Achieving a suitable hygro-mechanical compatibility between the substrate and the repairing mortars in historic masonry constructions.

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Abstract. It is essential the study of restoration mortars on historical construction, because these must provide protection against harmful agents and must be sacrificable, not to cause damage on the primitive materials in case of removal by a new valorization. Repair mortars must have physical, chemical and mechanical compatibility with the substrate where they are applied and their mechanical strength must be similar to that of the wall where they are applied. The presence of water generates serious deterioration in the constructions, affecting its durability and causing greater maintenance and replacement costs for damaged materials. The characteristics of the repair mortars must be such that they do not allow water to enter the external faces and allow the evaporation of the water on internal faces. In this work the characteristics of compressive strength of different composition mortars have been evaluated; absorption, speed of capillary suction and air permeability. The results obtained can facilitate the choice of mortars for the rehabilitation of heritage buildings.

Keywords: mortar, compatibility, strength, capillarity, permeability, masonry.

1 Introduction

In the studies of value of heritage buildings, existing and repair materials must be analyzed, so that there are no incompatibilities between them, and they do not cause damages greater than those of normal behavior. In the restoration of historic buildings, preserve the original materials; and that replacement materials do not harm primitive construction is paramount argue Válek et al (2012).

In the case of historical mortars, the originals should be kept as possible, because in them the technology, technique and construction history of the time in which they were made are documented. If it is necessary to replace them in some places, they must have similar characteristics to the primitives, and have chemical, physical and mechanical compatibility with the support material. Likewise, restoration mortars must be designed so that they do not damage the historical construction, they must be “sacrificable”, that is, they must be degraded before the support material (Gisbert Aguilar et al, 2011, Domizio et al, 2016).

Masonry mortars have important and distinct properties depending on whether they are fresh or hardened. In the fresh state the properties that determine its aptitude in work correspond to the workability and water retention. In the hardened state the properties that influence the behavior of the masonry are: adhesion, durability, elasticity and compressive strength.

Methods have not always been developed to quantitatively evaluate all the behavior properties of the mortar, so that traditional specifications are applied as guidance in value enhancement.

A case study that has been monitored since its enhancement in 2015 is a heritage school of cooked ceramic masonry built between the end of the 19th century and the first decade of the 20th century and that has suffered the effect of earthquakes and lack of maintenance (Maldonado et al, 2011). Since its rehabilitation, a follow-up of the constructive pathologies is maintained and since 2017 an environmental monitoring of ambient temperature and humidity inside the premises and outside the school, which has allowed a mapping of the surface dampness in all the walls of the school as indicated in Domizio et al (2018), observing the importance of new uses and air conditioning technologies that impact historic masonry and its mortars.

2 Materials and Methods

2.1 Physical-mechanical characterization of mortars

After the analysis of the pathologies found in the restoration mortars, the proportionsof mortars were studied. Due to the lack of national regulations for restoration mortars, is applied national regulations CIRSOC 501 (2007) and 501 – E (2007), INPRES CIRSOC 103 Part III (2016) and the local regulation CCSR´87 (1987). Mortar cubic specimens have been made, with normalized volume proportioning; then, they have been tested for compressive strength at 7, 28 and 56 days. The cement used is Pozzolanic Portland Cement (PPC40), with wide local availability. The water content was determined experimentally, until a workable mixture was obtained; with water/cement ratios ranging from 0.56 to 3.02. In addition to the normalizedproportioning, three more dosages were prepared for mortars without lime, increasing a part of sand, from the typical 1: 3 dosage, until reaching 1: 6, to contrast the dosage with lime, 1 cement: 1 lime: 6 sand.

Table 1 shows the proportions used, the w/c ratio, the designation according to the regulations analyzed and the test identification; and finally, the compressive strengths grouped by ranges, according to the values given in the INPRES CIRSOC 103-Part III (2016) regulation and in Fig. 1, the results obtained are plotted.

Table 1 Summary dosages mortar volume and test results.

Test	Proportions				Standard Quality		Compressive Strength (MPa)		
	Cement	Lime	Sand	w/c ratio	CIRSOC 501 IC 103-III	CCSR 1987	7 days	28 days	56 days
PPC40 1:3	1	-	3	0.56	Elevate	M3	18.2	29.9	33.1
PPC40 1:4	1	-	4	0.78	-	-	11.5	15.2	19.0
PPC40 1:5	1	-	5	0.89	-	-	8.9	13.3	17.4
PPC40 1:6	1	-	6	1.11	-	-	5.3	8.3	9.5
PPC40 1:0.5:4	1	0.5	4	0.89	Inter-mediate	-	6.5	11.3	16.7
PPC40 1:1:6	1	1	4	1.00	Normal	M2	7.3	12.2	15.4
PPC40 1:1.5:9	1	1.5	9	1.78	-	-	2.7	4.7	6.0
PPC40 1:3:9	1	3	9	2.22	-	-	1.7	3.2	4.6
PPC40 1:4:9	1	4	12	3.02	-	M3	1.3	2.1	3.1

