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Behavior of Mortar Coatings Subjected to Extreme Conditions: Lack of Curing and No Substrate Moistening

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Abstract- The mortar coatings are made in several ways: single layer, two layers, with or without roughcast, with industrialized mortar or dosed on site. The coatings dosed on site may contain cement, lime, natural or artificial aggregate and / or additives. The qualities of these coatings link to the quality of the construction. However, coatings, sometimes, are not made in the proper manner, use appropriate materials, or are applied under favorable climatic conditions. Disrespecting any of these conditions, there will be pathologies in the coating. Aiming at these problems, we carried out a research to test the adhesion strength of various types of mortar coatings and to analyze possible pathologies, which may arise when the mortars do not suffer the cure process and the substrate is not previously moistened. Expecting to find the coating that has the best result and to associate the possible causes. The conclusion of this study was that the preparation of the substrate, the technique of applying the coating mortar and the cure are of uppermost importance to assure the quality of the mortar, especially for mortars with additive. The lack of cure affects adhesion directly, but even so, the cement-lime mortar met the standard specifications.

Keywords- *Mortar Coating, Adhesion Strength, Pathologies, Curing of Mortars*

I. Introduction

Mortars can be classified as homogeneous mixtures of inorganic binders (cement or lime), small aggregates (sand) and water, and may contain additives that improve their characteristics. They can be previously prepared as industrialized mortar or dosed in the field [1]. According to [2], mortars made on site are generally composed of natural sand and the binders are Portland cement and hydrated lime.

The mortar coatings are fundamental to ensure the quality of the construction, as they contribute with 30% of the thermal isolation, 50% of the sound isolation, 70% to 100% of the water tightness, resistance to small damages and fire safety, if they are executed correctly [3]. However, if the materials used and the execution of the mortar ratio are not correct, pathologies will appear in the coating [4]. Some pathologies that may be present in the coatings are efflorescence, mold, vesicles, detachments and fissures [5].

The performance of the mortar can be largely associated with rheological characteristics. Such as, the mineralogical nature and aggregate size [6], finishing [7], mechanical resistance from the materials used [8, 9, 10] and the amount of water in the mixture [10]. It is also worth analyze the characteristics of the substrate, the techniques of execution and the climatic conditions of the coating execution, the influence of these factors interfere in the quality of the mortar [11] . Studies have always fixed the material used as the cause of the pathologies, without mentioning other factors such as the substrate, which influences the quality of the coating. It is important to relate the characteristics of both, substrate and mortar, to understand the importance of them on adhesion resistance [12]. To ensure the integrity of completed construction, it is important to conduct regular inspections to verify the performance of the building and to provide solutions for errors that may appear, intended to generate minor impacts to those involved [13, 14]. In this context, the general objective of this research is to carry out a technical-scientific study on adhesion and macrostructure of eight different types of mortar coatings without the adoption of the correct conditions of cure recommended by standard and without previously wetting the substrate.

II. Materials and Methodology

A. Methodology

The following stages compose the methodology used in this study to accrue the worst scenario for the mortar coating:

- First, a residential building was visited in the metropolitan area of Belo Horizonte and was checked the availability of the space for the experiments with the responsible engineer. The engineer provided two walls, which eight parts divided it, for the test of eight different types of mortar coating.
- The engineer and construction workers specified by him aided with the execution of the mortar coating and with the supply of materials. It was used natural and artificial sand, plasticizers additive for preparation of some mixtures in the field and industrialized mortar coating. The cement used was CPII-E-32. To represent the worst exposure

situation, the base was not wetted and it was not cure. The coating was applied directly to the cured roughcast.

- The adhesion strength of each sample was checked according to [15]. The equipment used was the dynamometer, provided by the DEMC (Department of Engineering Materials and Construction) of UFMG, which checked its calibration.

- The results were collected acquiring digital microscope photos, adhesion strength values and cataloging the pathologies found. The characteristics of the coatings, correlating them with the materials used, application form, cure conditions and pathologies found at the date of analysis.

B. Materials

Eight walls were made of different types of mortar coating:

Wall 1: Natural medium sand with fine sand in proportion 60/40%, lime, without additive. The cement, lime and sand ratio was 1:1:6.

Wall 2: Natural medium sand with fine sand in proportion 60/40%, with plasticizer additive 1. The cement and sand ratio was 1:6.

Wall 3: Natural medium sand with 50% of fine sand, with plasticizer additive 1. The cement and sand ratio was 1:6.

Wall 4: Artificial sand and additive plasticizer 2. The cement and sand ratio was 1:6.

Wall 5: Industrialized mortar coating for external coat, adding seven liters of water for each bag, following the manufacturer instructions.

Wall 6: Natural medium sand with 50% of fine sand, with plasticizer additive 1. The cement and sand ratio was 1:6. However, the amount of additive was smaller because cracks appears on wall three.

Wall 7: Artificial sand and additive plasticizer 2. The cement and sand ratio was 1:8.

Wall 8: Artificial sand and additive plasticizer 2. The cement and sand ratio was 1:6.

