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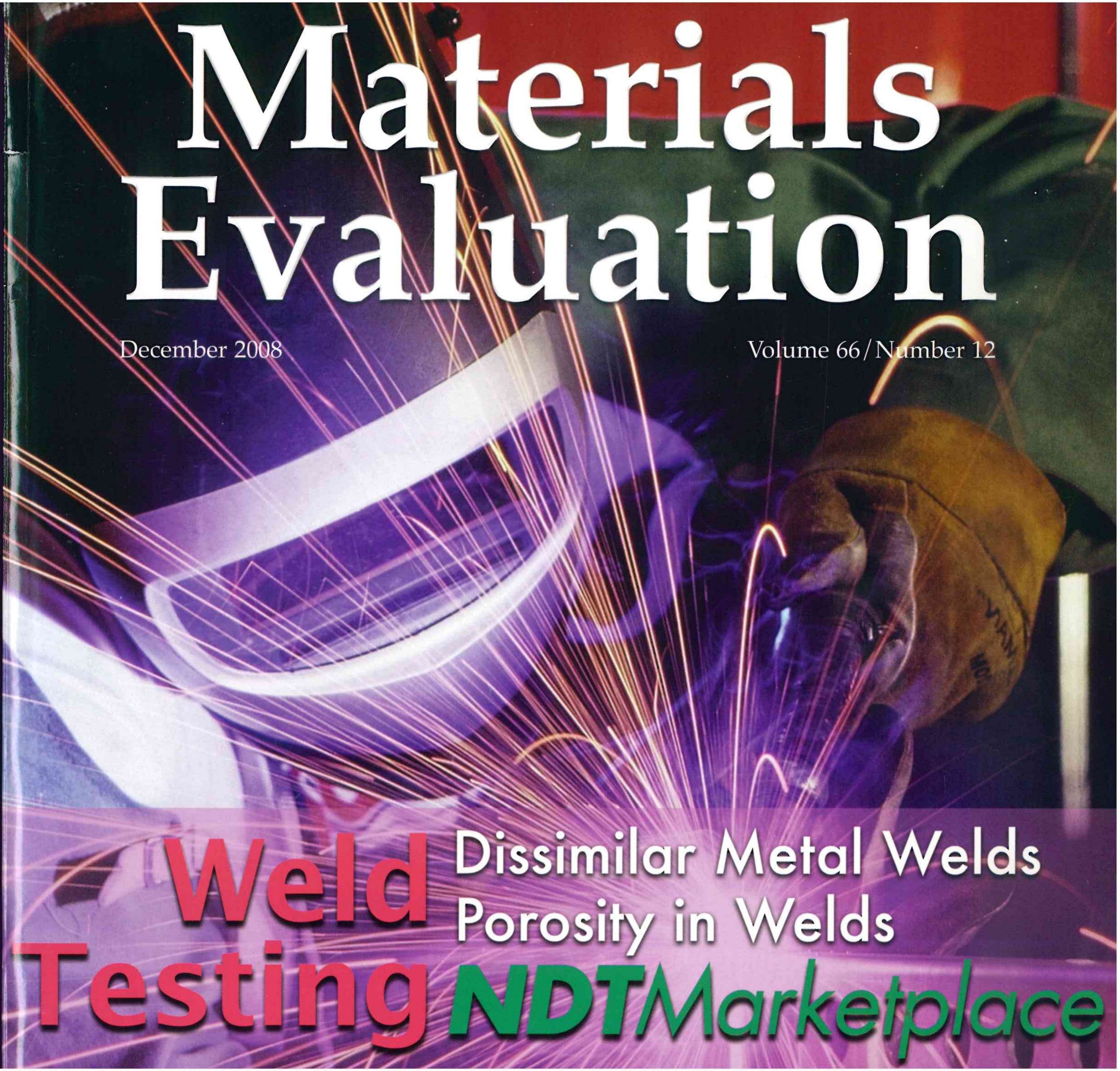

Weld Testing

Dissimilar Metal Welds

Porosity in Welds

NDT Marketplace

Features

Technical Papers

A New Year

With 2009 coming up, be sure to follow ASNT's plans for the new year. ASNT conferences and topical meetings are listed in the *Materials Evaluation* Calendar, and information on Refresher Courses and ASNT examinations are given in each issue of the journal. Be sure to read Society News and any Special Notices to be aware of the Society's activities throughout the year.

In This Issue

This issue includes a feature article, technical paper and Product Spotlight focusing on weld testing, one of the most important and popular NDT applications. It also includes ASNT President Jocelyn Langlois's incoming speech, given at the 2008 Fall Conference, beginning on page 1215.

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Volume 66 Number 12

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The American Society for Nondestructive Testing

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ASNT exists to create a safer world by promoting the profession and technologies of nondestructive testing.

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Submitted July 2008

Thermal and Hygroscopic Characteristics of Restored Plasters with Different Surface Textures

by Elisabetta Rosina,* Nicola Ludwig,† Stefano Della Torre,‡ Simona D'Ascola,‡ Chiara Sotgia** and Paolo Cornale**

ABSTRACT

Fresco restoration includes the integration of missing plaster. Restorers use different tools and materials for the intervention. Recent research shows that restored plasters have different thermo-hygrometrical behaviors at low temperature and high ambient humidity rate. Field observations of the hygroscopic behavior of different mortar textures showed that textures obtained with hard tools (spatula, wooden float, trowel) have harder, denser surfaces, which favor vapor condensation, while soft tooled finishes (sponge, sponge float) have a rough surface that facilitates absorption and evaporation of moisture. In case of contiguity between two different finishes, the edges of the rougher surface (around a more compact texture) show more damage than the smoother and compact surface. Despite chemical compatibility of mortar compounds, the effect of changes in water state on the surfaces causes differential damage, starting from the edge of replastered areas. The durability of plasters applied with different tools, resulting in heterogeneous textures, can be shorter than that of homogeneous textures. Early detection of risk areas, by means of infrared thermography at transient conditions, is very helpful for the preservation of historical buildings without a controlled heating/cooling system, and it offers an improvement in restoration techniques of precious surfaces.

