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Case Study

The plasters of the *Sacro Monte* of Varallo Sesia. From the characterisation to the proposition of a restorative mix

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ABSTRACT

In this paper, the systematic physical-chemical characterisation of historical plasters of the *Sacro Monte* of Varallo Sesia, Italy, the study of the local constructive techniques, as well as the evaluation of new restoration plasters is presented.

The selected samples (from XVI to XVIIIth centuries) are in a quite good state of conservation despite the prolonged exposition to weathering agents. This behaviour is due to the good manufacturing and to the peculiar smooth finishing layers which reduce water permeability and allow water drops to slide off.

The plasters characterisation realised in laboratory for *in situ* integration is also presented. These plasters should meet functional and aesthetical requirements and must satisfy the compatibility issues not only related to the physical-chemical aspects.

1. Introduction

In ancient architecture, plasters are one of the main expressive elements which strongly contribute to define the image of the architectures. Nevertheless, the conservation of plasters is not only an aesthetic need, but it is necessary for the correct maintenance of the buildings structure and to hand down the architectural heritage (Arioglu and Acun, 2006; Feiffer, 1997).

In Piedmont, North-Western Italy, as anywhere all over the world, it is possible to identify a multiplicity of local practices in terms of masonry construction, finishing and decoration methods that are linked to local materials and resources. Each local technique gives rise to special problems of compatibility with the necessary interventions of restoration.

In this paper, the systematic physical-chemical characterisation of the historical plasters of the *Sacro Monte* (Sacred Mountain) of Varallo Sesia, the study of the local constructive techniques as well as the evaluation of new restoration plaster, is presented as a case study. The final goal of the research is to provide the *Riserva Speciale Regionale del Sacro Monte di Varallo* (the organism which manages the site) and the restorers useful correct practical methods to periodically perform maintenance, conservation and restoration works (Schueremans et al., 2011; Rosário, 2001). The

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complexity of conservation problems, related to environmental factors and to the application of local materials, is under discussion. In fact, it may be necessary to operate on the surfaces of a building to cover superficial plasters detachment or to fill in deeper lacunae. In any case, the preservation of the authentic material, marked by time, is the main goal as it is a piece of unquestionable value.

A critical approach to the theme of compatibility, which is a complex concept that could not be confined to the physical-chemical aspect of the intervention, is necessary. In fact, the peculiar characteristic of the site, the immaterial components and the local culture should be considered as a stimulus for a conservation project (Delgado Rodrigues and Grossi, 2007).

2. The site of the case study

The *Sacro Monte* of Varallo Sesia belongs to the UNESCO Sites since 2003 together with other eight *Sacri Monti* of Piedmont and Lombardy in Italy.

The *Sacro Monte* of Varallo Sesia is the oldest and the most important Sacred Mount of the alpine region and was conceived at the end of XVth Century, on initiative of the Franciscan Father Bernardino Caimi, keeper of the Holy Sepulchre. He planned a reproduction of the Holy Land as a place of pilgrimage for people unable to go to Palestine. Concluded in the middle of XIXth Century, the *Sacro Monte* of Varallo includes a basilica and forty five frescoed chapels populated by over eight hundred full size statues made in wood and terracotta (Stefani, 1994).

Currently, some of these buildings show conservation and restoration problems and the complexity and heterogeneity of the site makes the maintenance difficult. Moreover, further characteristics of the site complicates the situation: the high relative humidity value and the cold temperatures frequent in this area, the tall trees distributed among the chapels, which are part of the contest, and the open space of the chapels.

3. Materials and methods

3.1. Sampling

Samples were collected in accordance with the criteria of Nor.Ma.L. 3/80, in collaboration with the Head of the *Riserva Speciale Regionale del Sacro Monte di Varallo*, on the basis of a deep historical research.

16 samples from 7 chapels were collected and could be grouped as follows on the basis of the features of the peculiar finishing layers:

Type 1: The chapels 13, 14, 15, 17 and 25 are characterised by a smooth finishing layer with a blue-grey colour, sometimes lighter or darker. These surfaces are the original exterior finishes of the considered chapels. Despite off the long period of application and the direct exposition to the weathering agents, these plasters are in a quite good state of conservation. Moreover, it can be observed that on the external surfaces of each chapel a yellow paint (probably a lime wash) was applied. This intervention was realised during the XIXth century to conform the surfaces with the taste of this historical period. This layer is now strongly degraded and it is currently visible mainly in the areas sheltered from rainfalls by the slope of the roofs.

