Evaluation of the porosity of natural and artificial stones by Infrared Thermography

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Abstract

With the designation of Filippo Juvarra as the first architect of the Savoy kingdom, Turin saw the flourishing of new monuments in which he used an interesting variety of natural stones. Prominent among these is Chianocco marble, recognisable on the Turin façades of Palazzo Madama and Rivoli Castle. This material, which is easy to work on, nevertheless needed to be well selected to reduce its strong inhomogeneity and contain its high porosity, leading to even intense degradation over time.

The need expressed by restorers to find relatively quick in situ methods to check the behavior of the stone material for conservation purposes, e.g., by assessing the possible presence of surface protectants, provided the opportunity to start an experiment that made use of infrared thermography. The use of TIR makes it possible to non-destructively analyse surface heat exchange during and after the contact sponge method. In the present work, the contact sponge method was integrated with thermographic monitoring to observe the evolution of the process of spatial diffusion and moisture evaporation over time, in a dynamic manner.

The path adopted started with the analysis of the stone directly onsite. It continued in the laboratory with tests on altered samples of the same material taken in situ and unaltered samples taken in the quarry according to the principles of the inductive method.

The project now goes on by testing materials with similar characteristics, but with greater uniformity. The data obtained show the effectiveness of the thermographic technique for analysing the porosity of the stone; in the cases under examination, it was possible to characterize the material's response to absorption and diffusion of water.

Keywords: infrared thermography, natural stone, artificial stone, water diffusion, moisture.

Introduction

The artistic vision of Filippo Juvarra, in charge as the first civil architect at the Savoy court in 1714, led to the realisation of significant architectural works in Turin. His working method was based on studying ancient monuments, also taken as a model for choosing materials. He used Piedmontese marble and stone of different origins to construct the façades of the royal palaces and mansions he designed and built. In particular, in the case of Palazzo Madama, the starting point of this study, he selected the Chianocco marble of the lower Susa Valley. This material, which came from reopening the old Roman quarries, offered the exceptional possibility of producing large blocks in huge quantities.

Juvarra was aware of the sensitivity of this material to moisture. He, therefore, eliminated rising dampness in the lower part of the façade by inserting a full thickness *serizzo* plinth. Even in the upper part, there are problems of decay, mainly due to the difficulty of disposing of the large rainwater amount carried by the roof of the castle to which Juvarra's front was leaning. This problem, which had already become apparent a few decades after the construction of the façade, has remained unsolved to this day and is one of the issues addressed in the latest restoration project.

The non-destructive diagnostic investigations conducted within the study and restoration site on the central portion of the façade of Palazzo Madama[1] provided the basis for the development of experimental activities. Starting from in situ and laboratory tests on natural and artificial stones of different porosity, the research aims to characterise the response of the materials tested to the absorption and diffusion of water to contribute to the scientific debate prompted by the need for heritage conservation.

In situ tests

In the first phase of the diagnostic site, thermographic scans[2] of the Juvarra front made it possible to identify the areas under the greatest thermal stress and

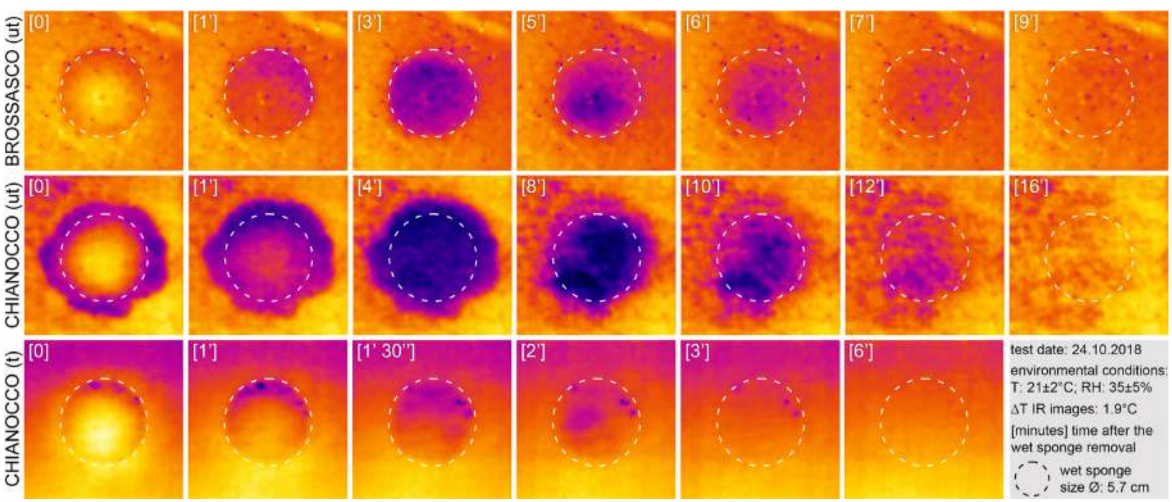

Fig. 1 Brossasco and Chianocco marbles treated (t) and untreated (ut): selection of IR images at significant times after the wet sponge removal.