Keywords: *infrared thermography, surface roughness, plaster damage, videomicroscopy, condensation, restoration mortars, planned conservation.*

INTRODUCTION

Multispectral analysis techniques and integrated test procedures to evaluate the thermo-hygrometrical behavior of restored plasters, especially those applied with different tools, are presented in this paper. Lack of ventilation and proper heating often cause surface damage (Camuffo, 2004; Camuffo, 2007). The damage affecting plasters is particularly visible, and it persists even if the cause of decay has been removed. Early detection of risk elements and susceptible areas, together with the analysis of the key factors causing the damage, are areas of preventive maintenance.

Research in the field of planned conservation (Della Torre et al., 2005; Rosina et al., 2005) shows that periodical control of the critical areas is a necessary condition for timely intervention, resulting in localized actions that have a limited effect on a building's structure and safeguard the preservation of historic materials. Therefore, an early survey of risk factors is the first step for real and effective preservation. Periodical controls enhance effectiveness and reliability if they can be used in combination with multispectral analyses aimed at detecting surface dyshomogeneity in severe microclimatic conditions (Ludwig and Rosina, 2006; Rosina et al., 2004). For example, recaptures at the visual and thermal infrared spectra are very useful in mapping surface and subsurface anomalies that are responsible for damage.

STATE OF THE ART

In several studies, active thermography showed different thermal characteristics in restored plasters, even though components and porosity were similar (Rosina et al., 2008). Previous studies hypothesized that such thermal differences could be caused by the roughness of different finishing applications. Roughness of the original plaster may be caused by the tools used for application or by the surface state of preservation. New restoration plasters may have different roughness because different tools were used for the application. The hypothesis that a different roughness could affect the thermal properties of the exterior layer of the surface was verified in a previous study. Twenty-four samples were prepared by applying the most common plaster (lime, sand, marble powder and calcium carbonate) on industrial bricks. Active thermography showed differences in temperature increases (about 1 K) on the plaster where calcium carbonate was added, especially between applications with a spatula and sponge (Rosina et al., 2005).

SAMPLE PREPARATION

New measurements were set for the present research. Three series of new samples were prepared with mortar composed of lime, sand and calcium carbonate. The proportion and quantity of components (including water) were controlled, and samples were made with the same geometry and thickness (Camuffo, 2007). Homogeneous plasters were prepared accurately using plastic boxes with rigid edges (Figure 1a).

The plaster surface was finished with a spatula, trowel, sponge and sponge float. The hard tools (spatula and trowel) had a metallic blade (Figure 1b) and, during the last application, operators kept them both parallel and perpendicular to the samples' surface, applying a higher pressure than that required in the application with soft tools, according to the common use of the tools in the field. Soft tools are used especially to apply plaster on an extensive surface, while a spatula is normally used, with higher pressure, on smaller surfaces (for example, during repointing).

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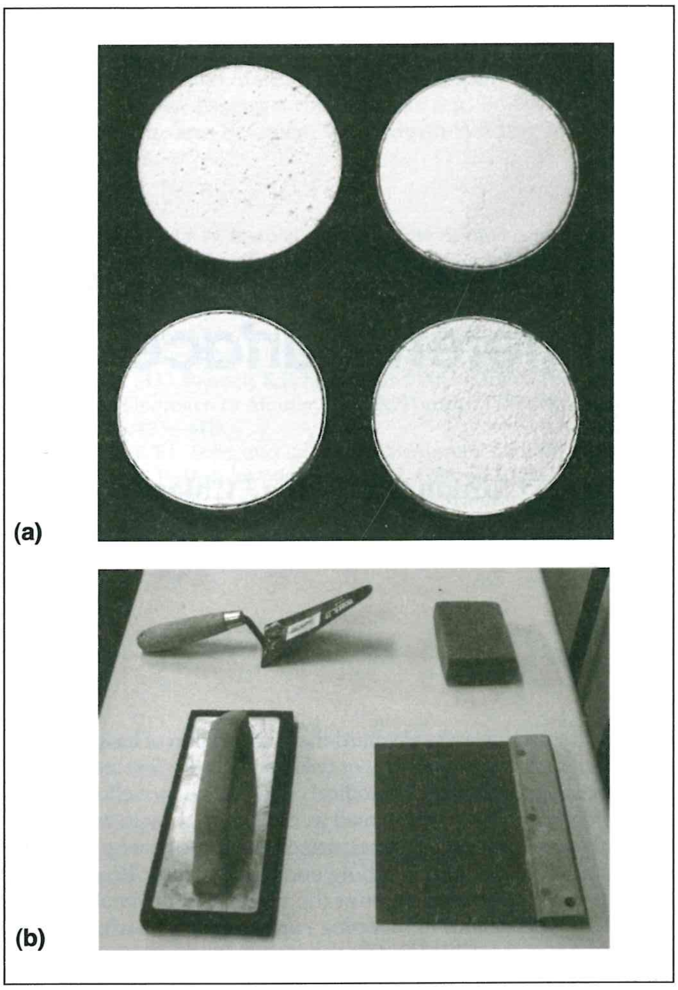

Figure 1 — Samples and tools: (a) four samples of the same series, with only the sample on the upper left, finished using a sponge float, showing obvious differences; (b) trowel, sponge, spatula and sponge float.

Preliminary porosimetric tests showed very similar curves confirming a total homogeneity in the bulk samples (Figure 2). The results confirmed the good preparation and homogeneity of the plaster, when considered in its entire thickness (6 mm). Therefore, any resulting difference in absorption/evaporation capability was due to the difference in the finish application.