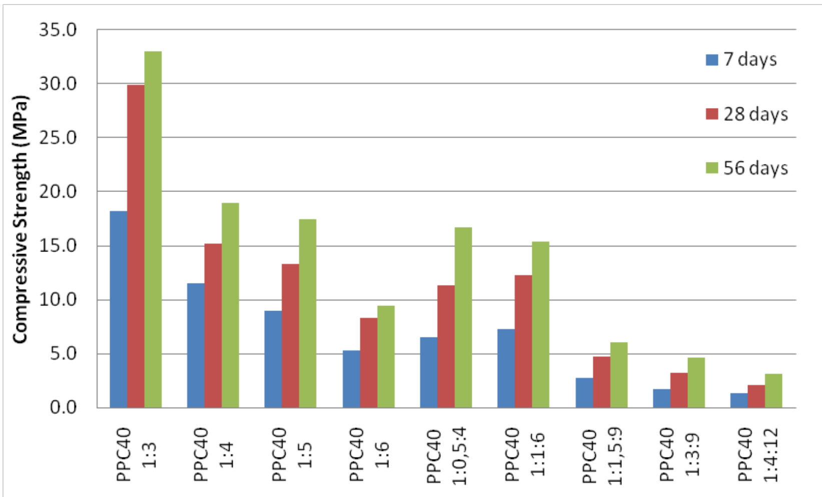
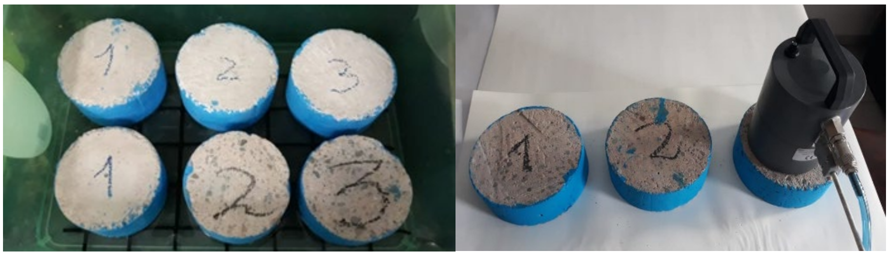


Fig. 1 Results of the compressive strength of different mortars studied

To characterize the behavior of repair mortar and substrate, the capillary suction test was conducted that guides the level of impermeability of the mortar (IRAM, 2004). Fig. 2.a shows the laboratory test layout and the result of it in Fig. 3.

Two types of mortar samples were made, molded discs (M) and sawn discs (S) of 100, 110 and 150 mm in diameter and 50 mm high. The sorption slope is the same for all specimens, but the sorptivity increases more in the molded samples than the sawn ones and decreases with the diameter.

The air permeability test studied by Ebensperger and Torrent (2009) and Romer (2005), which allows guidance on the quality of the mortar used as indicated by Dobel et al (2013), has been used to verify the behavior of the mortar-mortar interface (Fig. 2b and 4).



a) b)

Fig. 2 Provision of specimens for suction test (a)and air permeability test (b).

