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Analysis and laboratory tests to evaluate the composition and the behaviour of some dehumidifying mortars used in the restoration field

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Abstract

The aim of this work is to study some commercial products, defined dehumidifying mortars, in order to verify their composition and their performance characteristics in comparison with the technical specifications supplied by the industries. In fact, the real composition and the properties of the commercial products often differ from those declared by the suppliers. In the field of conservation the commercial products are widely used and the restorers choose the most appropriate one also on the base of the declared characteristics. So it is of particular relevance in conservation and restoration applications to know the real composition and the performance characteristics of a commercial product. Starting from these general remarks, 20 commercial products were examined, in collaboration with the Society Mapei, in order to verify their composition and their physical-mechanical characteristics. The analyses of the mortars were carried out in the Laboratory of Diagnostics for Conservation and Restoration of University of Tuscia and in the Mapei's research laboratories in Milano. The analyses and tests were performed on the products and on the specimens prepared according to the specifications referred in the technical data sheets supplied together with the mortars. In particular, the following analyses were undertaken: 1) Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES), X-ray diffraction (XRD), thermo gravimetric (TG) and differential scanning calorimetry (DSC), and Fourier Transform Infrared spectroscopy (FT-IR) in the Mapei's laboratories, and 2) granulometry analysis, colour measurements, pH and conductance measurements, FT-IR spectroscopy, in the laboratories of University of Tuscia. Moreover, some specific tests were carried out to study the mechanical and physical-chemical properties of the specimens: capillarity water absorption (UNI 10859: 2000), water absorption due to total immersion (imbibition capability, NORMAL 7/81), drying index measurement (NORMAL 29/88), and micro drilling tests. The results of this study indicate that the examined dehumidifying mortars not always respect the requisites required to a product to be used in the restoration of historical buildings. This suggests the necessity to verify the composition

and the characteristics of the commercial products used in the conservation applications in order to choose the most appropriate materials and procedure to guarantee the safeguard of the historical buildings.

Key words: restoration mortars; granulometry; colour measurements; Fourier Transform Infrared spectroscopy; water absorption; micro drilling.

Introduction

Replacing or repairing masonry mortar is usually necessary in the restoration of historical constructions, but the selection of a proper mortar is often problematic. Awareness of the need for compatible materials for the preservation of the architectural heritage has resulted in the revival of lime-based mortar technology and applications (Elert et al., 2002) (Lanas and Álvarez, 2003) (Izaguirre et al., 2009). However, knowledge of the preparation process and procedure influencing the final quality of lime mortars is limited, and controversy persists in the conservation community regarding the most appropriate material for conservation treatments. An inappropriate choice can lead to failure of the restoration work, and perhaps even further damage (Yang et al., 2010) (Lo Monaco et al., 2011). Thus, a thorough understanding of the commercial restoration mortars is an important research goal as well as that of knowing the original materials. In fact, this necessity of knowledge is critical, since the rehabilitation work must guarantee physical, chemical and mechanical compatibility between former and restoration mortars (Marques et al., 2006) (Schueremans et al., 2011) (Papayianni et al., 2013).

This paper would like to be a little contribution to the knowledge of some commercial dehumidifying mortars used in the restoration of historical buildings, as declared by the producers, in order to verify their compositions and their physical and mechanical properties. The dehumidifying characteristics of these mortars are established on the base of their final performances, as reported in the technical data sheets, in particular: the absence of cement, the high salt-resistance, the low capillarity action water absorption, the low permeability to water vapour, and the absence of saline efflorescence. So, these parameters will be taken into consideration in order to evaluate the dehumidifying character of the examined mortars and their applicability in the restoration of historical buildings.

The chemical characterization of the mortars was carried out mainly in the Mapei's laboratories in Milan through different kinds of analysis: Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES), X-ray diffraction (XRD), thermo gravimetric analysis (TGA) and differential scanning calorimetry (DSC), and Fourier Transform Infrared spectroscopy (FT-IR). Mapei supplied a detailed technical report© on the analysis whose main results will be shown and discussed in the present paper. Other kinds of analysis were performed in the laboratories of University in Viterbo both on the powders and on the test specimens in order to investigate the properties of the mortars, in particular colour measurements, pH and conductivity measurements, capillary water absorption, imbibition capability, drying index, drilling resistance. The behaviour of the mortars in relation to the water is particularly relevant for the whole performance of mortars applied on old masonry. In fact, renders and plasters must protect the masonry against water, preventing the easy entry of significant volumes of water and promoting their quick drying (Veiga et al., 2004). Besides, water is a major degradation factor for old mortars, because i) it has some capacity of solubilizing mortars constituents, ii) it can facilitate reactions that promote the degradation of the

mortars' constituents, iii) it increases volume when it turns into ice, iv) it solubilizes salts and promotes their movement through the mortar, v) it facilitates fixation of biologic colonization. So the study of mortars' characteristics concerning water, namely water absorption and drying behaviour, is of particularly relevance in their application on historical buildings and opens the possibility of trying to formulate new mortars with similar characteristics, consequently with similar expected durability and adequate to protect the masonry.

Experimental

Twenty selected mortars were examined in this study. The mortars are divided into renders and plasters as function of their use in repairing or replacing masonry mortars. The characteristics of the examined mortars, supplied by the producers, are shown in Tables 1 and 2.

Weight fractions were obtained by sieving the mortars with an Endecotts Octagon Digital instrument equipped with the following sieves: 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.063 mm.

To measure the pH and the conductivity, 100 mg of mortar powders were put in 100 ml of distilled water (conductivity grade, 18 MΩ), according to the methodology described in the UNI 11087 (UNI11087: 2003). pH measurements were performed with an Hanna instrument Model HI1280. Conductivity was measured by using an Hanna instrument HI8733.

