SWBSS 2011
19 - 22 October
Limassol, Cyprus

Salt Weathering on Buildings and Stone Sculptures

Editors:
I. Ioannou & M. Theodoridou

EDITORS:

Ioannis Ioannou, PhD
University of Cyprus
Department of Civil and Environmental Engineering
Building Materials & Ledra Laboratories
PO Box 20537
1678 Nicosia
Cyprus
ioannis@ucy.ac.cy

Magdalini Theodoridou, PhD
University of Cyprus
Department of Civil and Environmental Engineering
Building Materials & Ledra Laboratories
PO Box 20537
1678 Nicosia
Cyprus
mtheodo@ucy.ac.cy

ISBN 978-9963-7355-1-8

Salt-fog experiments on consolidant and water-repellent treated dimension stones

Leal N. [1,*], Simão J.[1], Gartmann C. [1] and Silva Z.[1]
[1] Centro de Investigação em Ciência e Engenharia Geológica, Departamento de Ciências da Terra - Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa (CICEGe / DCT - FCT / UNL), Campus de Caparica, 2829-516 Caparica, Portugal
*corresponding author´s email: n.leal@fct.unl.pt

ABSTRACT

Carbonate (three limestones) and silicate rocks (one nepheline syenite and one granite) were selected in order to study the effects produced by marine environments, after surface treatments had been applied in their polished surfaces. Four samples of each type were prepared, involving the use of a consolidant and/or of a water-repellent. Samples were subjected to six salt-fog experiment series, according to an adaptation of European Standard EN 14147 Each series comprehends 15 cycles with a sequence of 4 hours of saline fog and 8 hours of rest, at 35ºC, inside a salt-fog chamber. Rising weight during the first stages seems to indicate that salt has been integrated into the treatment products. In the sequence, stabilization occurred and treatments played their intended effects.

Keywords: salt fog; dimension stone; consolidant; water-repellent

1 INTRODUCTION

*Coastal environments are a major cause on rocks degradation and dimension stones are no exception to this situation (Benavente et al 2007; Cardell et al. 2003; Chabas & Jeannette 2001; Galembeck et al. 2007, 2008; Moropoulou et al. 1995; Silva & Simão 2009; Simão et al. 2010; Zezza & Macrì 1995). Although polishing somehow reduces salt fog mechanisms to act on the surface (Silva et al. 2010), the effects of saline solutions on buildings and other edifications exposed to sea-water spray are, in most cases, significant. One of the best ways to preserve dimension stone surface is to cover it with a water-repellent product, that does not allow salt-rich water to stay there for a long time. Sometimes, due to human action or to other causes, fractures occur on dimension stones, causing structural damages and visual impacts. This also enhances the possibility of water to penetrate the stone surface and damage its inner parts, both by salt crystallization pressures and minerals dissolution. The situation can be overcome using a consolidant product that seals the fractures.

Due to their mechanical characteristics, limestones are among the most used dimension stone rock-types. However, igneous rocks are also frequently used, mainly because of textural variety, colours and resistance. These two groups of rocks show contrasting characteristics, the limestones being soft carbonate rocks, and igneous rocks being (most of them) hard silicate rocks.

In order to understand the effects of the above mentioned protection products on dimension stone characteristics, five different dimension stones (three limestones, one nepheline syenite and one granite) have been treated with a water-repellent, a consolidant, and both products.

This kind of experimental studies is important to evaluate the performance of these products when applied in dimension stones in coastal environments in order to prevent aesthetical, structural and economic negative impacts.