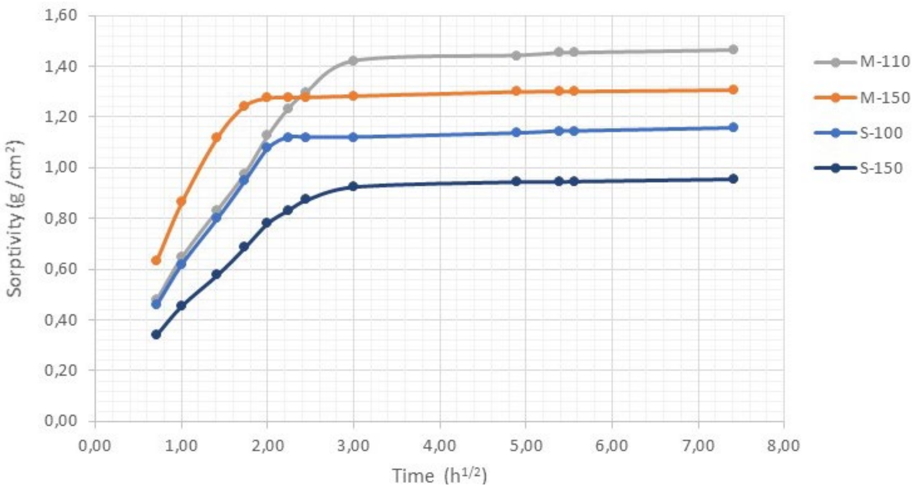


Fig. 3 Results of suction test

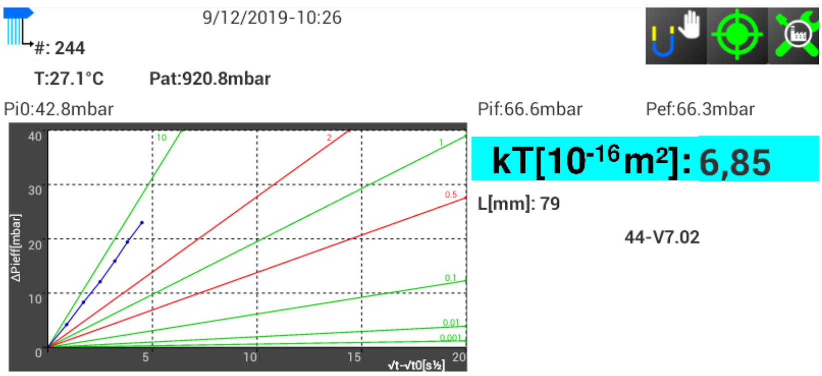


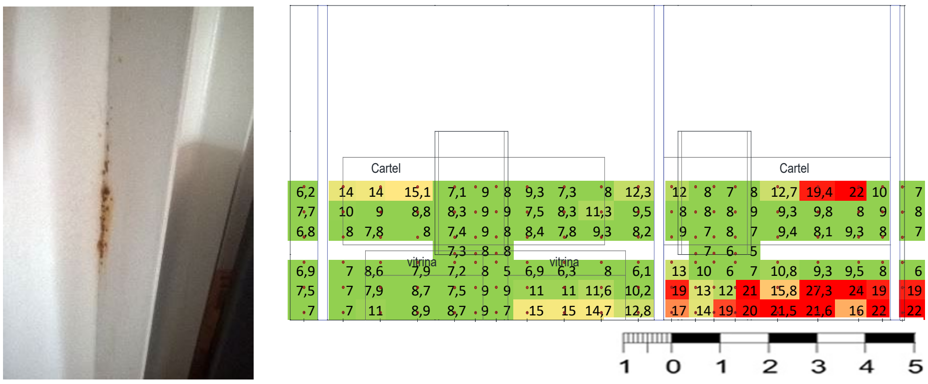
Fig. 4 One measuring test on the screen of equipment (b).

2.2 Environmental monitoring and surface moisture mapping

The use of cementitious plasters, generated new problems in the rehabilitated building, because there are chemical and physical incompatibilities with the heritage masonry. Over the years, large concentrations of sulfate salts were deposited inside the walls. The combination of these salts present in the masonry, the cement hydration compounds of the new plasters, high humidity conditions and low temperatures during their placement; made possible the formation of thaumasite and ettringite, two salts that cause the appearance of efflorescence; and then, expansion, cracking and disintegration in mortars (Maldonado et al, 2017) (Fig. 5).

a) b) c)

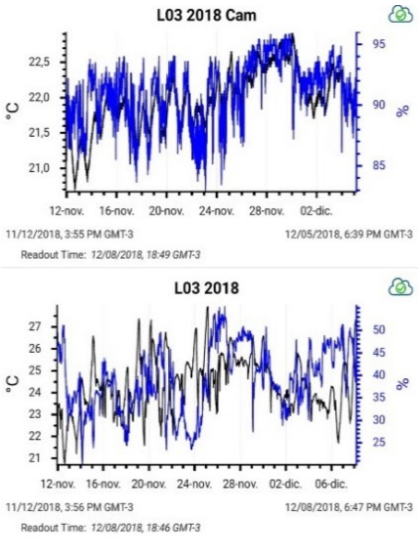
Fig. 5 South Wall #3 State in a) 2017 b) 2018 c) 2019



a) b)

Fig. 6 Corrosion in metal reinforcement profiles (a). View of the south wall Local 3, with surface moisture mapping (b)

The monitoring of temperatures and humidity was carried out with HOBO brand dataloggers, inside the premises, inside the ventilation chambers, and also outside. It was verified that the relative humidity in the ventilation chambers of the premises was around 80-90% (Fig. 7a).The reason for the high humidity in the ventilation chamber of a room, after a visual inspection of it, was that the floor was very wet, close to the foundation beam of the south wall, which borders an old construction and in poor building conditions. The chemical analysis of the soil detected the presence of escherichia-colii that corresponds to contamination due to loss of sewage effluents.



a)

b)

Fig. 7 Humidity and temperature data in the ventilation chamber of room 3 and in the habitable zone of the same room (a). Photograph of the interior of the ventilation chamber of room 3 (b).