LABORATORY TESTS

The objective was to verify that plaster application by different tools affects water absorption and the surface's capacity to transfer water. Research focused initially on the identification of factors determining different thermal absorption curves (by active infrared thermography). Subsequently, the effect of roughness and compactness on surface hygroscopicity was studied.

Standardized tests to measure hygroscopicity were not used because of the limited thickness of the surface layer (under 1 mm), which is mostly affected by the use of tools, as shown in the literature (Jornet et al., 2005) and in preliminary porosimetric tests. The tests described by standards (ASTM, 2005; CEN, 1998; CEN, 2004) focus on measuring water/vapor permeability of the bulk surface (about 10 mm). Also, experimental tests shown in the Hamstad report (Roels et al., 2003) deal with bulk and matrix density, total open porosity, vapor transmission and capillary moisture content. Those studies focus on the behavior of materials versus liquid water and the phenomena of water transfer inside the structure. The study of ambient interaction is not the main scope of these papers, but it is the limiting factor to keep in mind during the study of mass transfer. The present paper shows procedures used to verify thermohygrometrical behavior of the exterior surface layers, which are the most precious part of frescoes and, after restoration, the most affected by restoration products and applications.

TESTING PHYSICAL PROPERTIES OF THE EXTERIOR LAYER OF PLASTER

Weighing Techniques — Contact Sponge Test

The test provides quantitative measurements of water absorbed through a surface by pressing a small soaked sponge on the surface. The procedure was devised by the research groups of P. Tiano, of

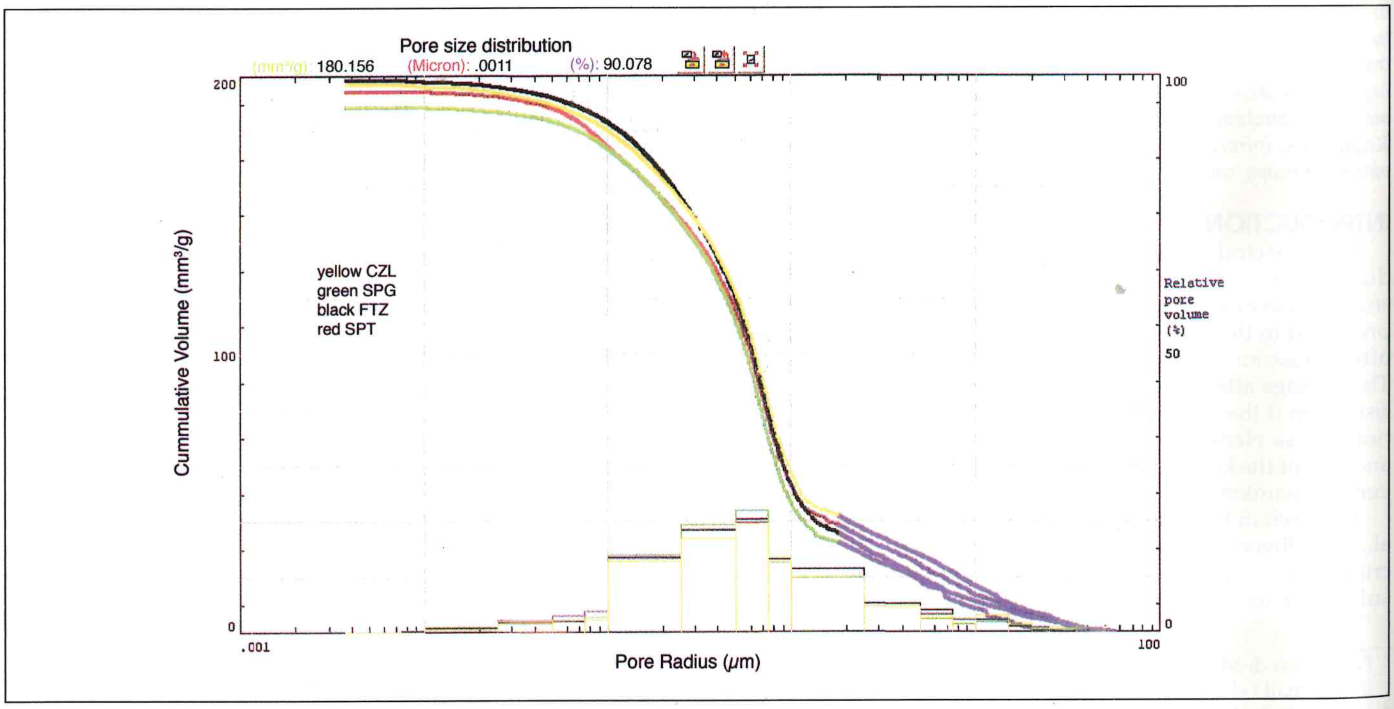

Figure 2 — Porosimetric curves of the four samples, showing porosity distribution and size: the yellow curve corresponds to the specimen surface treated with a trowel; the green curve corresponds to the specimen surface treated with a sponge; the black curve corresponds to the specimen surface treated with a sponge float; the red curve corresponds to the specimen surface treated with a spatula.

NR-ICVBC in Florence, and Luigi Dei, of Florence University; it as used to test the differences of liquid water sorption on samples ter the application of restoration products (Croveri et al., 2007; rdini and Tiano, 2003).