2 MATERIALS AND METHODS

2.1 Dimension stone petrography

The carbonate rocks are bioclastic limestones (Moura 2007), mainly composed by calcite correspond to the Semi-rijo (SR), and Moleanos macio (MOL) limestones from the Fátima (Central Portugal) region and to the Cinzento azulado (AC) limestone from the Lisbon region. They differ slightly on their chemistry and mineralogy; SR also has minor amounts (< 6%) of dolomite, as well as quartz and iron oxides. These limestones present varied open porosity values, respectively, 12.0, 7.6 and 0.5 %, thus exhibiting different behaviours during salt-fog action, when no treatment had been applied to them. The silicate rocks (Moura 2000) are a medium to coarse-grained nepheline syenite (NS) from the Monchique (Southern Portugal) region and a fine-grained biotitic granite (SPI) from the Alpalhão (Central Portugal) region. The commercial designation of these rocks are “Cinzento Monchique” and “Cinzento azulado de Alpalhão”, respectively, and they both have low open porosity values (around 0.7%).

2.2 Sample preparation

Four samples of each dimension stone having polished finishing were used for the experiment: one was used as a reference (ref); the other three were covered with a water-repellent product (a), a consolidant product (c), or with both products (ca). These products have been applied according to the manufacturer’s indications, by manually spraying them on the rock surface, in order to promote a better efficacy of the surface distribution and the impregnation action.

2.3 Salt spray chamber experiments

The samples, sound and with different preparations, of the different lithologies were tested in a salt spray chamber (Ascot S120T) following the European Standard EN 14147:2003. The salt spray cycles comprised 4 h of saline spray followed by 8 h of drying at (35 ± 5) ºC. The concentration of the salt solution was 100 ± 10 g/l. A total of 90 cycles (45 days) were performed in the camera. Each series of 15 cycles the samples were observed in a binocular stereoscope (Olympus SZ51) microscope and the alteration features photographed with a Olympus DP20 camera. Then they were washed and rinsed with water during a week to dissolve the excess of salt and then dried and finally weighed to determine the mass variation.

2.4 Samples weight variation

Figure 1 represents the cumulative rock mass loss evolution along 6 salt-fog cycles.

