and interdisciplinary approach

**EU Project Desalination**

*scientific coordinator Fulvio Zezza*

- University IUAV of Venice - Faculty of Architecture, Italy
  Fulvio Zezza
  renaud@ian.it

- Netherlands Organisation for Applied Scientific Research
  TNO Built Environment and Geosciences, The Netherlands
  R.P.J. (Rob) van Hoes
  rob.vanhoes@tno.nl

- Cercle des Partenaires du Patrimoine
  Laboratoire de Recherche des Monuments Historiques, France
  Véronique Vergès-Belmann
  veronique.verges-belmann@culture.gouv.fr

- Eindhoven University of Technology - Department of Physics, The Netherlands
  Lee Pol
  lpol@tue.nl

- Fachhochschule Krefl - University of Applied Science, Germany
  Adkai Herbage
  adrian.herbage@fh-krefl.de

- Rijksbouwmeester B.V., The Netherlands
  Edt. H. Steen
  info@rijksbouwmeester.nl

- Rijksgebouwendienst - Government Building Agency, The Netherlands
  A.J. van Bommel
  bert.vanbommel@rmv.nv.nl

- Entrepeneur Quidin, France
  Thomas Vienneau
  vauhe-sonne@wanadoo.fr

- Eric Pailot ACMB, France
  Eric Pailot
  eric.pailot.acmb@wanadoo.fr

- J. Paul Getty Trust - Science Department, USA
  Eric Dodrill
  edodrill@getty.edu

**Figure 2:** Partners consortium
EXPERIMENTAL

In order to provide those responsible for the care and maintenance of the built cultural heritage with clearer guidance to aid in the selection of salt reduction methodologies and materials and to improve the understanding of how salt reduction works, it is necessary to determine the influence on desalination treatment of i) the physical properties of substrates, ii) the environmental conditions of the site, iii) the poultice characteristics.

On this purpose, Non-Destructive Technique (NDT), laboratory test and Nuclear Magnetic Resonance (NMR) analyses were employed.

An innovative research methodology based on Non-Destructive Technique (NDT), as digital image processing, colour measurements, ultrasonic pulses, infrared thermografic analysis and resistivity measurements, has been performed to assess the salt damage of different substrates and to control the effects of desalination treatment (Fig.3). Lab tests were undertaken to provide additional evidence to support the case study results. The relationship between petrography, porosity, soluble salt and water content of the substrate and identification of the sources of salt are fundamental to the interpretation of the NDT results [6]. Computerized analyses can highlight the kind and structural properties of the building material, the weathering forms, the presence of salts on the exposed surfaces and moist spots. Colour measurements, collected throughout the year, allow the determination of chromatic coordinates and their variation in relation to relative humidity and temperature. Ultrasonic pulses were used to detect the mechanical properties of the substrate. Temperature changes in the masonry linked to salt crystallization were recorded using IR thermography. Resistivity measurements were employed to determine sub surfaces variation linked to the presence of salt and moisture. This methodology was applied at selected case studies, on different building materials (brick and hard stone) in relation to the environmental conditions and the weathering processes affecting the monuments under investigation. The procedure comprises the pre treatment diagnosis phase, and the post treatment control phase: the diagnosis concerns the qualitative and quantitative characterization of supports, while the control focuses on the assessment of treatment by comparing analyses to determine the effectiveness of salt extraction.

Figure 3: The NDT research methodology (IUAV)
Laboratory tests analyzed different substrate-mortar/poultice combinations with different granulometry, also developing practical methods to assess the quality of desalination and to select the best performing poultices to be applied on the different building materials (Fig.4). Consistency, workability and adhesion of poultices were studied and drying behavior and salt extraction efficiency tests were performed to understand how the composition of poultice mixture can affect the poultice properties [7]. The moisture and salt distribution in the substrate and in the products applied were measured by means of hygroscopic moisture content (HMC) and Ion Chromatography (IC). In addition, the pore size of different desalination materials (sand, cellulose, kaolin and bentonite), mixed in different proportions or considered as single component, was determined by the Mercury Intrusion Porosimetry (MIP) technique and the NMR analysis [8-9-10]. Moreover, the effect of selective salt extraction and the behaviour of residual salts remaining in the masonry after treatment were considered. The moisture and ion transport in the combination of mortar/poultice and substrate was investigated through Nuclear Magnetic Resonance (NMR), a non-destructive technique for quantitative mapping, useful to define the transport mechanism dominant during desalination following the distribution of water and dissolved ions in time during wetting or drying [8].