The test was modified for the present research. Contact time was duced (from 5 to 2 min) and samples were kept on a horizontal an. The amount of water used in each test was 5.6 g. Results owed that the test is precise and accurate: standard deviations ere between 0.2 and 0.35 for average values between 13.1 and .6 g. Calculated accuracy of the test is approximately 2%.

eighing Techniques — Measures of Evaporation Flux

The test consists of weighing the sample during evaporation to tain the sorption curve of vapor. The water/vapor exchange be- een the sample surface and the air was measured using this pro- dure. Evaporation flux measures by surface unity allow the quan- itive testing of differences due to sample surface characteristics.

ptical Techniques — Videomicroscope Recapture

The recapture of three sampled areas for each specimen permit- l the measurement of the ratio between the sand grain surface d the total area of the recaptured zone (exposed grains average ea; Zendri et al., 2001). The procedure was first tested on brick d mortar samples. The second series of mortar required more ac- racy because of the higher smoothness and homogeneity of the faces. Homogeneity was due to a smaller grain size of the sand, use of plastic containers with rigid edges, the diameter of the stic boxes (which is smaller than the tools' [trowel, spatula, float] dth) and the timing of finishing (when mortar began to carbon- ; Della Torre et al., 2005). A correlation exists between the surface a material and its porosity (Gregg and Sing, 1982; Roels et al., 03). Moreover, surface characteristics are most important in the ndensation process on porous materials, which occurs in inverse portion to the pore diameter according to the Kelvin effect nchez-Moral et al., 2005).

tical Techniques — Condensation Test in the Peltier ge System

The test permits the observation of vapor condensation on the died surfaces with an electronic microscope. This test accurately asures the differences in morphology of drops condensing on surface of each sample. A dynamic analysis of specimen cooling erformed with the Peltier cooled stage. The Peltier stage system s a thermoelectric module to alter temperature, which, in con- ction with increased pressure in the specimen chamber, creates densation on the sample surface. The primary applications for effect are producing moisture on the sample or keeping the ple wet.

The test permits the evaluation of speed and the shape of con- sed vapor on the surface through an observation in progress. This cess depends on the local morphology of the surface (Cornale and nini, 2002). Drop formation is observed by a scanning electron mi- scope working in the following conditions: images in secondary trons; tension of acceleration at 25 kVs; work distance from sample pproximately 9 mm; temperature operating range of 5–6 ± 0.5 K; ssure of 865–940 Pa; relative humidity from 95 to 100%.

rmographic Techniques — Water Drop Test

The test permits the measurement of the surface characteristic of orption and diffusion of liquid water by recapturing an infrared mographic video sequence, without temperature increase and ptimal ambient conditions of ambient temperature = 296 K and tive humidity = 50% (UNI, 2000).

Passive recapture by infrared thermography every 0.08 s results 10 min sequence. During recapturing, an operator drops one of distilled water on the sample surface. The sequence shows water diffusion on the surface according to the geometric char- ristics of the surface and its compactness.

rmographic Techniques — Moisture Ring Test

he contact sponge test was monitored by infrared thermogra- A continuous video recaptured 9 min of evaporation starting at the end of the sponge application. The procedure let the operators observe the differences in water diffusion on the surface. Evaporation of water causes cooling of wet areas, and due to the cooling phase the thermal gradient is higher when the evaporation flux is higher (Ludwig et al., 2004). The evaporation flux on the samples' wet areas was calculated considering the same physical characteristics of the surface and the water content was obtained from the values of evaporation flux.

Thermographic Techniques — Measure of Shape Factor Shape/Contour

Non-dimensional parameter s/c is the ratio between the square of the perimeter delimiting the zone of evaporation and the surface affected by evaporation. It permits the evaluation of the extension of wet areas as a function of a surface characteristic and its geometry.

TESTS RESULTS

Weighing Tests — Contact Sponge Test

Results of the quantitative evaluation of average values of adsorbed water were:

- the surface treated with a trowel absorbed the smallest amount of liquid water (0.4 g + 0.23 σ),
- the surface treated with a sponge absorbed the largest amount of liquid water (2.9 g + 0.29 σ)
- the surface treated with a spatula absorbed a medium to low quantity of liquid water (1.19 g + 0.39 σ)
- the float finished surface absorbed a large quantity of liquid water (2.17 g + 0.35 σ), yet lower than the amount absorbed by the sponged surface.

It was taken into consideration that samples were not uniform and they had large cracks (float and spatula), and small cracks (sponge and trowel). Nevertheless, cracking did not appear to affect liquid water absorption during the tests. Values were measured in 10 sets of the test. Results showed that the differences in surface finishing caused a variation in water absorption of 0.6/13.8 g for surfaces treated with soft tools (float and sponge) and of 0.8/15.6 g for surfaces treated with blade tools (trowel and spatula).

Weighing Tests — Measures of Evaporation Flux

Figure 3 shows evaporation flux versus water content (as weight percentage). Different evaporation phases can be distinguished on the four surface finishes. Sponge, spatula and trowel finishing have values of evaporation flux higher than float finishing, and their values are constant, with a water content up to 10%. Float

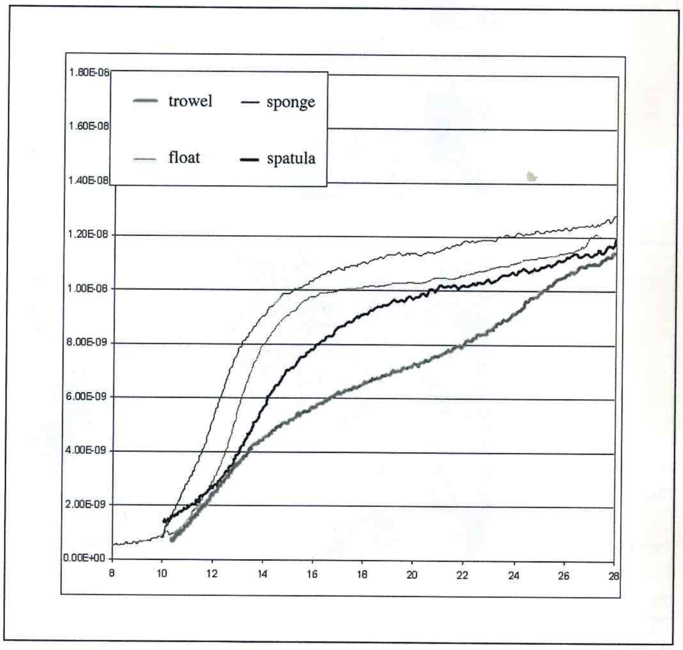

Figure 3 — Evaporation flux on sample surfaces.