to locate the most porous areas. The check of the detachment of the slabs was excluded in advance due to their high thickness. Once the scaffolding was installed, it was possible to approach the stone surfaces directly. Based on the thermographic results and the restorers' requests (presence of protective agents on the stone surface), five areas were selected on two different lithotypes (treated and untreated): Chianocco[3] and Brossasco[4] marble, on the façade and statues, respectively. Thermographic monitoring was conducted on these areas, in the same weather conditions, while measuring the water absorbed following the contact sponge method[5] (Fig. 1) [Ludwig *et al.*, 2018; Pardini *et al.*, 2004]. In this way, it was possible to highlight the evaporation front and thus show the diffusion of water in the stone, both in space and time, allowing the maximum extent of the cooling surface and the drying time to be defined.

The results show the effectiveness of the test conducted and the congruence between the IR data and the amount of water absorbed by the stone following wet sponge contact. A comparison between the untreated marbles indicates that the Brossasco (absorbed water: 0.0231 g), compared to the Chianocco (a. w.: 0.335 g) (Fig. 2), has a more spatially limited diffusion of water through the pores (1.1 cm vs. 2 cm compared to the sponge contact diameter). The evaporation phenomenon lasts less than half as long (7' vs. 15'30"). Completely different is instead the behavior of the Chianocco marble in which protective layers are still present (a. w.: 0.048 g) where the extension of the surface involved in evaporation is minimal (max. 0.4 cm) and the signal total abatement occurs only 3' after removal of the sponge.

Laboratory tests on Chianocco marble

The research was developed by carrying out experimental tests under controlled lab conditions.

The first two samples analysed were taken directly from the ancient quarry face. However, these only represent the material used in Palazzo Madama in terms of composition, not texture, as they come from a residual portion of the quarry. However, the need was to refer to a sample with features more comparable to façade marble. Therefore, a fragment of the lower portion of a column of the top balustrade that had been replaced during

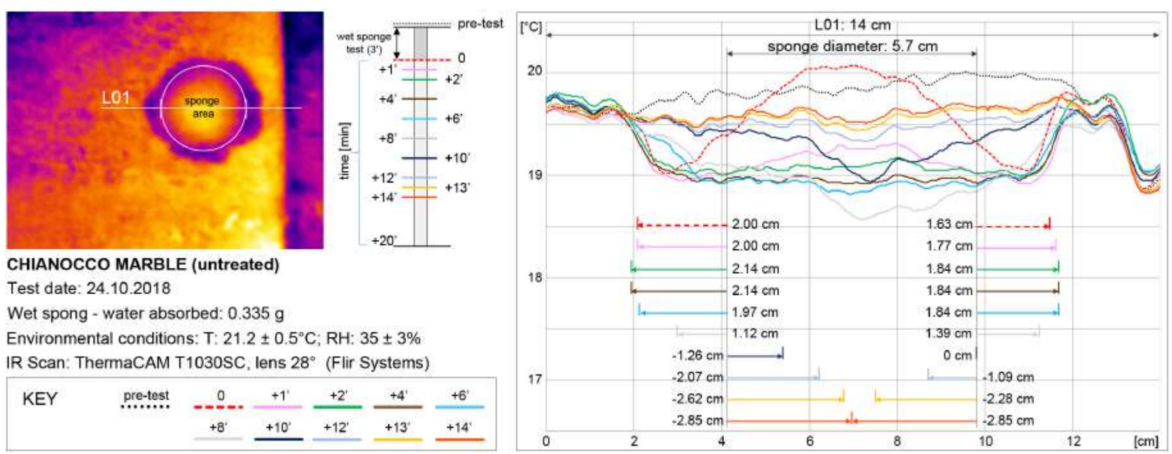

Fig. 2 Chianocco marble untreated. Data from IRT sequence (20 min) after the removal of the wet sponge. Temperature profiles on the horizontal centre axis (L01) at significant times.

an intervention in the last century was analysed. Found in the Palazzo's gardens, this sample is representative as it is altered by prolonged exposure to the external environment and without surface treatments that may have modified its physical behaviour over time (Fig. 3).

The specimens, examined on both faces, were subjected to IRT scans during tests to verify the dynamics of water absorption and diffusion. In addition to the sponge method already used, the stones were subjected to absorption tests by imbibition following immersion and evaporation tests adapting the standards UNI EN 13755:2008 and UNI EN 1925:2000 to the experimental activity. For the latter tests, the analysis on both sides of the sample taken *in situ* had the objective of simulating the evaporative thermal behaviour in the case of water present in the structure and the times and methods of imbibition of the stone in the case of heavy rain for example, in the awareness of working on a slab that was thinner than the one in the façade.

