Evaluation of hydric behavior into porous building stones by means of Infrared Thermography (IRT)

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Abstract – **In this study, the infrared thermography method (IRT) has been carried out to evaluate the water distribution into stone specimens in the laboratory, in order to simulate the same hydric behavior in real scale material systems in situ. Samples of sandstone and calcarenite have been tested by means of hydric tests under stable laboratory conditions (temperature and relative humidity). Capillary water absorption and evaporation transport phenomena, which are responsible of the majority of decay processes occurring in masonries, have been monitored through IRT. This technique allows to record thermal images at different intervals of time highlighting the internal capillary and evaporation rise heights into the investigated materials across two splitting planes, in order to obtain useful results that could be applied for real masonries. Thanks to obtained results, IRT can be exploited as a non-destructive technique, with the aim of characterizing physical stone features and effectiveness of applied conservation treatments.**

I. INTRODUCTION

Hydric tests are very important in the characterization of the porosity of stones, especially in terms of the movement of waterthrough the pore system, which is the main factor controlling water uptake and its transport inside the stone itself. In particular, the open porosity of stones and their effective pore size is affected by the movement of water, as obtained by authors who based their research on thecomparison of pore size distribution values of various building materials[1].

The study of hydric behavior in porous building materials is vital, in order to understand their durability in front of decay processes (e.g. ice or salt crystallization) [2].In fact, as well known from literature, especially capillary rise and evaporation processes control decay effects in porous media and may generate serious damages, such as salt decay on heterogeneous systems like historic masonries [3].

Infrared thermography (IRT) has been used to detect the water absorption/desorption of different building materials in real scale systems. The temperature variations detected by infrared thermography were up to now explained by theirpore system.

In this work, the explanation of infrared thermographs is attempted throughthe study of capillary rise uptake and evaporation, in porous building materials and simulating masonry prototypes in lab,aiming tocombinetraditional standardized hydric techniques with nondestructive tests as IRT.

II. MATERIALS AND METHODS

A. Stone samples

Two types of porous sedimentary stones currentlyquarried in Calabria, in the south of Italy and sold as construction and decorative materials[4], have been selected:

1) Fuscaldo sandstone (AF), a porous Miocenic sandstone quarried in outcrops located in Fuscaldo. AF contains silico-clastic matrix (50%) and clasts (50%) and it is classified as *graywacke*[5].

2) San Lucido calcarenite (CS), a medium porous Miocenic calcarenite quarried in the still active quarry of Motta Lupo in San Lucido, with micritic matrix and visible fossils. CS is classified as *biopelmicrite*[6] and its carbonate content is quite high, reaching 94% at the maximum.

Regarding porosity fabrics, in previous studies [7] AF and CS have been classified as "with many pores" and "with pores", respectively.

B. Test methods

32 cubic specimens(50±5 mm edge), for each lithotype, have been tested. For each specimen the spatial coordinates (X, Y and Z) have been marked according to the quarrymen's convention [8].Specimen lengths have been measured with a Mitutoyo digital caliper with a precision of ±0.01 mm. Measurements have been taken in

each of the three orthogonal directions and averaged.

Open porosity and pores size distribution have beenevaluated by the mercury intrusion porosimetrytest (MIP) with anAutopore IV Micromeritics mercury porosimeter.

The capillary water absorption test has been carried out according to the EN 1925:2000 standards [9]along two anisotropic directions (X and Z). Specimens have been placed in water of 3 (±1) mm height and the weight increase has been measured continuously at the following time intervals: 1, 3, 5, 10, 15, 30, 60, 180, 480, 1440, 2880 minutes until constant massis reached.The capillary coefficients C1 (along X), C2 (along z) and the mean value Cc have been calculated[9].

The water desorption content (Wi(Ds)) has been determined following the Italian standard ICR-CNR NORMAL 29/88[10]. After reaching the saturated conditions, the same cubic samples tested by the capillary absorption have been dried under constant laboratory conditions (temperature and relative humidity). Their weight loss has been registered in the same given time intervals of the absorption test performed and plotted as a function of time.

During hydric tests an Infrared Thermography camera (Thermacam B4 - Flir Systems) has been used for the evaluation of the moisture distribution by capillary rise (absorption, evaporation) into samples. Infrared Thermography detects the radiation that a material emits and can render the image of the surface area in black and white colors, in relation to a temperature scale, providing thermal maps.