The value of the internal humidity of the party walls with Tramex humidimeter has also been verified, exceeding the average values of 99% relative humidity, which indicates the saturation of the masonry and the consequent problem that affects the mortars of coatings, since the presence of soluble salts is located above the level +1.50 m (Fig. 8).

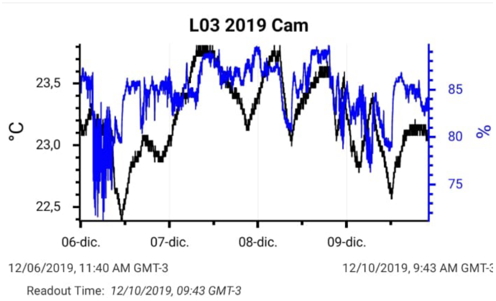
a) b)

Fig. 8 Provision of probes to measure internal wall moisture and measurement (a). Internal humidity measuring point in room 3 (b)

3 Results and Discussions

In the present study, the analysis of the environmental monitoring in the patrimonial construction and the mapping of surface moisture in the walls has been carried out to evaluate the appearance of the new pathologies, after the putting in value and second use of the building. The natural ventilation of the humidity of the chambers is not possible due to the location of the school: between buildings of many floors and with different orientations, and because of the low wind in the city of Mendoza. As a consequence, that moisture contained in the chambers, rises by capillarity in the walls and affects the plasters, in the places where there is concentration of salts, and to the metal profiles, in the areas of greatest humidity in the walls.
The opening of the mouths of the air chambers in summer has shown an effective reduction of the moisture content, a 5% decrease in five days, but they are not compatible with the current uses of the building (museum) such as the use of natural cross ventilation (Fig. 9).

a)



b)

Fig.9 Basement air chamber cover opening (a). Measure of humidity and temperature data in the ventilation chamber of room 3, after opening of the mouths of the air chambers in summer (b).

The study of the compressive strengths of the standarized mortars, dosed in volume, allowed to determine: 29.9 MPa at 28 days, for the pure cementitious mortar, with a dosage of 1: 3 (the minimum resistance of 15 MPa, required in the regulation IC 103-III is doubled). For dosages 1: 4 and 1: 5, the resistance values are similar to each other, close to 15 MPa; and the 1: 6 dosage, has resistance below 10 MPa, at 28 and 56 days.
Lime mortars, Intermediate Quality of CIRSOC 501 and IC 103-III (1 cement: 0.5 lime: 4 sand), M2 of CCSR 1987 and Normal Quality mortar of CIRSOC 501 and IC 103-III (1 cement : 1 lime: 6 sand), have a resistance close to 12 MPa at 28 days, but exceed 15 MPa at 56 days. The M1 dosages of CCSR 1987 (1 cement: 4 lime: 12 sand) and own proposals with 1 cement: 1.5 to 3 lime: 9 sand, obtained resistance less than 5 MPa.

The study of capillary suction and air permeability in mortars made with Pozzolan Portland Cement according to the standard dosages, allowed to obtained the capillary suction speed, around 24 $g/m^2\ s^{1/2}$,and the air permeability coefficient kT, that was greater than $2x10^{-16}\ m^2$; these values indicate high permeability, in relation to results for normal concrete.

4 Conclusions

From the results obtained, it is concluded that:
• The environmental monitoring of a rehabilitated building allows its preservation and helps to understand the appearance of new pathologies.
• In cases of walls that have a capillary elevation of the water, it is not appropriate to use cementitious restoration mortars, especially with the 1: 3 dosage, due to their high resistance, which implies low permeability, with respect to the other dosages but with a great capacity of capillary absorption. It is better in these cases, the use of resistance mortars similar to the original masonry, and that are as permeable as possible, to allow evaporation of the water contained inside the walls to the outside.
• For the case study, if forced ventilation is implemented in the chambers, it is possible to evacuate the moisture contained therein. With this, the ascent of water to the walls would be cut and the appearance of efflorescence and new pitting of corrosion in the profiles of the structural reinforcement would be avoided.

AcknowledgementsThis work has been part of Program PICT 2015-761 supported by the Technological National University of Argentina, National Agency for Promotion of Science and Technology of Argentina and Government of Mendoza. The authors want to thank the University staff, the professionals of preservation of Heritage Bureau of Province of Mendoza and CONICET, that they had made the development of the research program possible.

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