Type 2: The chapels 28 and 36 are characterised by a smooth finish with a brown-grey colour. As reported in the historical original records, these surfaces were realised in the middle of the XIXth century using lime, local aggregates, fragments of bricks and porcelains and blast furnace slag.

3.2. Characterisation of the samples

Original plaster samples were studied using the following methods and instrumental techniques:

The morphology and texture of the plasters were investigated by means of a scanning electron microscope (SEM, Hitachi S2300-D), equipped with an energy dispersive X-ray spectrometer (EDS Kevex) for elementary semi-quantitative analysis.

The mortar samples were roughly ground and sieved to divide aggregates and binder. The X-ray diffraction analysis (XRD, Philips PW 1710) was performed on both the fractions. When present, the coloured finishing layer has been always separated from the mortars before crushing and analysed separately.

Optical microscopy was used for mineralogical-petrographical characterisation of the constituents in thin sections of plaster samples. Image analysis was also performed to determine aggregates size and quantity in volume and the ratio aggregate/binder.

Spectrophotometry was used to measure the chromatic parameters and the absorbance spectra of the finishing layers. The measurements were taken *in situ* on the finishing layer and on the surfaces of the samples manufactured in our laboratory. A spectrophotometer (Minolta CM 700 d) using the LAB system space was utilised according to the Italian Recommendation Normal 43/93.

The absorption rate of a water drop was measured according to the standard method test RILEM 25 PEM (UNESCO 1978) on the finishes of all the plaster samples.

The Karsten pipe method was used to evaluate the permeability to water under low pressure. To perform the test, the Karsten pipe was attached to the sample of plaster prepared in laboratory with plastiline. The method was applied according to the RILEM II.4 recommendation.

4. Results and discussion

4.1. Characterisation of the existing plaster: the arriccio layer

4.1.1. Identification of the aggregates

From optical microscope observations, aggregates result of natural clasts with a grain size mostly in the field of the average-coarse sand (0.2–2 mm). Their roundness is low and is function of their mineralogical composition and of the transportation distance of each clast.

The clasts of greater size are formed by lithic fragments, while the fine-grained ones are mostly composed of single minerals. The systematically and prevalent lithologies are siliceous rocks (gneisses, mica schists and quartzites), followed by greenschists and basic granulites; clasts of talcschists are relatively scarce but ubiquitous.

Also XRD analyses performed on the aggregate support a common origin, since they are very similar and mostly present peaks of quartz, albite, calcite, muscovite, clinochlore, hornblende, orthoclase, clinozoisite and antigorite.

In conclusion, the mineralogical-petrographical composition of the aggregates is quite homogeneous and easily referable to the alluvial deposits of the near Sesia River. More details are available in Tulliani et al. (2013).

4.1.2. Characterisation of the binder of the arriccio layer

The crystalline phases present in the samples were detected by XRD investigation of finely pulverised plasters and are presented in Tulliani et al. (2013). The XRD patterns indicate that calcite is the main component of the matrix even if the presence of magnesite indicates that a magnesian lime was used. This material was probably obtained from the local dolomia. More detailed informations about binder composition were achieved by thermal analysis.