III.   RESULTS AND DISCUSSION

Open porosity and percentage of pores are reported in Table 1.

Table 1. Macro (>5μm) and micro (<5μm) porosity[11] and open porosity (Po) values in percentage obtained by the MIP test.

Sample	Macro (%)	Micro (%)	Po (%)
AF	2.96	97.04	12.93±2.53
CS	31.41	68.59	20.94±0.71

Capillary coefficients and water desorption content values are reported in Table 2, while the capillary absorption curve and the kinetic of desorption are plotted in Fig. 1 and Fig. 2, respectively.

Thermal images obtained during hydric tests are shown in Fig. 3 and Fig. 4.

According to the values reported in Table 2 and as shown in Fig. 1, CS shows the highest values of capillarity. It shows the same hydric behavior along the two investigated directions, while AF demonstrates a completely different behavior according to the sample orientation. Along the X direction, AF absorbs water

more quickly than the Z axis. The first part of each curve (Fig.1) defines the capillary water absorption, while thesecond part defines the saturation.

Table 2. Hydric tests. Capillary coefficients along X (C_1), along Z (C_2), mean value (C_C)expressed in $g/m^2 s^0$andwater content evaporated (Wi_{Ds}) expressed in %.

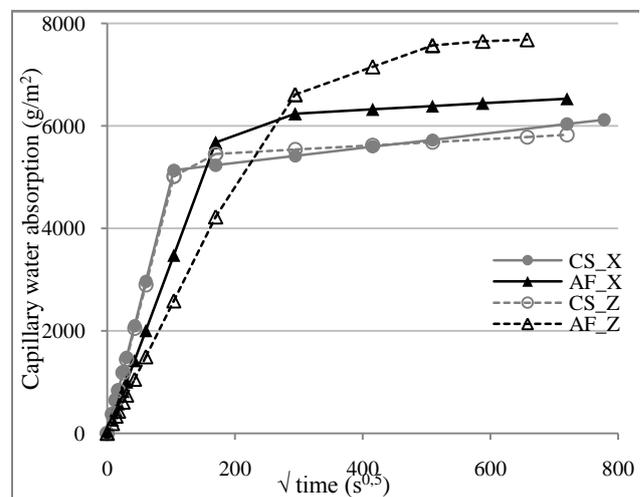| Sample	C_1 $(g/m^2 s^{0,5})$	C_2 $(g/m^2 s^{0,5})$	C_c $(g/m^2 s^{0,5})$	Wi_{Ds} (%)
AF	33.46	24.89	29.18	1.95
st.dev.	*9.41*	*5.79*	*6.06*	*0.13*
CS	49.44	48.27	48.86	2.49
st.dev.	*10.11*	*3.38*	*0.82*	*0.33*