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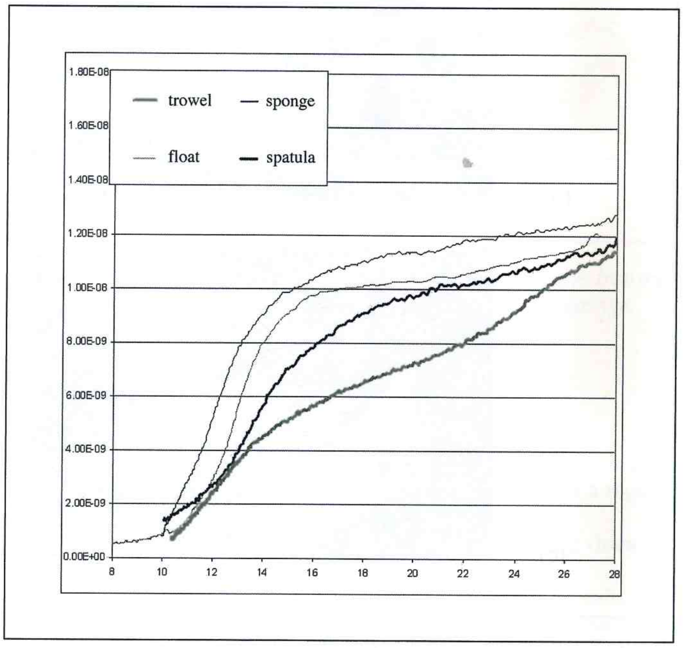


Figure 3 — Evaporation flux on sample surfaces.

finishing differs because it has an initial high value of flux in which most of the water content evaporates. Consequently, in a subsequent step of the process, the evaporation flux value is lower than that on the other finishing surfaces. As passive infrared thermography verified, float finishing has a very different behavior from other finishing.

Optical Techniques — Videomicroscope Recapture

In spite of the similar appearance of the four surfaces, the exposed grain average area parameter showed slight differences: hard and soft tool application on the surface caused exposed grain average area values of 0.11 to 0.14 and 0.29 to 0.31, respectively. Videomicroscopy shows the homogeneity of the surface, and it is very useful in validating evaporation flux results (Figure 4). Exposed grain average area is clearly linked to the evaporation flux trend in specimens treated with soft tools. The results of evaporation flux on surfaces treated with hard tools showed lower values than those of surfaces treated with soft tools.

Optical Techniques — Condensation Test in the Peltier Stage System

Observations of the surface of samples placed in the Peltier cooled specimen stage using the environmental scanning electron microscope confirmed the hypotheses regarding superficial porosity. The Peltier stage permits us to perform variations in temperature and pressure that modify relative humidity values up to 100%. During these variations, the sample is observed with the microscope (Figure 5). In such conditions, condensation begins to form on the surface of the test sample (Cornale and Olchini, 2002). Information on the characteristics of the surface's permeability to water may be obtained by measuring drop dimensions. The results of the test permitted us to divide the samples of mortar into two groups:

- Sample finishing by trowel and spatula introduces characteristics of superficial porosity that allow the formation and permanence of the water drops. Drops dimensions are 20 to 50 µm, and the form is well-defined and circular.

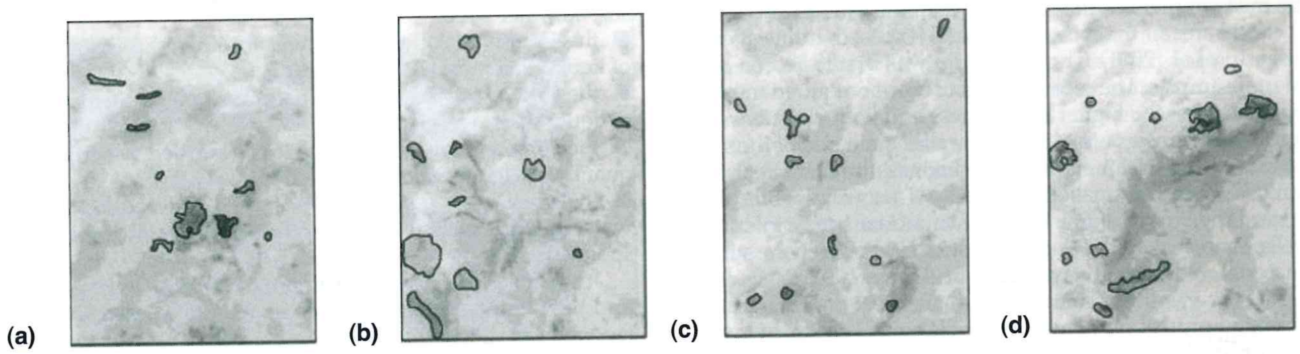


Figure 4 — Localization of exposed grain average areas by finishing process (videomicroscope, 100×): (a) trowel; (b) float; (c) spatula; (d) sponge.