Most of the samples are typical aerial lime plasters of dolomitic nature with an important weight loss at temperatures ranging from 550 °C to 900 °C. In some samples (*arriccio* layer of the chapels 13, 15 and 25) further endothermic peaks attributable to the thermal decomposition of the hydromagnesite were identified (De Silva et al., 2009). The DSC curve of these samples presents 4 endothermic peaks at about 260 °C, 401 °C, 508 °C and 774 °C, respectively, associated to mass losses of about 2.3, 6.7, 2.1 and 12.6% as reported in Fig. 1. The endothermic effects at 258 °C and 408 °C are associated, respectively, to the dehydration and dehydroxylation of the hydromagnesite (Hollingbery and Hull, 2010), whereas the peak at 504 °C is imputable to the thermal decomposition of the magnesium carbonate. Finally, the broad peak centred at about 780 °C is due to calcium carbonate thermal decomposition. The obtained values are comparable with the data found in literature. The presence of hydromagnesite in these samples was also confirmed by SEM observations: it was identified as a mineral forming rosettes and made of only magnesium, as evidenced by SEM/EDS analysis (Fig. 2). Hydromagnesite is only formed in strictly controlled conditions, when the solution pH ranges between 7.5 and 9.0 and in CO_2(g) excess conditions, as highlighted in many papers (Dheilly et al., 1999; Villasenor and Price, 2008; Lanas and Alvarez, 2004; Lanas et al., 2006). To conclude, the data showed a homogeneous composition of the analysed plaster, which was unchanged over time.

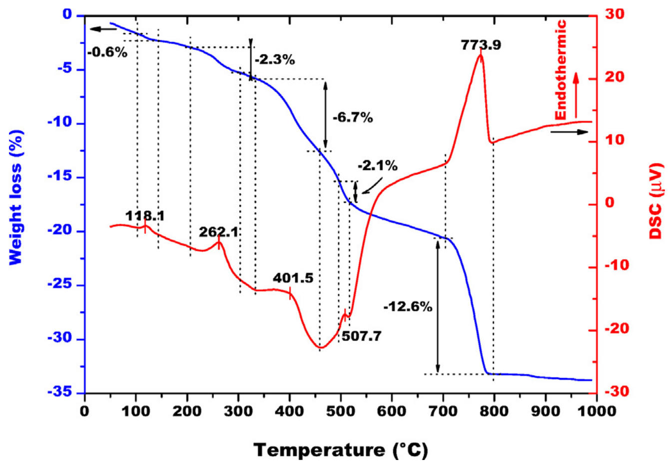

Fig. 1. TG-DTA curves of the *arriccio* layer (chapel 25).

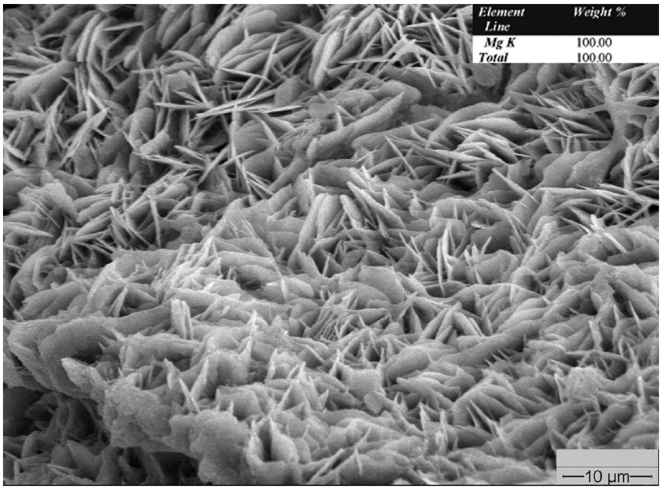

Fig. 2. SEM micrograph of hydromagnesite crystals. In the highest right portion the elemental composition is reported.

4.2. Characterisation of the finishing layer

The aim of plaster specimen investigation is to confirm the feasibility of plaster surfaces reintegration by applying compatible materials and technologies. For this reason, the analysis were performed to observe the morphologies of the finishing surfaces and to analyse their main components.

Type 1: the grey-blue finishing

These kinds of finishes were applied directly on the *arriccio* layer which is characterised by a fine-medium sorting of the aggregates, as described before. In any case, SEM observations confirmed the good state of conservation of this layer and its high level of compactness and low porosity. The cohesion between the top and bottom layers is diffuse and strong. The thickness of the finishing layer for the samples of the chapel 13 is about 1 mm, while the finishing layer of the chapels 14, 15, 17 and 25 is about 100 μm.