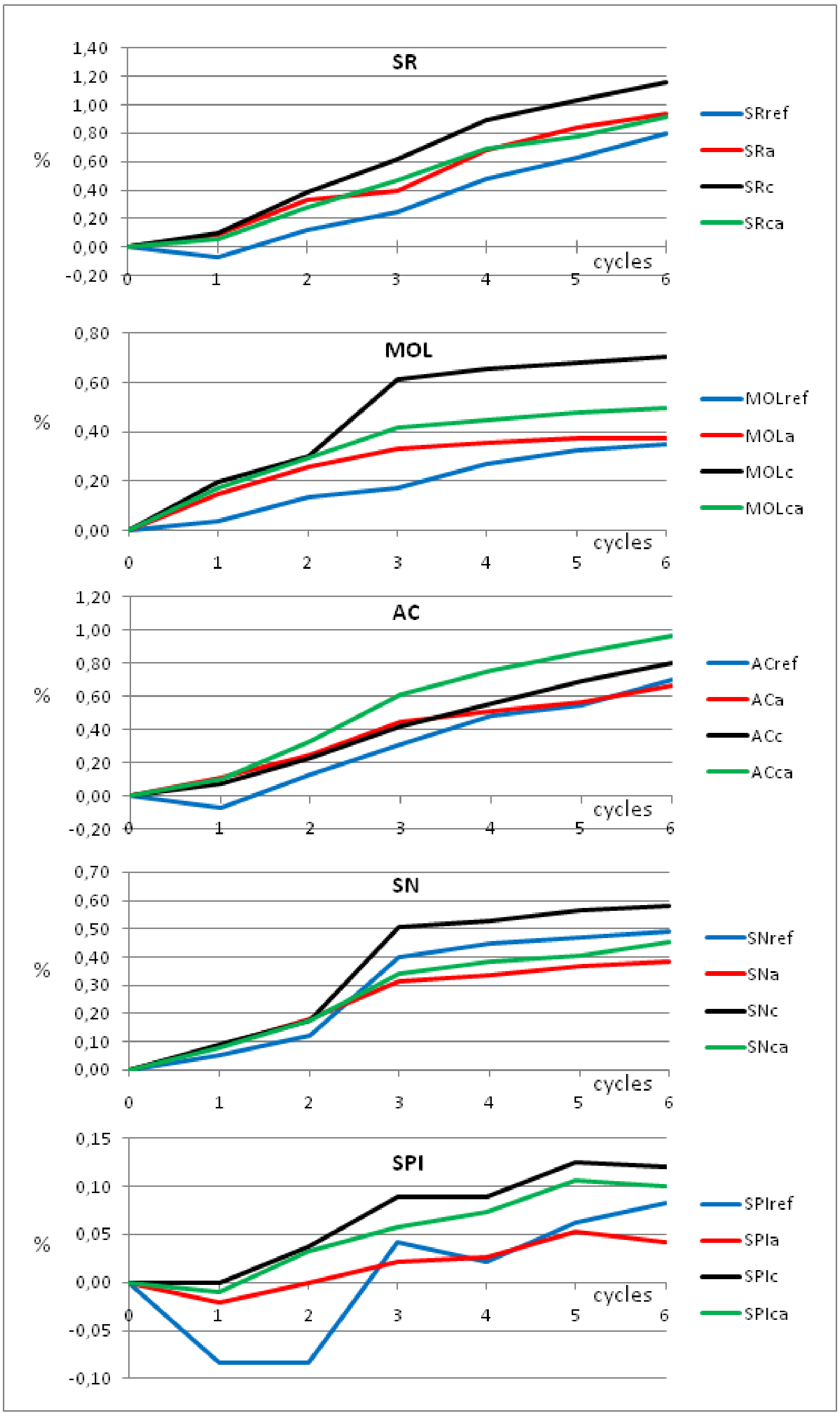

Figure 1. Cumulative rock mass loss (w/w %) evolution along 6 salt-fog cycles.

As observed in Figure 1, all rock types experienced mass losses during the tests, exhibiting different behaviours, according to their different textural characteristics. The limestones present the highest mass losses values (between 0.7 and 1%) and the igneous rocks have the lowest values (< 0.6%). This is mainly due to the higher chemical resistance of the igneous rocks, composed mostly by silicate minerals, as compared to the carbonate rock, calcite–rich, more soluble.

As the carbonate rocks are concerned, the higher mass losses values presented by SR and AC, may be due to high porosity value of the former and the AC dolomite (and quartz and iron oxides) content of the latter, that may account for an easier disaggregation than for MOL limestone.

Among the two silicate rocks, SPI granite presents very low mass loss values (< 0.15%), mainly because of its fine-grain character, which promotes a very high mechanical resistance. SN, in turn, shows higher mass loss values due to its coarser grain and to the presence of undersaturated minerals, such as nepheline, that are known for its weaker resistance when facing aggressive atmospheres (Silva & Simão 1998).

2.5 Changes on dimension stones surfaces

During the experiment, monitoring of the samples surface was done, by means of petrographic binocular microscope observations, followed by photographic documentation. As the salt-fog cycles succeeded, the appearance of the surface became yellowish and gradually lost the initial polishing luster. Also, some detaching occurred, mainly in hydrated minerals such as epidote (Figure 2a: SNca) and pyroxene (Figure 2b: SNa), and on iron oxides and biotite (Figure 2c: SPIc). In every cycle, salt crystallization occurred, sometimes as hopper-crystals (Figure 2d: MOLca; Figure 2e: SNca; Figure 2f: SPIa; Figure 2g: MOLca) and sometimes as crusts (Figure 2h: ACca), as result of different rates of crystallization on top of different lithological materials.