The tests conducted on Chianocco marble show a highly non-homogeneous material in its thermal behaviour in the presence of water absorption and evaporation phenomena. The response to absorption is characterised by rapidly evolving dynamics in which areas subject to strong evaporation coexist, just a few centimetres apart, with others that are significantly inert and whose geometries change over time even with significant temperature differences; these thermal dynamics are apparently not directly correlated with the distribution of porosity and are only partially related with the Chianocco marble's textural anisotropies.

Laboratory tests on fired clay bricks

The characteristics of Chianocco marble, which were particularly complex to verify the applicability of water diffusion assessment, suggested continuing the research on porous but more homogenous materials.

Two series of tests were conducted under controlled environmental conditions on several historical and contemporary fired clay bricks. The contact sponge technique was applied to all the samples, and, as in the previous tests, the induced effects were monitored by IRT. The temperature variations were analysed with an algorithm [Cernuschi et al., 2001] conceived to measure in-plane thermal diffusivity. But water diffusion can be described by the same mathematical apparatus.

The data analysis starts from the observation that once the wet sponge is removed, a temperature drop occurs in the area affected by the imbibition due to evaporation; it is also observed that over time the shape of the

Fig. 3 Sample altered by external exposure: in situ location (left), laboratory cutting steps (center), specimens obtained for testing (right).

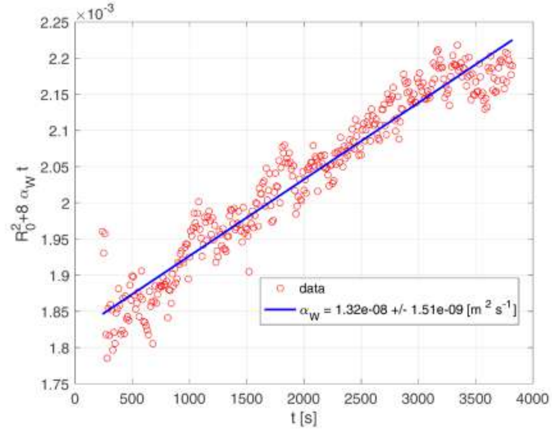

Fig. 4 The diameters of the temperature profiles increase in time as a straight line. The slope is water diffusivity.

thermal alteration changes, initially increasing, depending on the material and surface treatment. Evidently, the two phenomena, water diffusion and heat diffusion, are working at the same time. It is hypothesised that the temperature signal is mainly due to the diffusion of water, rather than to the diffusion of the heat generated by the temperature decrease due to evaporation. The diameters of the temperature profiles, as shown in Fig. 2, increase in time as a straight line whose slope is the water diffusivity. Fig. 4 shows the data fitting where R_0 is the initial diameter of the imprint, αw is water diffusivity, and t is time. As shown in the legend, the value of water diffusivity is one order of magnitude less than the thermal diffusivity of the dry material, which was obtained from the measurement of thermal conductivity, specific heat, and density[6]. This fact proves that the two phenomena, water diffusion, and heat diffusion, are working at different time scales and, therefore, can be separated in principle.

Conclusions

IRT has proven to be an effective and relatively quick technique for the *in situ* assessment of stone porosity and the verification of surface protection. At this stage, it is a comparative assessment from known samples of the same material, dependent on the wet contact sponge technique.

Laboratory tests have made it possible to characterise the material's response to water absorption and diffusion. However, the separation of thermal effects due to heat and water diffusion should be better understood. The experimental tests conducted probably need further fine-tuning of the analysis method and a more significant number of samples on which to conduct extensive tests to constitute a statistically reliable set of results.

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Notes

[1] Study entrusted to the Centro Conservazione e Restauro ‘La Venaria Reale’ in 2018. Thermographic surveys by the Non-Destructive Diagnostics Laboratory, Politecnico di Torino (2018-19).

[2] IR scan by Flir T1030 SC (spectral range: 7.5 – 14 µm).

[3] Chianocco marble is a very fine-grained, slightly yellowish crystalline marble with a calcitic and dolomitic composition in varying proportions. The most evident degradation phenomenon on the surfaces of this material is washout. This washout also occurs by removing considerable material thicknesses due to very high porosity, which is uncommon for a marble family stone.

[4] Brossasco marble is a slightly pinkish-white, heterogeneous-grained crystalline marble of essentially calcitic composition. In addition to the possibility of the formation of rusty haloes at the dark veins, this material's most evident degradation phenomenon consists of a slight form of washout that leaves some more resistant crystals in relief on the surface. Its porosity is average for crystalline marble.

[5] Tests performed by Centro Conservazione e Restauro ‘La Venaria Reale’ based on UNI11432:2001. Wet sponge contact time: 3 minutes.

[6] Thermal conductivity was measured by Hot Disk TPS2500 apparatus, the specific heat by Netzsch STA 449 C and the density by hydrostatic balance.