Focusing the attention on the components, EDS analysis were carried out to investigate the presence of common inorganic black pigment and these data are reported in Table 1. These analyses underlined the absence of iron, manganese and phosphate, suggesting the use of other carbonaceous materials. For this reason, by comparing these data, the historical documents and the geological maps of the area, the use of a local black earth (Black earth of Boca) made of lignite was supposed. Even if the aesthetic appearance of the considered chapels is comparable, the technique of application was not the same.

The finishing layer of the chapel n.13 is smooth, compact and quite thick, in particular if we consider the exposition to atmospheric agents for 5 centuries at least. In this case, the earth pigment was added to the lime and this paste was applied and smoothed when the layer was still fresh in order to avoid the white deposition on the surfaces. In the other chapels, the finishing layer is still smooth, but thinner. In this case, a lime wash painting on the *arriccio* was applied. Considering the saturation of the colour and the considerable thickness for this type of finishing, we hypothesise that a low dilution of lime with lime water was employed.

Type 2: the grey-brown finishing

The finishing layer applied on the outdoor façade of the chapels 28 and 36 is grey, thin and smooth and from its appearance, it is comparable to the other finishing surfaces analysed in this site. Despite this, the composition of this layer is

Table 1
Elemental composition of the finishing layers.

Oxide	F 13 (wt%)	F 14 (wt%)	F 15 (wt%)	F 25 (wt%)	F 28 (wt%)	F 36 (wt%)
CaO	61.08	69.22	58.40	33.68	1.40	2.94
SiO_2	10.14	4.91	7.97	14.71	3.16	1.59
MgO	17.89	18.80	27.65	32.73	1.54	2.71
Al_2O_3	7.32	7.07	5.97	8.02	–	–
Fe_2O_3	3.56	–	–	10.86	93.89	92.17
SO_3	–	–	–	–	–	0.60

Table 2
Ratio of the different materials used to prepare the restorative plasters.

Panel	L1	L2	L3	L4
Type of finishing Volumetric dosage	Coloured mortars Lime: sand Pigment: lime putty = 1:12 (wt)	Coloured mortars Lime: sand Pigment: lime putty = 1:6 (wt)	Coloured mortars Lime: sand Pigment: lime putty = 1:6 (wt)	Lime wash paint Lime putty: water = 1:2 No aggregate Pigment: 20 wt% of the lime putty

very different from the other surfaces. In fact, a mix of iron slag (called *maciaferro*), *pozzolana*, kaolin, marble powder, local magnesian lime and *cocciopesto* was applied and smoothed with the appropriate technology as reported in the archival document (Archivio, 1842). The use of this particular slurry to obtain a waterproof "mortar" was well known at that time.

The relevant amount of iron detected in the finishing layer by EDS analysis confirms the use of metallurgical slag in the slurry.

XRD analyses performed on the surface of the sample put in evidence the presence of magnesium and of calcium oxide, which are also components of metallurgical slags. In addition, peaks corresponding to alumino-silicate and $4CaO.Al_2O_3.13H_2O$ (C_4AH_{13}) were detected. Despite this reaction between the binder and the aggregates, the thermal analysis showed that iron slag and ceramic aggregates addition did not result in the formation of hydraulic phases.

5. Design of restorative plaster

Based on the collected data, the second part of the work involves plaster laboratory formulation, in order to plan a possible intervention of restoration. The formulations were studied to guarantee an aesthetical and mechanical continuity with the existing surfaces by applying materials currently available on the market. The study of the historical and the local constructive technologies helps to design intervention projects that take into consideration the social cultural context. In this way, the issues of compatibility are pursued under all the different aspects (Aguiar, 2001; Gil et al., 2011).

The raw materials selected for the design of the repair mortar and plasters consist of magnesian putty provided by Piasco as the binding material and of siliceous aggregates (sand) from the Sesia River. For the finishing layers, the black earth of Boca was used. The grey coloured mortars were applied in a thin layer (< 1 mm) on top of the *arriccio*. The ratio of the different components is reported in Table 2. The pigments were added directly into the lime putty used to prepare the plasters. The mortar surface was smoothed with a hardened steel mason spoon when it was still wet.

Concerning the lime wash, a low dilution of the lime putty was preferred to obtain a dense paste. In this sample the finishing painting was applied with a brush in two paint coats.