Colour measurements were performed on the powders and the test specimens by using an X-Rite CA22 reflectance spectrophotometer. The characteristics of the color measuring instrument are the following: color scale CIEL*a*b*; illuminant C; standard observer 2°; geometry of measurement 45°/0°; spectral range 400-700 nm; spectral resolution 10 nm; measurement diameter 4 mm; white reference supplied with the instrument. Three measures for each point were performed, and then average values and standard deviations were calculated. The CIELAB color system was used where L* describes the lightness while a* and b* describe the chromatic coordinates on the green-red and blue-yellow axes, respectively. The differences in lightness (ΔL*), chromatic coordinates (Δa* and Δb*), and total colour (ΔE*) between the specimens and the powders were then calculated using these parameters according to NORMAL 14/93 and EN 15886. The total colour difference, ΔE*, between two measurements ($L^*_1a^*_1b^*_1$ and $L^*_2a^*_2b^*_2$) is the geometrical distance between their positions in CIELAB colour space. It is calculated using the following equation: $\Delta E^*_{2,1} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{½}$.

FT-IR spectra were obtained using a Nicolet Avatar 360 Fourier transform spectrometer. For

Table 1. Description of the renders, as supplied by the producer.

SAMPLE	DESCRIPTION
1	Pre-mixed mortar based on hydraulic lime (HL)
3	Natural hydraulic lime (NHL 3.5), hydraulic lime (HL 5) and micronized natural pozzolan
6	White natural hydraulic lime and rheologic supporting additives
8	White dry mortar based on natural lime, sulphates' resistant hydraulic binder
10	Pre-mixed render based on selected pozzolanic binders, air lime and special additives
13	Natural hydraulic lime (NHL) and natural pozzolans. Low content of soluble salts.
17	Pre-mixed mortar, cement-free, made of special hydraulic binders. Special additives and synthetic fibers.
19	Pre-mixed mortar based on highly pozzolanic hydraulic binders. Low content of soluble salts
21	Natural hydraulic lime

Table 2. Description of the plasters as supplied by the producer.

SAMPLE	DESCRIPTION
2	Pre-mixed mortar based on hydraulic lime (HL), without cement. Macro-porous and highly transpirant
4	Natural hydraulic lime (NHL 3.5) with natural extra-fine pozzolan. Porous and highly transpirant
5	Natural hydraulic lime (NHL 3.5) with natural extra-fine pozzolan. Porous and highly transpirant
7	White natural hydraulic lime, light inerts with thermal insulation features and special airing natural additives
9	White dry mortar based on natural lime, sulphates' resistant hydraulic binder, fireproof, and additives used to improve the workability, the adhesion and the transpirability
11	Pre-mixed plaster based on selected pozzolanic binders, air lime and special additives. Macro-porous plaster
14	Natural hydraulic lime (NHL) and natural pozzolans. Low content of soluble salts.
18	Pre-mixed mortar, cement-free, made of special hydraulic binders. Special additives and synthetic fibers.
20	Pre-mixed mortar based on light lime and special additives. Highly transpirant plaster with low content of soluble salts.
22	Macro-porous plaster based on natural hydraulic lime
23	Natural hydraulic lime (NHL 5). Fibred natural product cement-free and highly transpirant

each sample 128 scans were recorded in the 4000 to 400 cm^{-1} spectral range in diffuse reflection modality (DRIFT) with a resolution of 4 cm^{-1}. The following samples were examined: bulk powders, ground with spectrophotometric grade KBr (1% sample in KBr) in an agate mortar, and the extracts with acetone and diethyl ether.

Cylindrical laboratory specimens of 110 cm^3 were prepared according to the specifications supplied in technical data sheets and to the NORMAL 26/87. The percentage of the water used to prepare the specimens varied from 14% in sample 1to 80% in sample 7. Sample 7, in particular, needs much more water than that indicated in the technical sheet to obtain a suitable specimen.

These specimens were used to perform the capillarity water absorption test according to the UNI 10859:2000, the total imbibition water absorption (NORMAL 7/81), the drying index (NORMAL 29/88) and the micro drilling resistance measurements (DRMS). The drilling resistance measurements were performed with a Sint Technology cordless system in the following conditions: 300 rpm rotation speed, 10 mm depth and 3 mm hole diameter.

Results and discussion

Grain size distribution

Weight fractions of the renders and plasters, after sieving, are shown in Table 3. From the table it is apparent that the grain size distribution of the mortars shows different patterns. In fact, the binding material content of the renders, defined as the whole mortar passing through the 0.125 mm sieve (Maravelaki-Kalaitzaki et al., 2005) varies from 57.38% in sample 10 to 23.56% in sample 1. Concerning the plasters, the binding material content ranges from 69.08% in sample 7 to 24.34% in sample 2. The binder/aggregate ratio can be obtained by dividing the mass of the mortars passing the 0.125 mm sieve by the mass retained by the same sieve. The grain size

Table 3. Weight fractions (%) after sieving and estimated binding content.

Sample	Sieve aperture (mm)							Binding content
	< 0.063 mm	0.063 mm	0.125 mm	0.250 mm	0.500 mm	1 mm	2 mm	
1	7.84	15.72	12.88	18.28	14.54	15.24	15.38	23.56
2	15.58	8.76	18.62	17.50	24.44	15.20	0.00	24.34
3	26.64	5.72	6.98	27.74	17.22	7.56	8.12	32.36
4	23.48	4.82	6.90	31.04	19.98	8.04	5.82	28.30
5	29.00	4.22	4.94	30.80	17.70	6.14	7.12	33.22
6	21.66	3.42	5.96	12.22	20.86	27.44	8.52	25.08
7	61.42	7.66	2.64	2.80	2.66	12.36	10.42	69.08
8	34.26	2.90	4.44	9.16	19.26	24.14	6.10	37.16
9	8.00	24.40	9.92	14.84	17.36	23.36	1.96	32.40
10	52.92	4.46	4.36	6.22	12.60	15.72	3.60	57.38
11	43.24	6.80	8.12	11.42	15.34	12.48	2.86	50.04
13	39.18	9.26	10.10	19.42	20.96	0.60	0.00	48.44
14	37.16	2.48	5.28	19.70	31.52	3.56	0.12	39.64
17	52.24	1.44	3.60	12.64	10.76	9.72	9.64	53.68
18	27.86	1.78	1.66	14.98	33.98	11.38	8.36	29.64
19	12.76	26.38	6.58	6.62	1.64	23.72	22.04	39.14
20	43.18	4.44	1.76	14.26	10.02	10.34	16.56	47.62
21	33.68	10.88	5.84	11.16	31.56	6.98	0.00	44.56
22	51.22	9.06	6.08	2.98	16.36	14.68	0.04	60.28
23	32.22	7.50	6.58	13.02	18.04	13.64	8.94	39.72

distribution of the mortars enables estimation of the binder/aggregate ratio from 1:3 in renders 1 and 6 and in plasters 2 to 2:1 in plaster 7. A high ratio binder/aggregate (3:2) has been found also in render 10 and in plaster 22.