3 DISCUSSION

Mass values decreased in all samples as the salt-fog experiment proceeded. The shapes of the curves represented in Figure 1 indicate that stabilization is near the 6th cycle, already reached at least by MOL and SN rock types. Although in most cases the major losses occur in samples without any cover, this does not mean that the treatment itself enhanced rock degradation. In fact, the products mass correspond to up to 0.17%, and so a significant part of the obtained values may be due to products losses rather than to sample losses. Additionally, the shine loss previously referred corresponds to the products vanishing as the salt fog acted on them. So, the application of the products seems to have effectively protected the rocks. However, the yellowish colour that appeared after the 6 cycles indicate that an important chromatic modification occurred on the samples surface. This may be due to the products degradation, most probably promoted by salt-fog action, both by crystallization of NaCl and by the continuous and permanent rinsing by an acidic solution. This solution, provoked by dissociation of NaCl solution in a weak, but effective, HCl solution may have attacked the water-repellent, the consolidant products and the carbonate rocks.

The presence of crusts (Figure 2h: ACca) in AC dimension stone seem to indicate that quartz and iron oxides impurities and, mainly, the dolomite minor contents may have influenced the way the products were absorbed by the rock, in part because polishing itself may have not been as well achieved as in other rock types (due to these irregularities), and in part because perfect NaCl crystals tend to occur in completely flat surfaces. These crusts are sometimes so well developed at the surface that they microcrack because salt impregnate the sample (Figure 3a: ACc).