![Figure 4: The samples preparation for laboratory test (TNO) and the specialized NMR setup with insert as used in the experiments (TUE)](image)

**RESULTS & DISCUSSION**

The findings of the international survey reveal the application methods and type and frequency of any pre- and post-treatment assessments currently used on field and suggest a restricted number of treatments to be used within the project. The most popular method for desalination amongst conservators is aqueous extraction by poulticing (Fig.5) and the preferences regarding materials, workability and application methods adopted are revealed [4]. However, to optimize the salt extraction, an insight in the knowledge on how select the best poultice to suit the needs of different substrates is required. Moreover, notwithstanding the recommendations in the literature, the practice to monitor on site both the environmental conditions and the substrates properties before and after interventions is usually not followed. The Desalination project results, as we will see, are able to satisfy both this points and to give practical information.

A restricted number of case study was selected in five countries (Italy, The Netherlands, France, Germany and USA) to apply test panels for desalination treatment: advanced analytical techniques (i.e. hygroscopic moisture content, ion-chromatography) and non destructive research methodology were employed to assess the performance of poultices. In particular, the amount of salt in the substrate and the condition of the object before and after desalination were detected, as well as the depth of desalination reached.
The findings of the international survey revealed that the salt reduction method is the preferred desalination methodology used by restorers (UASC).

In Italy the case studies (Terese Convent and San Geremia Church, Venice) have been more extensive and additional investigations, including the innovative research methodology based on NDT techniques, have been carried out. The diagnosis phase (support characterization) enabled to identify in the Terese convent masonry the presence of different bricks in terms of composition, colours and structures and to differentiate the behavior of the same material (hard stone - Terese Convent and San Geremia Church) presenting different structural characteristics [6].

Figure 5: The findings of the international survey revealed that the salt reduction method is the preferred desalination methodology used by restorers (UASC)

Figure 6: Poultices application on the Terese convent masonry (a). Summarized salt content (g/m²) determined from measurement of electric conductivity after extraction in deionised water for poultices applied on different substrates: b) bricks (Terese Convent); c) Istria Stone (Terese Convent and San Geremia church)
In the control phase, the work was focused on compare the results of the different techniques employed, that, together with the poultices performance, allow to define the masonry as a "complex substrate" characterized by different structural properties and physical parameters [11]. In particular, the colour and resistivity measurements were considered, to verify and monitor, in a non invasive way, the effectiveness of the poultice treatments. From chromatic coordinates collected throughout the year it is possible to recognize the variations induced by relative humidity and temperature and to differentiate within the masonry the various types of brick and the damaged and undamaged stone. Resistivity measurements, supported by moisture content analysis (MC and HMC values) and poultice samples salts content determination, confirm the poultice effectiveness: after treatment a migration of moisture and salts occurs inside the brick coming from the treated surface or reclaimed from the inner part of the wall, while in the hard stone (Istria stone) the enrichment of salts is appreciable only when the substrate is fractured (Fig.6). However, the resistivity monitoring of the physical parameters over time reveals that the effects of the desalination is not permanent: the poultice-substrate relationship is affected by the environmental conditions, acting on the sources of salt [11]. Moreover, this non invasive methodology, extended to other case studies (Waag building, Amsterdam, The Netherlands), provides an exhaustive representation of the substrate condition, confirming the possibility of its application in different environmental conditions. For example, the digital image analysis (ICAW technique), according to geoelectrical measurements, shows the existence of different weathering rate in the brick column under investigation: the weathering rate map allows to differentiate the damaged bricks from the slightly damaged and the undamaged ones (Fig.7).

![Figure 7: Digital image analyses performed on the selected bricks column (Waag building, Amsterdam, The Netherlands): pictorial image (a); digital maps of the weathering rate (b): the six bricks correspond to damaged (C-D, grey color), slightly damaged (A-B, yellow colour) and undamaged (E-F, dark blue colour) bricks; the undamaged bricks (F) presents the highest apparent resistivity values, while the damaged (D), enriched in salt and moisture content, are more conductive (c) ](image)

All the case studies considered allow to assess and compare extraction efficiency of different desalination poultices. Once completed the assessment of the state of conservation and the characterization of supports, following the laboratory results, on the basis of the pore size distribution of the substrates, desalination poultice were selected for every case study. In the Waag building in Amsterdam (The Netherlands) a good extraction efficiency was obtained after only two applications, while in the church of Saint Philibert (Dijon, France) a close link between efficiency of desalination treatments and the properties of both the substrate and the poultice was verified [12-13-14]. The case study of Augustusburg Palace (Germany), due to the particular plaster composition (dolomite lime and gypsum), suffers magnesium salts damage (magnesium sulphate):
in this case, to avoid the risk of weathering is necessary to reduce the poultice moisture and application time as much as possible [15]. In New Orleans (USA), instead, the in situ tests performed on the Madame John's Legacy examine a warm, humid environment: to reach a significant reduction in salt content (90%) it is necessary to leave the poultice on to dry for months instead of weeks [16].