Chemical characterization of the mortars (Mapei's Technical Report©)

The overall results of the analysis on the mortars are shown in Tables 4-5. Apart from the FT-IR data, the other values come from the Mapei's Laboratory Analysis Report©. The alite/belite (C_3S/C_2S) ratio was estimated by applying the Rietveld method to the XRD data obtained from the analysis on the finest fraction (passing the 0.063 mm sieve) that can be considered the richest in binder content. The percentages of $CaSO_4 \cdot 2H_2O$, organic fraction (ORG. in the Tables 4-5), $Ca(OH)_2$, and calcium carbonate/calcium magnesium carbonate were calculated by TGA. According to these results it is possible to find that in most cases the binder of the mortars is made of Portland cement (samples 1, 3, 8, 13 and 19 for the renders and samples 2, 5, 9, 14, 20, 22 and 23 for the plasters). Samples 6 and 7 are made of natural hydraulic lime, as declared by the producer. Samples 10, 11, 17 and 18 are composed of aerial lime and blast-furnace slags in accordance with the specifications of the technical data

Table 4. Overall results of the analysis on the render samples.

Render	Fractions	wt%				FT-IR bands (cm^{-1})		OPC	wt%		
		$CaSO_4 \cdot 2H_2O$	ORG.	$Ca(OH)_2$	$CaCO_3$	Portlandite	Silicates		C_3S	C_2S	C_3S/C_2S
1	Total	0.19	0.04	1.07	4.70	3642.42	1160.10-1116.43-1038.47-925.60				
	< 0.063 mm	0.67	0.12	7.40	10.93	3642.60	1170.26-1118.66-922.03	17.4	54.7	7.6	7.2
3	Total	0.38	0.14	1.44	28.14	3643.08	1124.96-996.83				
	< 0.063 mm	1.00	0.58	7.85	23.25	3642.63	1127.47-925.01	25.2	33.2	19.9	1.67
6	Total	0.00	0.18	3.74	94.23	3642.78	1100.04-997.49-921.25				
	< 0.063 mm	0.00	0.95	17.97	41.20	3642.53	1106.56-996.50-912.81	not present	24.6	69.9	0.35
8	Total	0.00	0.19	0.37	73.41	3642.84	1126.15-930.32				
	< 0.063 mm	0.00	0.14	1.56	25.84	3642.43	1126.58-928.80	26.4	52.8	12.7	4.16
10	Total	0.00	0.07	2.22	53.77	3642.63	969.42				
	< 0.063 mm	0.62	0.07	5.02	27.68	3642.26	961.36	not present			
13	Total	1.86	5.95	9.17	11.61	tr	1115.63-1038.47-1005.69-918.27				
	< 0.063 mm	2.63	6.89	8.80	21.41	3643.36	1142.94-1110.17-1008.05-914.40	25.2	43.2	21.7	1.99
17	Total	0.00	0.53	2.34	12.98	3642.85	976.97				
	< 0.063 mm	0.00	0.23	7.98	9.16	3642.50	965.07	not present			
19	Total	0.72	0.14	0.00	8.43	3641.31	1122.81-941.30				
	< 0.063 mm	0.86	0.34	0.00	6.43	tr	1122.24-932.83	32.0	44.2	25.00	1.77
21	Total	0.48	2.42	0.00	87.44*	3643.35	1111.95-1028.65				
	< 0.063 mm	0.62	2.86	0.00	75.81*	3641.21	1108.46-1029.05	not present	6.2	5.5	1.13

* = dolomite.; tr = traces; OPC = Ordinary Portland Cement; ORG. = organic; C_3S = tricalcium silicate (alite); C_2S = dicalcium silicate (belite).

Table 5. Overall results of the analysis on the plaster samples.

Plaster	Fractions	wt%				FT-IR bands (cm^{-1})		OPC	wt%		
		$CaSO_4 \cdot 2H_2O$	ORG.	$Ca(OH)_2$	$CaCO_3$	Portlandite	Silicates		C_3S	C_2S	C_3S/C_2S
2	Total	0.48	0.14	2.47	63.02	3642.75	1164.61-1099.67-1040.37-939.72				
	< 0.063 mm	1.24	0.26	8.76	28.83	3642.39	1150.11-918.76	20.4	39.3	10.8	3.64
4	Total	0.62	0.14	6.25	30.16	3642.89	1124.25-1003.23-936.49		39.3	10.8	3.64
	< 0.063 mm	3.06	0.54	27.42	26.75	3642.52	1127.34-998.01-911.72	12.1	39.3	10.8	3.64
5	Total	1.10	0.20	1.81	23.50	3642.79	1128.72-996.74-926.12				
	< 0.063 mm	1.96	0.40	9.87	21.73	3642.7	1127.49-995.55-910.61	26.0	59.2	11.5	5.15
7	Total	0.00	0.40	13.73	18.07	3642.96	1058.49				
	< 0.063 mm	0.00	0.35	22.53	20.77	3642.55	999.45	not present	2.4	34	0.07
9	Total	0.00	0.03	0.49	84.50	3642.52	1034.04-932.12				
	< 0.063 mm	0.48	0.28	1.73	54.18	3642.51	1126.08-1034.04-925.33	15.5	29	4.4	6.59
11	Total	0.00	0.10	2.22	66.52	3642.85	1162.24-971.90				
	< 0.063 mm	0.00	0.30	6.70	30.48	3642.2	956.84	~2	5.1	3.2	1.59
14	Total	1.15	1.93	0.00	10.86	3643.21	1114.82-931.02				
	< 0.063 mm	2.77	3.70	0.00	22.68	3642.5	1119.94-916.65	26.0	50.9	20.9	2.43
18	Total	0.00	0.14	3.41	6.98	3643.25	985.51				
	< 0.063 mm	0.00	0.19	10.11	4.66	3642.64	953.88	not present			
20	Total	0.67	0.84	1.40	35.82		1098.86-987.06				
	< 0.063 mm	1.24	0.90	1.19	66.32		1160.65-931.82	17.1	16.8	5.3	3.17
22	Total	0.76	0.82	0.00	59.58*	3641.49	1099.18-1010.76-923.13				
	< 0.063 mm	2.25	1.39	0.95	42.31*	3641.48	1100.48-1011.38-921.25	19.2	44.3	8.7	5.09
23	Total	0.72	0.42	0.00	84.11*	3644.41	1025.94				
	< 0.063 mm	1.62	0.46	1.15	63.35*	3641.44	1011.09-914.26	9.6	28	10	2.8