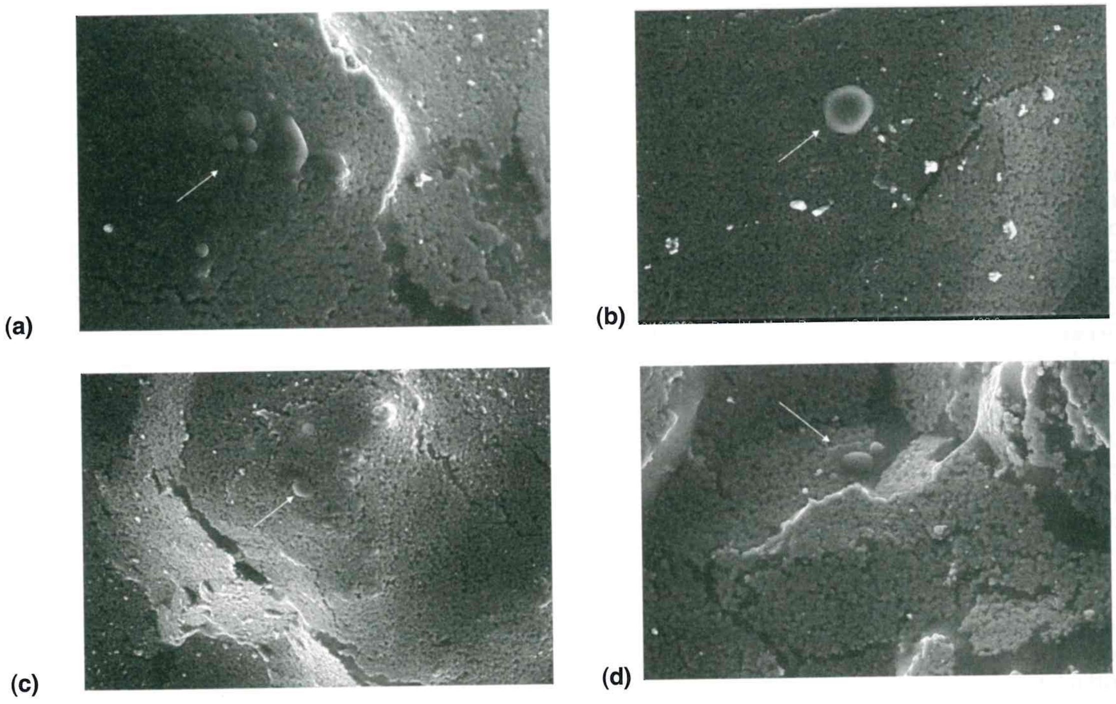
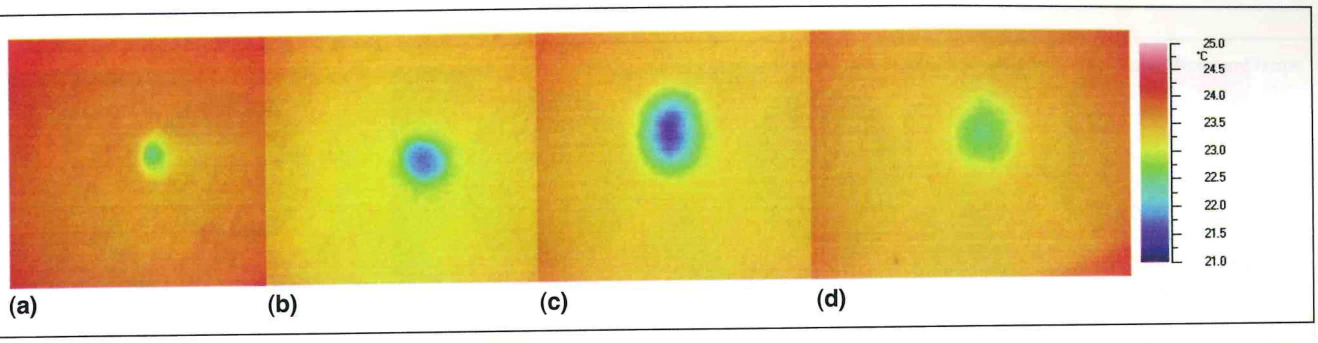


Figure 5 — Condensation of water drops on the surfaces treated with: (a) trowel; (b) spatula; (c) float; (d) sponge. Modality = environmental scanning electron microscope; relative humidity = 100%; magnification = 400×.



gure 6 — Water drops on the surfaces treated with: (a) trowel; (b) spatula; (c) float; (d) sponge. Infrared thermography after 10 s from contact time; ıbient conditions: relative humidity = 50%, ambient temperature = 293 K; emissivity = 0.85. Images have the same metric scale; the water content the drops is the same (20 mL).

Sample finishing by float and sponge introduces characteristics superficial porosity that allow very limited formation of drops of ater, since they are absorbed by the material in 5 to 10 s. The di- ensions of the drops are around 5 to 10 µm.

The test confirms that the permeability to liquid water of noother and compact finishes, applied with utensils with a blade ke a spatula and trowel, are lower than the permeability of ugher finishes, obtained with sponges and soft tools. On the test mples treated with a sponge or float, drop formation was hin- ered by the presence of micro-capillarity.

ermographic Techniques — Water Drop Test

The differences in water propagation into the dry samples are own clearly in Figure 6. The geometry of the drops is very differ- nt:

- on the surface treated with a trowel, the wet zone is small, with regular geometric shape, and the moisture ring is limited to a thin ntour around the drop
- on the surface treated with a spatula, the wet area is a bit more tensive than in the surface treated with a trowel, with a regular ape, and the ring is slightly thicker than in the surface treated ith a trowel
- on the surface treated with a float, the wet area is the widest, the ape is regular (a perfect oval) and the ring is the thickest among e four samples
- on the surface treated with a sponge, the wet area is wide, the ape is irregular and the moisture ring is smooth, with an irregular ntour.

Finally, the trend of temperatures along a profile across the drop bsorption areas was considered (Figure 7). The bottom of the urve corresponds to the drop; the more vertical parts of the curve orrespond to the areas between dry and soaked surfaces. The lope of the curve, where temperature changes around the drop, efines the degree of water diffusion inside the material. The transi- on area (moisture ring) has different shapes and extensions on ach specimen, depending on the type of finishing. The moisture ing is an area where surface capillarity around the drop causes vaporation fluxes. Moisture rings show minor extension on the urfaces treated with blade tools, suggesting that the mechanical brasion of the blade on the exterior layer of the surface creates nacropores with low conductivity (CEN, 1998).

hermographic Techniques — Moisture Ring Test

After wetting the surfaces using contact sponges, the dynamic neasurement of temperature permits us to measure the water dif- usion on the surface. The extension and shape of the wet moisture ing changes for each surface depending on the plaster finishing ool.