Fig. 1. Capillary water absorption averagecurvesalong the twospatialdirections X and Z. The capillary water absorption isgiven in g/m2 versus the squareroot of the time in seconds.
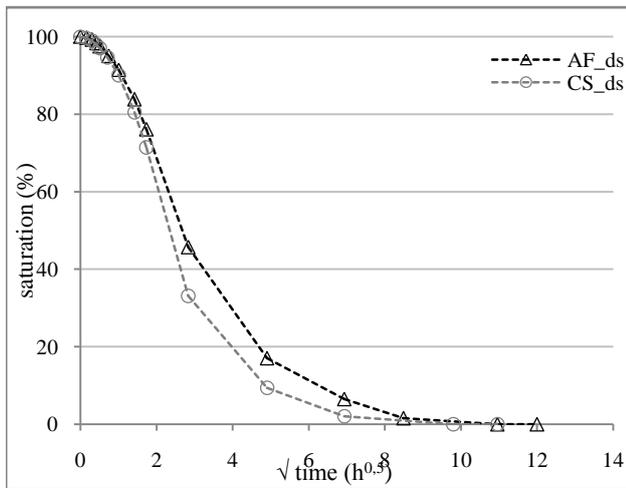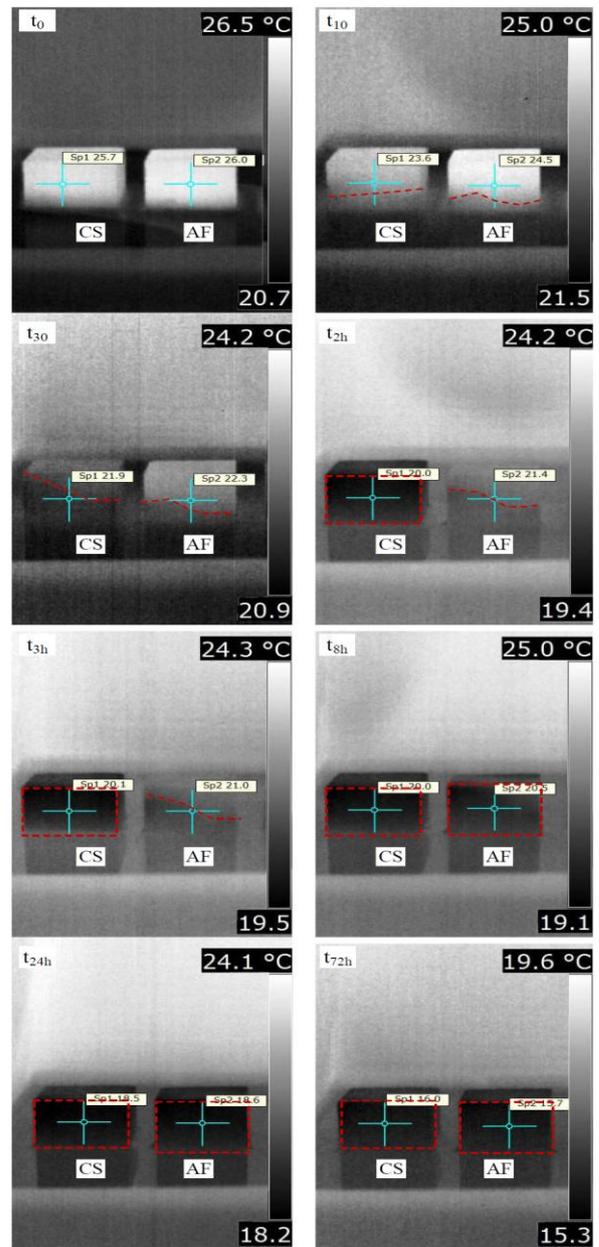
Fig. 2. Water desorptioncurves.

Fig. 3. Thermography images along the X direction.

Fig.1 highlights that CS absorbswater more quickly than the other stone (first part of thecurve), while AF absorbs the major water quantity due to its higher open porosity (the second part), coherently to the values reported in Table 1. The difference of capillary suction rate depends on pore diameter [12] and open porosity. CS, due to the presence of larger pores, absorbs water faster than AF, characterized by smaller pores (Table 1). The difference in the absorbed water quantity is to be related to the open porosity: as AFexhibitshigher open porosity than CS, it absorbs more water. This difference explains the different velocity of AF and CS in the two parts of the curve (Fig. 1).Results obtained by the
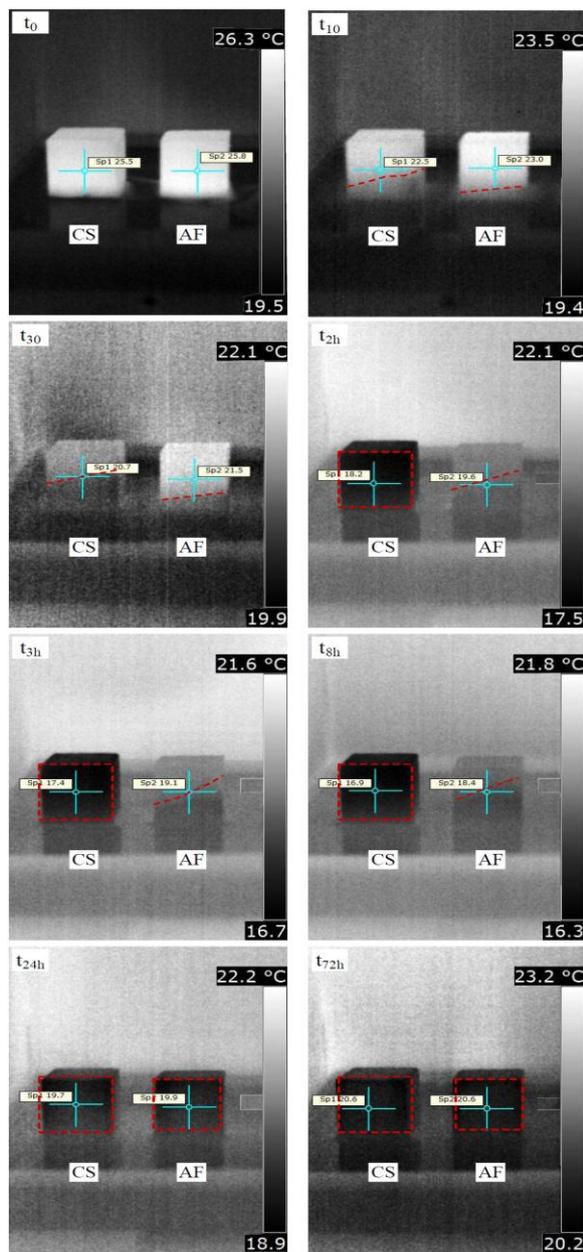
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Fig. 4. Thermography images along the Z direction.