* = dolomite.; tr = traces; OPC = Ordinary Portland Cement; ORG. = organic; C_3S = tricalcium silicate (alite); C_2S = dicalcium silicate (belite).

sheet. The presence of blast-furnace slags was estimated by using the amounts of Al and Mn, determined by ICP-AES, as markers. At last samples 4 and 21 are composed by natural hydraulic limes with additives (NHL-Z).

FT-IR spectroscopy was used to characterize the organic fraction of the mortars. The organic materials found in the mortars are generally made of VAC (Vinyl Acetate)/VeoVa (Vinyl Ester of Versatic™ Acid) copolymer mixed with stearate. VeoVa is usually added to improve the water resistance of the mortars (Gomes et al., 2005).

VAC/VeoVa copolymer was found in samples 5, 7, 8, 13, 14, 20 and 21 (Figure 1). The percentages of copolymer added to the mortars vary from 0.2% in samples 5 and 8 to 8.2% in sample 13.

The bands occurring in the spectrum of Figure 1 can be assigned as follows: 3641 cm^{-1} (OH stretching band), 2963-2874 cm^{-1} (CH_2, CH_3 groups stretching bands), 1740 cm^{-1} (C=O stretching), 1435 cm-1 (CH_2, CH_3, CO_3^{2-} bending), 1372 cm^{-1} (C-O stretching), 1238 cm^{-1} (C-O stretching), 1124-1024 cm^{-1} (C-O and CH_2 bending), 944 cm^{-1} (C-C in ester groups), 879 cm-1 (CO_3^{2-} bending), 606 cm^{-1} (C-O in ester group) (Gomes et al., 2005).

pH and conductivity measurements

Table 6 shows the values of pH and conductivity obtained by the measurements on the powders and on the specimens prepared in laboratory. The soluble salts content can be evaluated by measuring the conductivity of the water extracts.

The lowest content of soluble salts in the specimens can be observed in renders 10, 19 and 21, and in plasters 9, 11, 18, 20 and 23. In samples 1 and 8 the conductivity values are consistent demonstrating the presence of significant quantities of soluble salts. The conductivity value is quite anomalous in samples 7, in fact in the mortar 808 $\mu S \cdot cm^{-1}$ was obtained whereas in the powder of the specimen the value is 140 $\mu S \cdot cm^{-1}$.

The pH values clearly indicates the carbonation process in the aerial lime mortars (samples 10, 11, 17 and 18) and also in sample 21 an NHL-Z mortar. In the other cases, a slow setting can be hypothesized on the basis of the pH values measured after 28 days after the specimens' preparation.

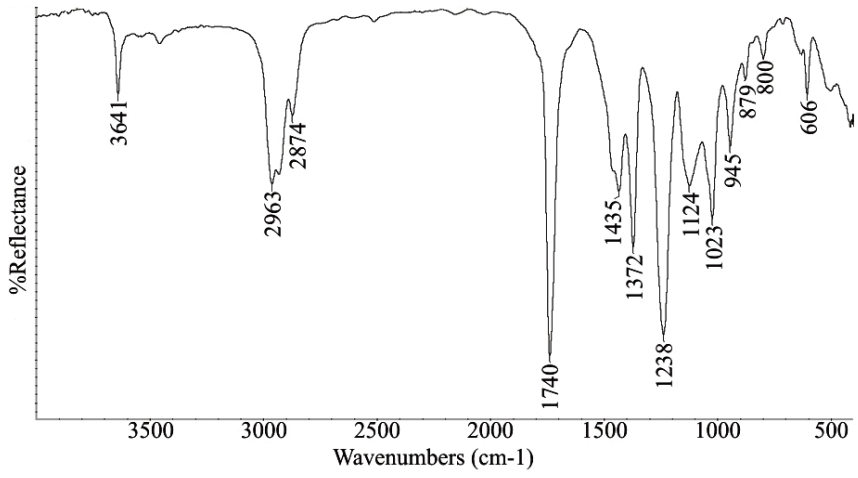

Figure 1. Infrared spectrum of the extract in organic solvent of sample 13. The spectrum was obtained in DRIFT modality.

Table 6. pH and conductivity values measured on the mortars and on the specimens.

Sample	pH		Conductivity (μS·cm-1)	
	Mortar	Specimen	Mortar	Specimen
1	10.48	10.41	465	303
2	10.33	9.93	327	133
3	11.02	10.07	442	236
4	11.00	10.15	381	252
5	10.30	10.22	319	227
6	10.98	10.12	428	241
7	11.44	9.42	808	140
8	10.47	10.55	526	425
9	10.06	9.13	243	95
10	10.38	7.98	158	106
11	10.49	8.19	176	101
13	10.91	9.84	349	194
14	11.02	9.83	320	184
17	10.95	8.61	250	102
18	10.55	7.69	145	95
19	10.24	9.03	310	103
20	9.36	8.98	102	93
21	9.31	7.81	90	91
22	10.65	8.73	197	114
23	9.98	8.50	106	104

Colour measurements

The results of the colour measurements are reported as L*, a* and b* coordinates (Table 7). Moreover the chromatic differences have been calculated to evaluate the changes in colour between the powders and the specimens. In fact, it is important to know the final colour of the mortars, after setting, especially in the case of plasters used in repairing ancient masonry mortars. By observing the data of Table 7, it is possible to assess that in most samples the total colour differences are quite small, anyhow $\Delta E^* < 3$ that is considered by some authors as the limit of colour changes detectable by the human eye (Lo Monaco et al., 2011). The greatest colour variations after setting can be observed in samples 19, 18, 5, 13, and 22 and they are mainly due to the changes in L* coordinate. L* undergoes both significant increase (samples 19 and 22) and decrease (samples 5, 13 and 18).