A primary aim of the laboratory research was to characterize, developing appropriate test procedures, mortars and poultices behaviour in order to obtain a successful desalination and to define a modular system of poultices, which can be adapted to different types of substrates [17]. The desalination model developed in the project proposes the pore size distribution of the substrate/poultice system as the main factor determining the efficiency of a desalination treatment relaying on advection. The optimal desalination poultice should have pores smaller than those of the substrate in order to allow capillary transport of the salt solution from the substrate into the poultice (Fig.8a). At the same time, the pores of a poultice should not be too small, otherwise they would delay the advection process [17]. The experiments suggest that size and arrangement of grains are important parameters to formulate poultices, while workability, adhesion, consistency and shrinkage are crucial properties in determining the actual possibility of using a poultice in practice [18-19]. The influence of the drying properties versus the pore size distribution (PSD) and the efficiency and depth of penetration front have been also analyzed. On this subject, the influence of the critical moisture content (CMC) on desalination has been studied. It is assumed that the poultice should have a lower CMC than the substrate (i.e. it should be able to maintain a continuous network of pores filled with liquid water up to lower moisture content) in order to improve the transport of the salt solution from substrate to poultice (Fig.8b). Moreover, the time needed to reach the CMC (Tcmc) should be longer for the poultice than for the substrate, that means the poultice should dry slower than the substrate, so that the advection process between the substrate and the poultice is not interrupted [19].

Figure 8: (a) Pore-size distributions of fine and coarse porous substrates and poultices selected for salt extraction efficiency test as measured by MIP (TNO); (b) an optimized arrangement of grains provides a continuity in pore size distribution (LRMH)

In the case of advection based drying poultices, the efficiency of salt extraction is strongly dependent on the relative pore-size range of the poultice/substrate system: for salt extraction to proceed efficiently, a significant quantity of the poultice pores must be smaller than those of the substrate. Consequently, it is possible to optimize the degree of salt extraction achieved by careful selection of the poultice mixture in relation to the properties of the object undergoing treatment. The possibility of obtaining different pore size distributions of desalination poultices was investigated by changing poultice components (clay, cellulose, sand), particle size of sand and
cellulose, type of clay (kaolin, bentonite) and ratio between these components [20]. This allowed to
develop the modular system of poultices on the basis of the classification of substrates according to
their pore size distribution (Fig.9a). However, it is also clear from the results that while the amount
of salt extracted could to some degree be controlled, nevertheless, the final distribution of the salts
remaining within the object after treatment could not (Fig.9b).

Figure 9: (a) Modular system of poultices: the arrows indicate the pore size the poultice should
have for each class of pore size of the substrate salt extraction efficiency test (TNO); (b) extraction
efficiency test: poultice salt content during drying as determined by IC analysis on two different
substrates (Bentheimer stone and Mignè stone - UASC)

The findings of NMR analyses identify two main steps as the working principle of a poultice: the
wetting phase, where water is transported from the poultice in order to dissolve salt, and the
extraction phase, where salt solution travel back to the poultice. The salt is transported due to two
different processes: a concentration gradient between the substrate and the poultice (diffusion) or
by capillary water flow from the substrate to the poultice (advection) [17-18].

Figure 10: Desalination by means of advection can be created when pores of the poultice are lower
than in the substrate

The advection based salt extraction method is the dominant process: it is relatively fast but it
depends on pore-size of the poultice and the substrate. Therefore, the pore-size distribution of the
poultice should be adapted to that of the substrate in order salt will drive by advection (Fig.10).
The extraction is effective on surface, but within the substrate further salt and moisture transport
can potentially occur.
Moreover, the poultice may change during drying because of shrinkage: poultices containing clay are affected by shrinkage and, destroying hydraulic contact in the poultice/substrate system, can detach from the surface of the masonry. In order to limit the shrinkage and to influence the water flow and the pore size distribution during drying sand may be added to the poultice [18].

CONCLUSIONS

The project findings give new knowledge about the way desalination works and the basic requirements to develop new products. A better insight in the quality of desalination methods and an improvement of these methods and products, as well as their way of application, was reached. The experience gained showed that any desalination treatment should be preceded by a thorough investigation of the building or the masonry to be treated, which should form the basis to decide on the treatment. Adequate poultices must be adopted to the substrate and to the type of salt recognized within a masonry: the research clearly shows the influence of the pore size distribution on the extraction of salts and that the crystallization behaviour of the salt mixtures pre and post product application is significantly affected by the interactions between relative humidity, salt mixture, use of intervention layer, poultice type and pre-wetting condition. Moreover, it is important to remember that the desalination effect is rapid but not permanent, as the NDT analyses have demonstrated through the geoelectrical measurements.

A practice oriented guideline for end users, including all important steps to be taken to perform an efficient treatment and to obtain optimal results, that may be used for treating a wide range of materials and which could be adopted by the EU industry for developing desalination systems, has been produced at the end of the project.

REFERENCES