5.1. Colorimetric measurements

The surface appearance attributes play a key role in the colorimetric interpretation and in the perceived final colour. This attention to the colour is not only dependant on an aesthetical need.

The grey colour can be observed on many chapels of the site built in different periods. The reflectance spectra of the northern façade of the Chapels 13, 14, 15 and 25 are reported in Fig. 3. The plain trend of the spectra confirms the achromatic grey tone of the analysed surfaces. The plaster finishing created in our laboratory has a grey colour comparable to the surfaces of the Chapels used as a reference.

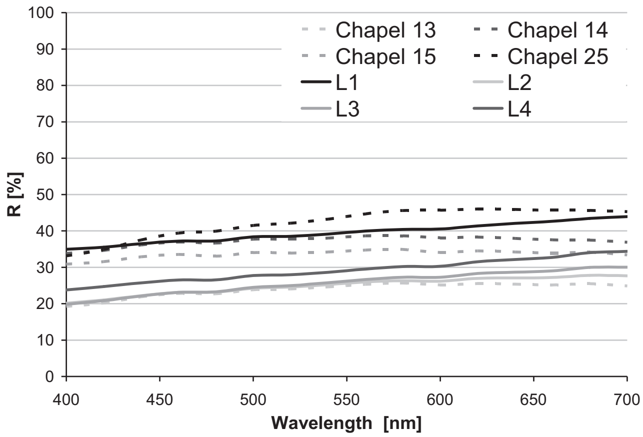

Fig. 3. Colorimetric comparison between the plaster applied in situ (Chapel 13, 14, 15 and 25) and the plaster realised in laboratory (L1, L2, L3 and L4).

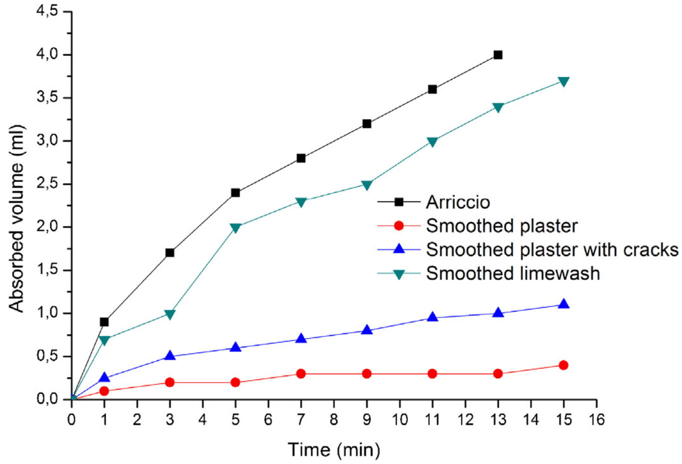

Fig. 4. Water absorption behaviour of the samples measured through the Karsten pipe test.

5.2. Influence of the finishing on the water absorption

Considering that this peculiar texture of the plasters is applied on the façades more exposed to the weathering agents, it is reasonable to consider that they carry out a protective function in particular against the pouring rain.

Significant results concern the wettability of the surfaces evaluated through water drop measurements were achieved. In fact, as it is well known, plaster absorb water instantly. When the lime smooth finish is applied, it is possible to notice that the drop time permanence on the surface was extended until 20 min. This fact demonstrates that the smooth finish provides an effective protection to the masonry.

The Karsten tube revealed the highest absorption rate for the lime plaster without the finishing layer, as reported in Fig. 4. On the other hand, when the finishing layer is well smoothed and is free from imperfections, the absorption rate is much slower. These data demonstrate that the smooth layer plays an important role in the protection of the wall from rainfall. Obviously, if this layer presents cracks and surface defects, water can penetrate inside the material. For this reason, the importance of the workmanship and of the ancient techniques knowledge is highlighted once again.

6. Conclusions

The ability to develop an effective conservation strategy is a complex task. The project of intervention must take into account the significance of the site, the building system, the materials, and the environmental and human factors. At this time, considering the compatibility of an intervention only for the material aspect is reducing. Other features, such as the economical, technical and sociological aspects, should be pursued.

Acknowledgement

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.cscm.2014.04.001.

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