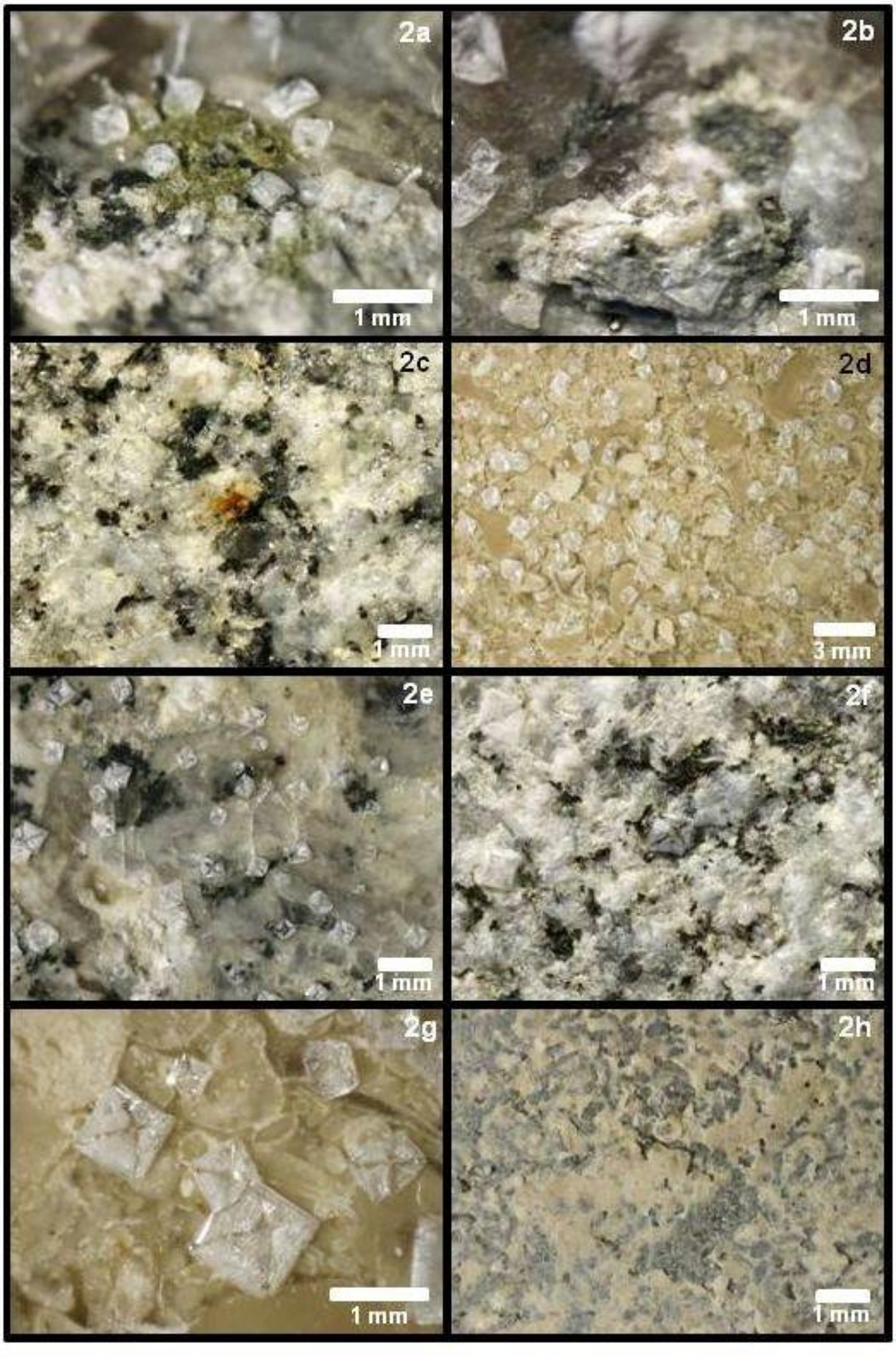

Figure 2. Effects of halite crystallization on the dimension stone surfaces after the salt fog experiments (a: SNca; b: SNa; c: SPIc; d: MOLca; e: SNca; f: SPIa; g: MOLca; h: ACca).