The following detailed observations were made:

- on surfaces treated with a trowel, the wet area is not extensive nd the edges and the diffusion of moisture on the surface are ex- remely irregular
- on surfaces treated with a spatula, the wet area is as wide as the ponge moisture ring and the edges are irregular

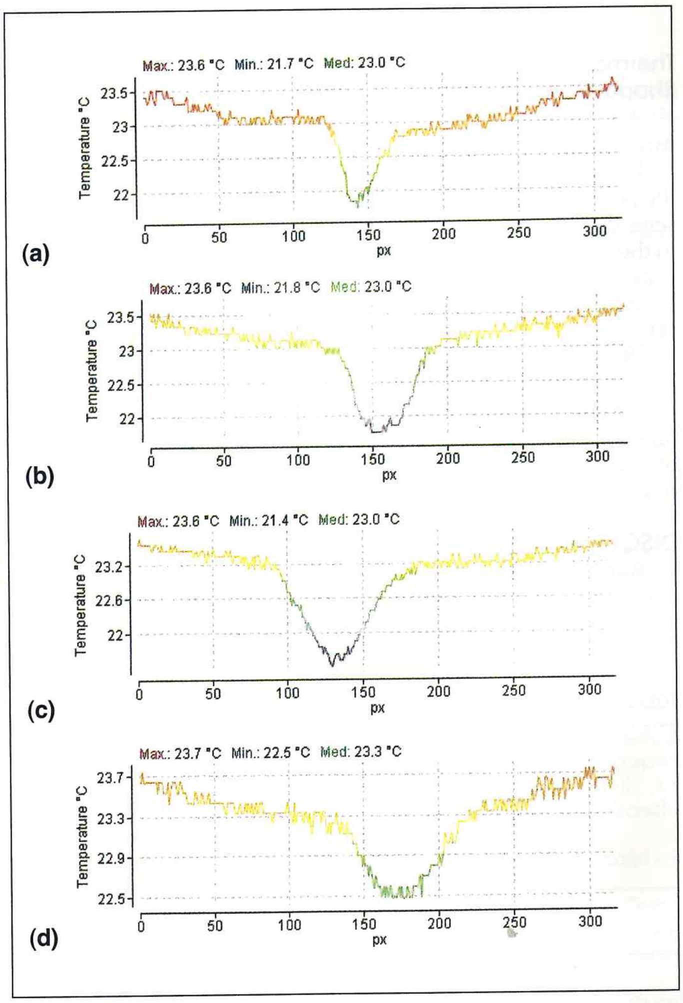


Figure 7 — Temperature distribution along a line crossing the drop on the surface treated with: (a) trowel; (b) spatula; (c) float; (d) sponge.

- on surfaces treated with a float, the moisture ring is the widest among all specimens and the shape of the edge is almost a regular circle (despite the cracks in the upper part)
- on surfaces treated with a sponge, the moisture ring does not have a large extension, and the shape is circular.

The thermograms in Figure 8 were recaptured after 8.5 min from the beginning of evaporation, when the phenomenon reached a steady condition of cooling and the moisture ring was at its maximum extension.

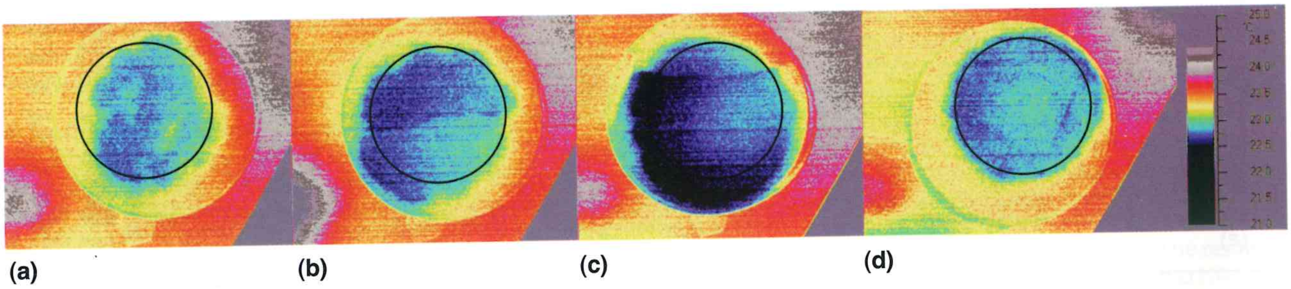


Figure 8 — Surface treated with: (a) trowel; (b) spatula; (c) sponge float; (d) sponge. Specimens were contained in plastic circular boxes. The black circles superimposed on the thermograms serve as metric reference for a qualitative evaluation of the moisture ring extension (ambient conditions: ambient temperature = 299 K, relative humidity = 59%, emissivity = 0.85).

Thermographic Techniques — Evaluation of Parameter Shape/Contour

An evaluation of surface capillary was obtained by geometric measurements of perimeter and area of evaporation surfaces.

Dimensional parameter s/c is the ratio between the square of the perimeter and the surface area affected by evaporation; it represents the water diffusion capacity on the surface, and it is correlated to the compactness of a surface:

$$\frac{s}{c} = \frac{P^2}{A} \Rightarrow_{\text{circle}} = \frac{4\pi^2 r^2}{\pi r^2} \cong 4\pi \tag{1}$$

This permits the evaluation of the extension of wet surfaces as a function of surface characteristics and geometry. In the extreme case of a circular droplet of water on a nonabsorbing surface, the value of s/c is 4π. Table 1 shows the results (Figure 9).

DISCUSSION

Test results are shown in Table 2. In the second column, a relative evaluation of the hand pressure during the application of plaster with specific tools is shown.

All tests permit distinguishing between surfaces treated with soft and hard tools. In addition, they verify that surface texture really affects water absorption, diffusion, evaporation and water exchange mechanisms between ambient and surface.