These findings put in evidence that the colour of the mortars can result quite different after the setting with respect to the powder. For this reason a colour control test should be performed before applying a restoration plaster to repair an historical mortar.

Performance characteristics of the restoration mortars

Concerning the capillarity water absorption action on the renders, two opposite cases are clearly visible in the Figure 2: sample 10, characterized by the highest capillarity water absorption, and sample 13 which exhibits the lowest one. Sample 10 is a mortar made of aerial lime and blast-furnace slags whereas sample 13 is a render based on Portland cement as binder. On the other hand, sample 19, also based on Portland cement, exhibits good capillarity water absorption. According to these results, it is clear that the presence of cement is not an index of capability to absorb water by capillarity. In fact sample 19, based on Portland binder, has good capillarity water absorption whereas sample 6 which is a NHL mortar has a quite low absorption.

Figure 3 shows the water absorption as function of time for the plasters. In this case, two main group can be distinguished in the figure: a group of plasters with low capillarity absorption including Portland based mortars and another group including air lime mortars (samples 11 and 18), NHL (sample 7) and Portland based mortars (samples 2 and 5).

The capillarity water absorption coefficient (CA, $mg \cdot cm^{-2} \cdot s^{-½}$), calculated according to the specifications of the UNI 10859, varies from 1.06 in sample 6 to 9.49 in sample 10 (Table 8).

It is worth stressing that the capillarity water

Table 7. Average values of the L*, a* and b* coordinates of the powders and of the specimens and colour differences between specimens and powders

Sample	L*		a*		b*		ΔL*	Δa*	Δb*	ΔE*
	Powder	Specimen	Powder	Specimen	Powder	Specimen				
1	55.05	57.14	-0.54	-0.19	8.37	6.37	2.09	0.35	-2.00	2.91
2	67.12	66.88	2.24	3.19	20.27	20.10	-0.24	0.95	-0.17	0.99
3	80.07	76.62	-0.19	-0.04	10.26	11.31	-3.45	0.15	1.05	3.61
4	80.61	80.66	-0.27	-0.08	9.80	9.81	0.05	0.19	0.01	0.20
5	77.44	71.48	0.10	0.66	11.25	13.15	-5.96	0.56	1.90	6.28
6	89.56	88.91	-0.16	0.15	5.50	5.94	-0.65	0.31	0.44	0.84
7	86.74	88.03	-0.37	0.48	5.88	3.74	1.29	0.85	-2.14	2.64
8	88.83	85.61	0.01	0.70	6.88	8.00	-3.22	0.69	1.12	3.48
9	90.54	86.84	0.54	1.15	7.62	9.93	-3.70	0.61	2.31	4.40
10	86.85	86.20	0.06	0.29	6.38	7.28	-0.65	0.23	0.90	1.13
11	86.38	87.52	-0.14	0.28	6.17	6.97	1.14	0.42	0.80	1.45
13	79.80	74.87	9.60	11.89	7.26	10.50	-4.93	2.29	3.24	6.33
14	72.94	76.88	-0.50	-0.15	11.65	11.74	3.94	0.35	0.09	3.96
17	88.46	84.67	-0.18	-0.29	5.15	6.80	-3.79	-0.11	1.65	4.14
18	85.50	76.39	-0.31	-0.27	4.52	5.39	-9.11	0.04	0.87	9.15
19	59.52	69.48	-0.71	-0.20	6.80	5.04	9.96	0.51	-1.76	10.13
20	81.16	76.46	-0.44	-0.17	5.48	7.00	-4.70	0.27	1.52	4.95
21	77.09	74.30	2.94	3.42	12.88	13.31	-2.79	0.48	0.43	2.86
22	70.95	77.44	0.75	1.23	11.19	10.02	6.49	0.48	-1.17	6.61
23	74.75	73.85	0.29	0.83	11.79	10.42	-0.90	0.54	-1.37	1.73

absorption coefficients of the examined restoration mortars are generally lower than those observed in the literature for historical mortars (Maravelaki-Kalaitzaki et al., 2005) and for mortar samples prepared in laboratory (Veiga et al., 2004), suggesting the suitability of the tested products in the restoration field (Pecchioni et al., 2008). In fact, it would be better that the ancient mortar preferably absorbs and then transfers the water, with the possible soluble salts, to the modern restoration mortar which will have a sacrificial function in case of localised deterioration (Carrington and Swallow, 1996) (Marques et al., 2006).

The results of the imbibition and drying tests for the renders are shown in Figures 4-5. Samples 10 (aerial lime and blast-furnace slag) and sample 21 (NHL-Z) reach the highest imbibition values within the first hour. Between the mortars containing Portland cements as binder, sample 8 reaches an imbibition value comparable to those of samples 10 and 21.

Sample 13, which exhibited very low capillarity water absorption, shows also low imbibition capability, as visible in the first part of the curve. Samples 10 and 21 also have a good drying feature whereas sample 19 has a particularly poor drying capability.

Regarding the plasters, sample 22 (Portland binder) shows a very high imbibition value together with sample 11, a mortar based on air lime and blast-furnace slag (Figure 6), this

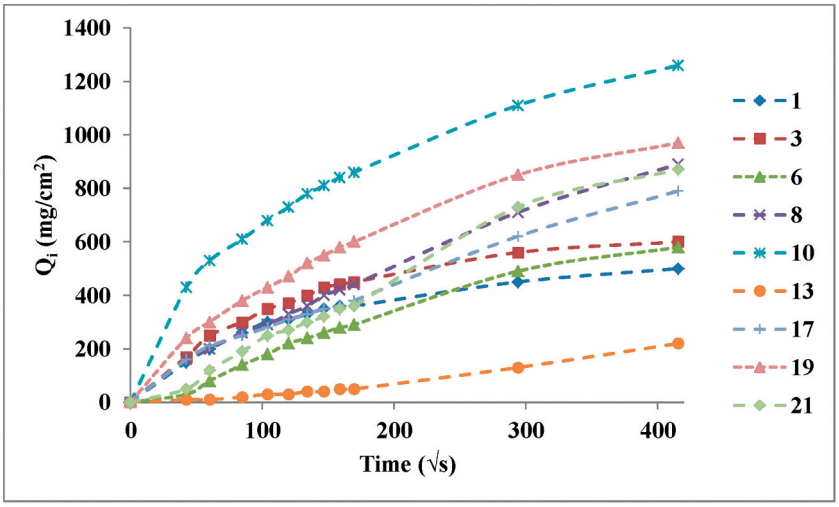

Figure 2. Capillarity water absorption action of the renders as function of time.