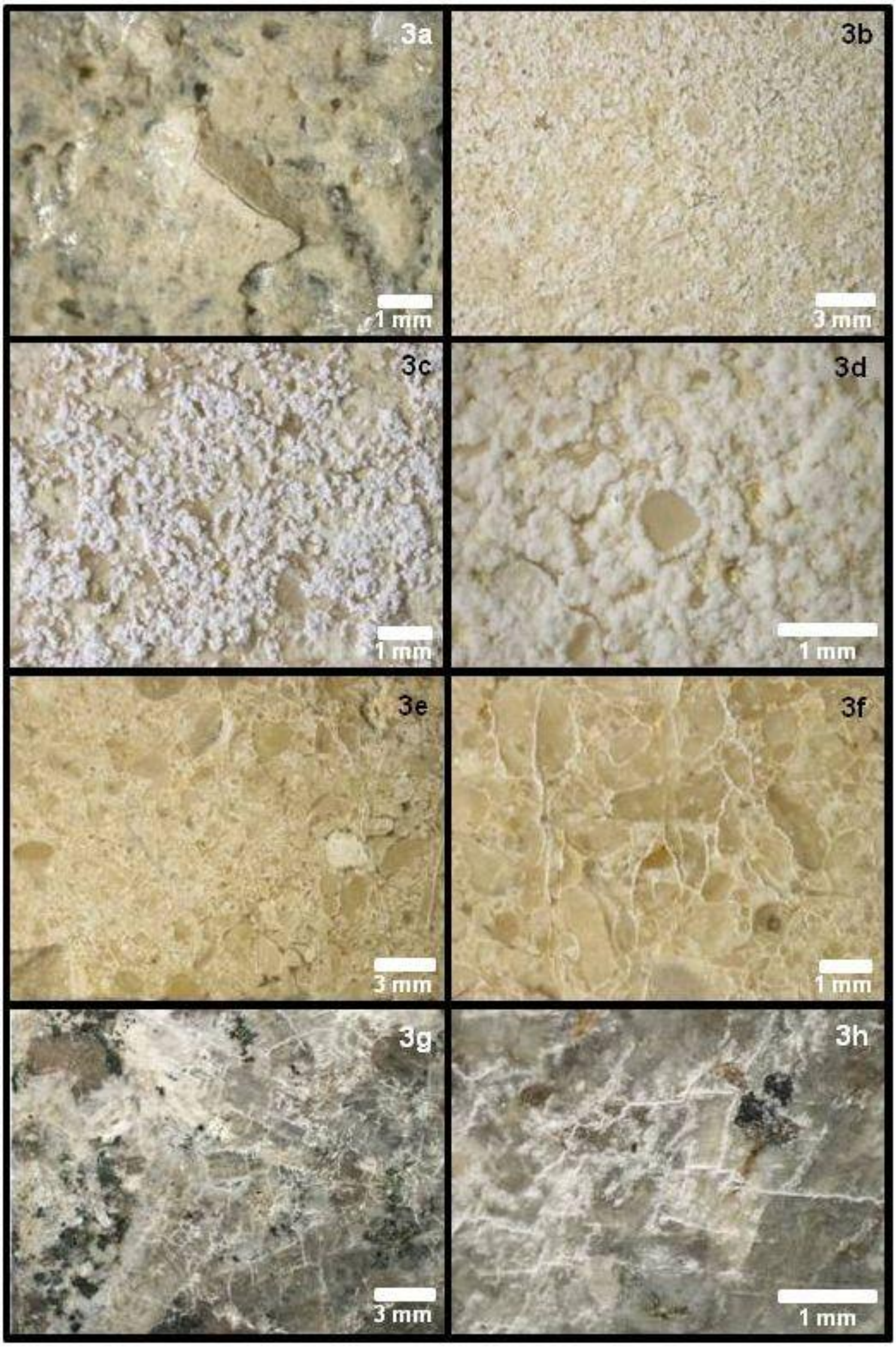

Figure 3. Effects of halite crystallization on the dimension stone surfaces after the salt fog experiments (a: ACc; b: SRa; c: SRca; d: Sra; e: MOLc; f: MOLc; g: SNref; h: SNref).

In contrast, all other rock types sometimes exhibit perfect hopper crystals (Figure 2d: MOLca; Figure 2e: SNca; Figure 2f: SPIa; Figure 2g: MOLca), or aggregate crystals (Figure 3b: SRa; Figure 3c: SRca), sometimes distributed as atoll-structures (Figure 3d: SRa); occasionally, these aggregates developed around the clasts, following the grain contours (Figure 3e: MOLc; Figure 3f: MOLc). In SN, often tiny crystals occur penetrating and following feldspar cleavage planes (Figure 3g: SNref ; Figure 3h: SNref).

4 CONCLUSIONS

After the observation of all rock-types samples with and without the selected treatments, some remarks must be made. Application of the consolidant product did not show to be effective by itself in these cases. On the contrary, the water-repellent product application apparently is a good approach, mainly on the igneous rocks, where it has a mass loss reducing effect. For all treatments, this is the best in terms of protection of dimension stone. When applied together with the consolidant, this effect is reduced and so, when consolidation is needed, other strategies may have better effects.

Although at the beginning of the experiment, the treatments seemed to be effective, both in terms of mass losses and of physical appearance, after three cycles some problems began to emerge. In fact, the chromatic change observed in the samples surface, turning them yellowish (for all kinds of treatments) strongly discourage the application of these products, together or not, as they have a negative visual effect on the original dimension stone characteristics.

The results reached by this work point to (i) the short-term efficacy of the treatments employed, mainly the consolidant plus water-repellent treatment for all stone types, and (ii) a long-term inefficiency of any of the selected treatments.

These results made possible to evaluate treatment efficacy and stone degradation when submitted to laboratory conditions, similar to those acting at the places where they will be applied. Among other important remarks, results showed the importance of mineral composition, rock texture and structure, and the need to evaluate the answer of the rock to artificial ageing tests before applying these natural products as construction materials. Stone selection and careful advise for the best solutions for rock application and treatments are important in order to prevent the material's degradation, thus contributing to avoid negative economic and aesthetic impacts.

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