Particularly, the use of blade tools causes:

- lower water absorption
- lower evaporation flux
- lower exposed grain sand surface
- condensation of drops
- water diffusion in the surface: low, limited extension, shape with irregular geometry.

These characteristics could be indicative of the presence of open macropores in the surface, which would hinder the mechanism of capillary conduction.

The use of soft tools causes:

- high absorption capability
- major evaporation flux
- high evaporation flux trend although water content decreases
- very poor condensation of drops
- water diffusion in the surface: high, medium high extension, regular geometry of the shape of moisture ring.

Table 1 Measurements of the drop evaporation surface areas and evaluation of s/c parameters

	Perimeter Square	Area	s/c Factor	Moisture Ring Thickness
Trowel	1.35 mm	0.06 mm^2	21.2	16.0 pixels
Spatula	3.29 mm	0.19 mm^2	17.3	18.5 pixels
Float	8.02 mm	0.43 mm^2	18.4	36.5 pixels
Sponge	7.87 mm	2.80 mm^2	16	40.0 pixels

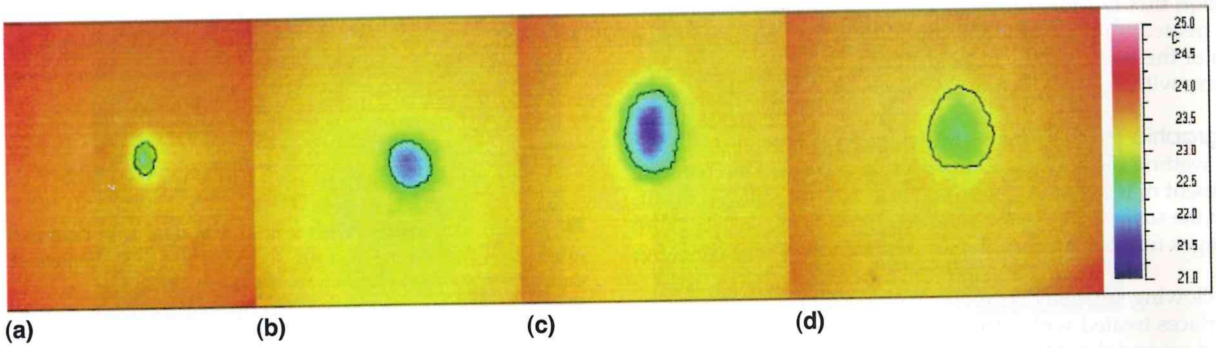


Figure 9 — Thermograms of water drops, taken at 10 s from the dropping on surface treated with: (a) trowel; (b) spatula; (c) float; (d) sponge. Water drop size is always 200 mL; images have the same scale.

Table 2 Summary of test results

Finishing Tool	Hand Pressure	Water Absorbed by Contact Sponge	Evaporation Flux	Exposed Grain Average Area	Condensation	Moisture Ring of Small Sponges	Moisture Ring of Drops (pixels)	Drops s/c
Trowel	2°	1.67 + 0.23 cg/cm^2	8×10^{-9} g/m^2 fast decrease	0.14	average	small area irregular shape	16	21.2
Spatula	1°	5.02 + 0.39 cg/m^2	1.02×10^{-8} g/m^2 regular	0.11	high	large area irregular shape	18.5	17.3
Float	3°	9.15 + 0.35 cg/m^2	1.07×10^{-8} g/m^2 regular	0.29	low	largest area regular shape	36.5	18.4
Sponge	4°	11.45 + 0.29 cg/m^2	1.18×10^{-8} g/m^2 regular	0.31	low	large area regular shape	40	16

Regular evaporation is caused by a continuous draining of the pores, at constant flux.
A differential trend of the flux is indicative of a change in the shape of surface and interior pores.

These characteristics could be indicative of an efficient distribution of water in the surface. These results suggest that the effect of blade dragging causes the differences described above: the use of blade and soft tools does not change the porosity of the bulk of the sample, nevertheless the application technique affects the hygroscopic behavior of the exterior layer of plaster.

CONCLUSION

The techniques described permit us to measure different characteristics of the structure of the exterior layer of plaster. The procedures presented belong to three different fields of investigation, and the consistency of the results shows their complementarity.

Some of these techniques are innovative, and their validity is shown by the comparison of data obtained with standard techniques, because data were confirmed by constant and regular procedures (in particular with the weighing test). The image analysis permitted us to connect the geometry of the whole surface and the wet areas to water distribution.

- The weighing tests confirmed the thermographic results, and they proved to be the most suitable tests to evaluate quantitatively the absorption capability and evaporation of liquid water.
- Passive infrared thermography showed good results in measuring the variation of surface texture caused by different tools by measuring the changes of the surface temperatures due to absorption, diffusion and evaporation of water.

The integration of infrared thermography and the test of water absorption by contact particularly permitted us to identify a factor which could have a major role for the identification of risk conditions. Contact sponge and water drop tests verified that diffusion of water is faster or slower depending on the capillary characteristics of the surface, and they connected it to the surface textures. Texture mainly depends on the tools used to apply the plaster. As shown, the propagation of liquid water occurs more extensively and faster when soft tools are used to apply the plaster. Therefore, when a surface treated with soft tools is adjacent to another treated with hard tools, liquid water diffusion occurs at the edge between the two surfaces not only because of condensation, but also due to mass transfer.

This is a first interpretation of the phenomena observed in the field, and it can explain differential damage forming on surfaces with similar and compatible physicochemical characteristics. Some of the tests presented are suitable for field application, in particular thermographic tests, videomicroscope recapture and contact sponge tests. The research begun on durability and compatibility of plaster restoration permits us to identify the zones at risk for damage. These areas are a reference for the evaluation of increasing damage and for monitoring, where it is possible, the effects of the intervention to reduce risk factors and damage.

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