capillary test agree with the open porosity values obtained by the MIP test.

In Fig. 2, the graphic of the evaporation rate on CS displayed values of a higher evaporation than AF. Within the first 3 hours the saturation of both CS and AF is still about the 90%. After the evaporation of the water from their surfaces, a pretty fast drying rate still keeps due to the internal absorbed water: within 21 hours (interval of time from 3h until 24h) they lose 60% of their water content. Probably,this can be due to a good connectivity of the porous system. After this point, there is an abrupt change in thedrying rate with a constant saturation of 10-15%. Basically, it could be summarized that the higher

the water absorption velocity, the higher the water desorption velocity and viceversa.

Thermographic images show a clear correlation among porosity, water absorption by capillarity and evaporation. The cooling down of the damp areas on the specimen surface is the effect of the water (both in liquid and vapour phase) transport phenomena. Thermal drop test images provide the measurement of the change of temperature due to these effects (Fig. 3 and Fig. 4). On CS surface, the wet area is wider than on AF specimens, and it has a regular shape too; this shape is due to the liquid which regularly fills up all the open pores at disposal. The widest area is due to the rapid absorption of the drop by the surface, that is rich in macropores, where water capillary spreading is faster. On AF specimens, the wet area has undergone the largest increase during the observation time, nevertheless the shape becomes irregular and the contour line is unreadable and vague,so that it is difficult to measure. This behaviour can be attributed to the macropores prevalence with respect to CS. The extension and shape of the wet moisture over the intervals of time changed for any tested materials, depending on their surface characteristics.Moreover, samples that present faster water absorption, exhibit considerable temperature reductions, while samples with lower absorption velocity offer small temperature differences.

Furthermore, analyzing thermal images obtained along the two directions, it can be observed how along Z the water uptake (Fig. 4) is more irregular and slower than along X (Fig. 3), especially for AF. This fact indicates that water rises with higher difficulty inside samples due the foliation planes orientated perpendicularly to the flux direction. In the case of CS, no significant differences are detected for the two directions, coherently to the similar values obtained for the capillary coefficients C_1 and C_2 (Table1) and to the quite parallel slope of the curves reported in Fig. 1.

IV. CONCLUSIONS

Performed tests allowed to distinguish the different hydric behavior of each investigated lithotype. The presented techniques allow to measure different characteristics of the exterior layer of stone building materials. Thermography images result suitable and effective tests to evaluate the absorption capability and the evaporation of liquid water into porous stone materials. Thus, IRT shows good results to indicate the variation into stones by measuring the changes of the surface temperatures due to absorption, diffusion and evaporation of water. The most influencing factors during the capillary test result the pores distribution and size in the very exteriorlayer of the materials, where the water exchanges occur much more frequently than the inner part of the stone. Concerning the relationship between hydric behavior and anisotropy directions, the way in

which stones are positioned in construction could influence the capillary rise and, consequently, their durability. Coherently to obtained results, it is suggested to put stones with a higher anisotropic hydric behavior vertically along the Z axis, where the water uptake is lower, to minimize decay induced by water ingress.

Furthermore, these results could be very useful when considering decay processes due to the water uptake, like salts or ice crystallization. In fact, IRT recording thermal maps obtained by IRT of real surfaces could provide useful information on the differential behaviour of the various materials on the masonry scale regarding the water impregnation and evaporation phenomena, which control decay effects in porous media. Hence, infrared thermography might be used as a non-destructive technique to evaluate the performance of conservation interventions and materials, in compatibility to the original materials on the level of the structures.

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