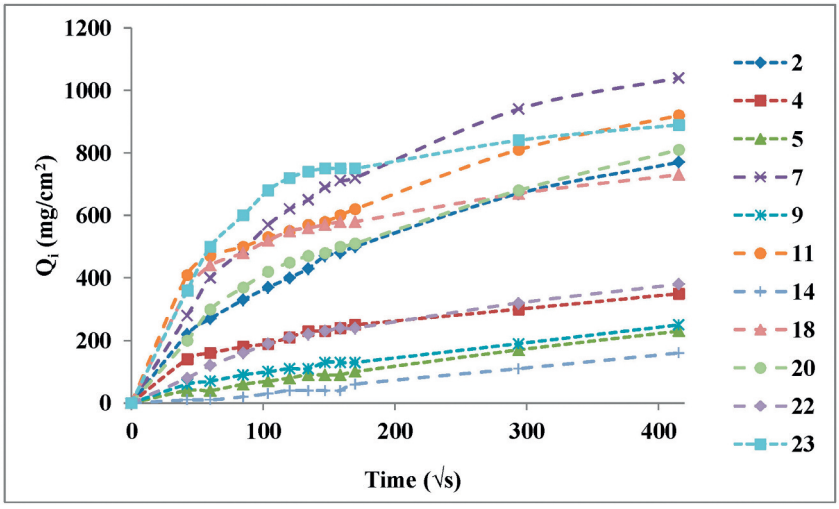

Figure 3. Capillarity water absorption action of the plasters as function of time.

feature is probably due to the macro-porous nature of these two plasters (see Table 2). Samples 4, 9 and 14 (based on Portland binder) exhibit the lowest imbibition values. The highest rate of drying has been observed in samples 2, 11 and 22 (Figure 7).

Drilling resistance measurements

The Drilling Resistance Measurement System (DRMS) was developed as an attempt to obtain a portable system capable of carrying out minor-destructive tests in laboratory and in situ based on microdrilling (Cheong et al., 1999) (Tiano et

Table 8. Capillarity water absorption coefficient (CA) calculated for the examined mortars.

Sample	CA (mg/cm²) s½
1	3.46
2	4.85
3	4.05
4	2.99
5	8.12
6	1.06
7	6.69
8	3.53
9	1.24
10	9.49
11	8.70
13	2.53
14	1.19
17	3.71
18	7.97
19	3.71
20	4.83
21	1.59
22	1.96
23	8.36

al., 2000) (Tiano, 2001). The original objective was to measure continuously and reliably the superficial resistance ("hardness") and the in depth cohesion properties of stone materials in order to evaluate the consolidating performance of conservative treatments (Tiano et al., 2000b). For these reasons it was chosen in the present study to evaluate the mechanical characteristics of the restoration mortars in such a way that can be applied also to the historic mortars.

The drilling resistance measurements put in evidence that in general the renders exhibit higher values of this parameter in respect to the plasters (Figure 8). Moreover, the mortars with high content of Portland binder (samples 1, 8, 13, 14, 19 and 20) show higher values of drilling resistance in comparison with the NHL or aerial lime mortars, apart from render 17 that is an aerial lime mortar with blast-furnace slags. However, the presence of Portland doesn't involve always a high drilling resistance as can be observed in samples 2, 5, 9, 22 and 23.

For sample 7 it was no possible to evaluate the drilling resistance due to its fragile character.

Conclusions

This paper reports the results of the study of 20 commercial dehumidifying mortars used in the restoration of historical buildings. The study would be a little contribution to the knowledge of some diffused products especially concerning their performance characteristics in order to avoid their possible unsuitable use in the conservation treatments.

The characterization of the commercial products allowed to obtain correct information on the composition of the mortars and in some cases disagreements with the composition declared by the supplier, especially regarding the presence of Portland cement as binder and the soluble salts' content. In fact, the results of the total conductivity showed that the mortars are generally affected by high content of soluble salts.

Colour differences between the specimens and the powders showed that in most samples the total colour differences are quite small. The greatest colour variations after setting, observed in five samples, are mainly due to the changes in L* coordinate. L* undergoes significant changes. These findings put in evidence that the colour of the mortars can result quite different after the setting with respect to the powder. For this reason a colour control test should be performed before applying a restoration plaster to repair an historical mortar.

The laboratory tests performed on the samples prepared according to the specifications supplied

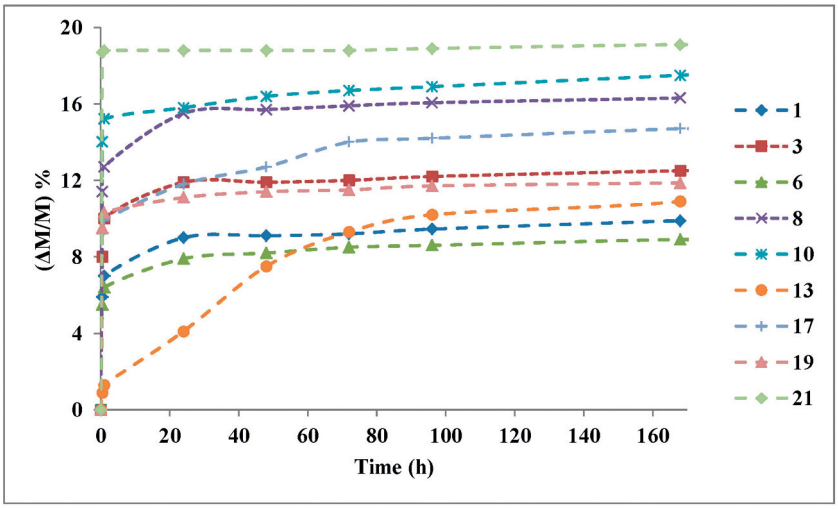

Figure 4. Result of the imbibition test on the renders.

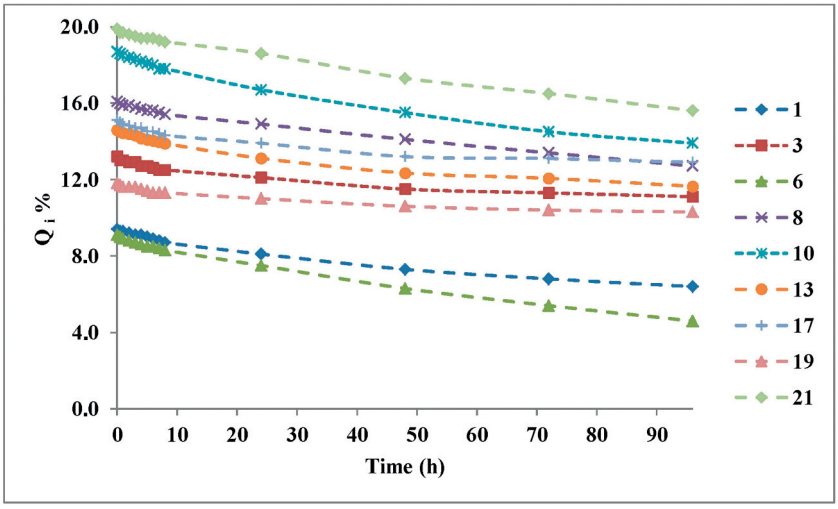

Figure 5. Result of the drying test on the renders.

in the technical data sheets, showed that in general the mortars exhibit low capillarity action water absorption, if compared with the traditional ancient and modern mortars. Moreover, the transpiring feature is independent from the presence of cement in the mortars.

The micro drilling resistances are generally higher in the renders than in the plasters but they are independent from the presence of Portland binder. For example, sample 17, an aerial lime with blast-furnace slags, is characterized by a good drilling resistance if compared with sample 19 that exhibits the highest value of this parameter.

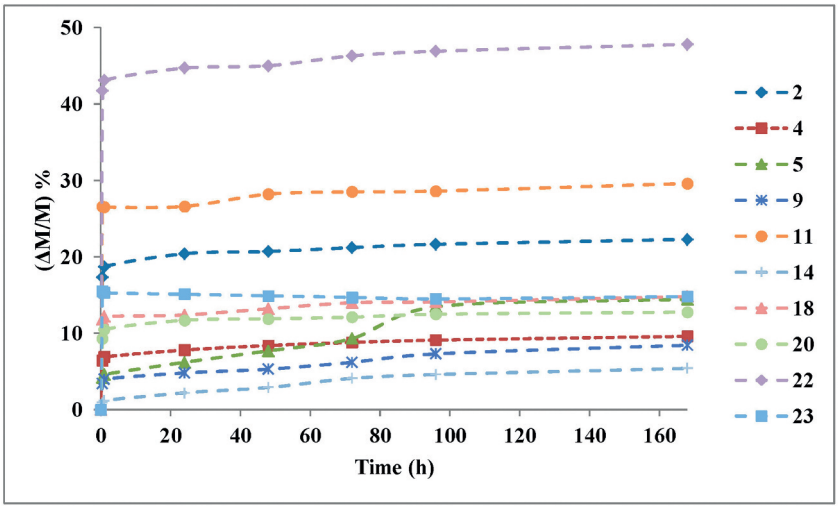

Figure 6. Result of the imbibition test on the plasters.

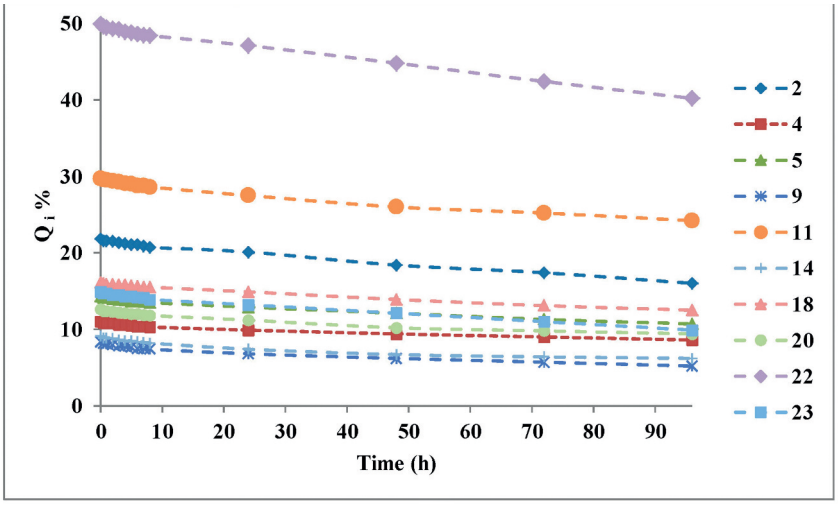

Figure 7. Result of the drying test on the plasters.

Considering the performance characteristics required to a dehumidifying mortar, the examined samples not always meet the requisites briefly described in the introduction, especially concerning the presence of cement and of soluble salts. As regards the water behaviour of the examined mortars, low capillarity action water absorption was generally observed even if the values of the coefficients are quite variable ranging from 1.06 (mg/cm²) s½ in sample 6 to 9.49 (mg/cm²) s½ in sample 10.

In conclusion, this study demonstrates that the commercial products may have very different chemical, physical and mechanical characteristic

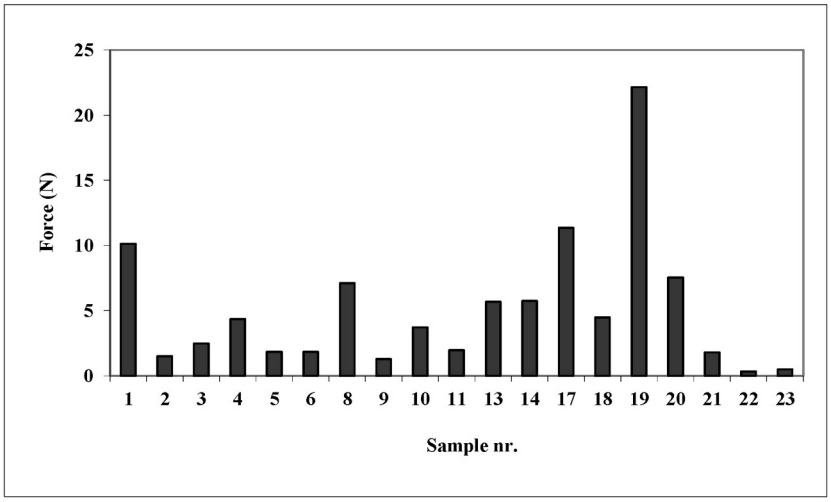

Figure 8. Micro drilling resistance of the specimens.

even if they are recommended for the same or similar applications. This result suggests the necessity to examine the restoration mortars, as well as the original ones, before applying them to repair or replace historical mortars in order to avoid conservative problems due to the restoration itself.

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References

Carrington D. and Swallow P. (1986) - Limes and lime mortars - part two. *Journal of Architectural Conservation*, 1, 7-22.

Cheong M.S., Cho D.W. and Ehmann K.F. (1999) - Identification and control for micro-drilling productivity enhancement. *International Journal of Machine Tools & Manufacture*, 39, 1539-1561.

Elert K., Rodriguez-Navarro C., Sebastian Pardo E., Hansen E. and Cazalla O. (2002) - Lime mortars for the conservation of historic buildings. *Studies in Conservation*, 47(1), 62-75.

EN 15886 (2010) - Conservation of cultural property - Test methods - Colour measurement of surfaces. Brussels Belgium.

Gomes C.E.M., Ferreira O.P. and Fernandes M.R. (2005) - Influence of Vinyl Acetate - Versatic Vinylester Copolymer on the Microstructural Characteristics of Cement Pastes. *Materials Research*, 8(1), 53-56.

Izaguirre A., Lanas J. and Álvarez J.I. (2009) - Effect of water-repellent admixtures on the behaviour of aerial lime-based mortars. *Cement and Concrete Research*, 39, 1095-1104.

Lanas J. and Álvarez J.I. (2003) - Masonry repair lime-based mortas: factors affecting the mechanical behaviour. *Cement and Concrete Research*, 33, 1867-1876.

Lo Monaco A., Marabelli M., Pelosi C. and Picchio R. (2011) - Colour measurements of surfaces to evaluate the restoration materials. In O3A: Optics for Art, Architecture, and Archaeology III. (eds): L. Pezzati and R. Salimbeni, SPIE, Volume 8084, Washington, P1-P14.

Maravelaki-Kalaitzaki P., Bakolas A., Karatasios I. and Kilikoglou V. (2005) - Hydraulic lime mortars for the

restoration of historic masonry in Crete. *Cement and Concrete Research*, 35, 1577-1586.

Marques S.F., Ribeiro R.A., Silva L.M., Ferreira V.M. and Labrincha J.A. (2006) - Study of rehabilitation mortars: Construction of a knowledge correlation matrix. *Cement and Concrete Research*, 36, 1894-1902.

NORMAL 7/81 (1981) - Assorbimento d'acqua per immersione totale e determinazione della capacità di imbibizione, CNR-ICR, Roma.

NORMAL 26/87 (1987) - Caratterizzazione delle Malte da Restauro, ICR-CNR, Roma.

NORMAL 29/88 (1988) - Misura dell'Indice di Asciugamento (Drying Index), ICR-CNR, Roma.

NORMAL 43/93 (1993) - Misure colorimetriche di superfici opache, ICR-CNR, Roma.

Papayianni I., Pachta V. and Stefanidou M. (2013) - Analysis of ancient mortars and design of compatible repair mortars: The case study of Odeion of the archaeological site of Dion. *Construction and Building Materials*, 40, 84-92.

Pecchioni E., Fratini F. and Cantisani E. (2008) - Le malte antiche e moderne: tra tradizione ed innovazione. Pàtron Editore, Bologna (Italy), 124-125.

Schueremans l., Cizer Ö., Janssens E., Serré G. and Van Balen K. (2011) - Characterization of repair mortars for the assessment of their compatibility in restoration projects: Research and practice. *Construction and Building Materials*, 25, 4338-4350.

Tiano P., Filareto C., Ponticelli S., Ferrari M. and Valentini E. (2000a) - Drilling force measurement system, a new standardisable method to determine the stone cohesion: prototype design and validation. *International Journal for Restoration of Buildings and Monuments*, 6, 115-132.

Tiano P., Delgado Rodrigues J., De Witte E., Vergès-Belmin V., Massey S., Snethlage R., Costa D., Cadot-Leroux L., Garrod E. and Singer B. (2000b) - The conservation of monuments: A new method to evaluate consolidating treatments. *Internationale Zeitschrift fur Bauinstandsetzen und Baudenkmalpflege*, 6(2), 133-150.

Tiano P. (2001) - The use of microdrilling techniques for the characterization of stone materials. In On-Site Control and Non-Destructive Evaluation of Masonry Structures and Materials. (eds): L. Binda and R.C. de Vekey, International RILEM Workshop, Mantova (Italy), 203-212.

UNI11087 (2003) - Cultural Heritage - Natural and artificial stones - Determination of soluble salts content, Milano (Italy).

UNI10859 ( ) Cultural Heritage - Natural and artificial stones - Determination of water absorption by capillarity, Milano, 2000.

Veiga M.R., Magalhães A.C. and Bokan-Bosilikov V. (2004) - Capillarity tests on historic mortar samples extracted from site. Methodology and compared results. In: Proceedings of the 13th International Brick and Block Masonry Conference. (ed.) D. Martens, Eindhoven University of Technology, 1-10.

Yang F., Zhang B. and Ma Q. (2010) - Study of Sticky Rice-Lime Mortar Technology for the Restoration of Historical Masonry Construction. *Accounts of Chemical Research*, 43(6), 936-944.

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