The plasticizer additive 1 (addition content on the cement mass should be 0.2% to 0.5%) also functions as an air entraining and is recommended for internal and external mortar coating, as it would minimize cracking, retraction and exudation of the mortar, and would decrease the proportion of lime from the mortar. The performance of the product linked closely to the conditions of substrate preparation, climatic conditions and technical knowledge of the worker [16].

The plasticizer 2, in conventional plastering, provides greater adhesion, absence of cracks and less exudation. The supplier indicates that the application surface of the mortar should be with roughcast, cured at least 3 days, and moistened before the application. It also suggests that the mortar coating components ratio should be 1: 6 cement and medium sand [17].

The lime used is CHI additive for mortar laying and mortar coating. The lime incorporates the following characteristics into the coating: reduces water consumption, increases water retention in the curing process, increases the plasticity of the mixture, increases adhesion in the fresh state and save cement.

According to manufacturer, the industrialized mortar is for external coating. It consists of cement, hydrated lime, selected sands and chemical additives. The base of the coating must have a minimum of 28 days if it is reinforced structural masonry structures and should be a moistened surface, only after 3 days the plaster can be applied. The coating must suffer a humid cure for at least 7 days in order to avoid premature drying of the mortar and, for example, cracking and low mechanical resistance. The supplier states that the mortar meets all specifications in [1], including the minimum adhesion strength of 0.3 MPa.

Fig. 1 and Fig. 2 illustrate the walls made for testing and analysis. It is observed that Wall 4 (holes 5 and 7), Wall 5 (holes 2, 3, 4 and 9) and Wall 8 (hole 2) broke even before the test was performed and may be due to the vibration of the equipment at the moment of drilling.

As well pointed out by the suppliers of plasticizers a preparation of substrate is important for the good use of the product. However, aiming for a worse situation, the walls have not undergone moistening of the base and no moist cure, which procedures the companies do not recommend. The recommended ratio 1: 6 cement and medium sand were used on all walls that use the plasticizer (2, 3, 4, 6, 8). Only wall 8 uses a ratio 1: 8 (cement, sand). Cement CPII, is compatible with all two types of products according to the supplier.

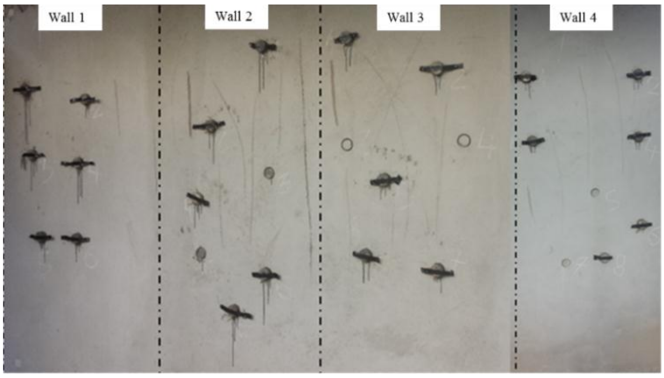

Figure 1. Identification holes in walls 1 to 4

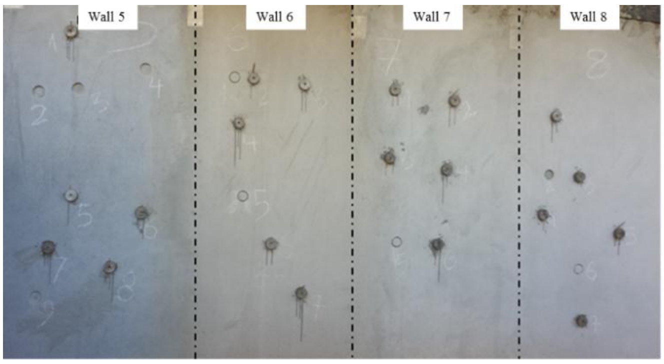

Figure 2. Identification of holes in Walls 5 to 8

III. Results

According to Tab. 1 and Fig. 3 it is possible to observe that the gradation curve of fine sand is a little off the limit established by ABNT NBR 7211:2005 and the fine sand has a higher content (6,8%) of powdery materials compared with the one specified for protected wear concrete (5%). The characteristics of fine and medium sand are according to [18].

The artificial sand has a higher content of powdery materials (15.16%). However, the content of powdery materials from rock crushing aggregate, the limit changes from 5% to 12%, if it has wear protection and it is proved that the grains does not interfere in concrete proprieties [19]. Therefore, the content is still above the limit, but in a lower proportion. The other samples are within the specification of [18], which establishes the Fineness Modulus of lower usable zone between 1.55 and 2.22, and the result was 1.55. In the gradation curve, just in Sieve 0.15 was a deviation (69.6%), it should have been between 85% and 100%.

The sands with a high content of fine can affect the adhesion of the mortar, because when occurs substrate suction, the fineness grains can take the place of the hydration substances of the cement, which is responsible for the adhesion of the mortar. Medium sands produce mortars that are more workable, sands with larger particles produce better adhesion because of the particle packing effect [20]. The higher content of powdery materials is determinant for the plastic retraction, because the higher is the fine content the greater is the retraction. For an adequate workability, the fines require a greater amount of kneading water, because of their high specific surface. However, it generates retraction and cracking [3].

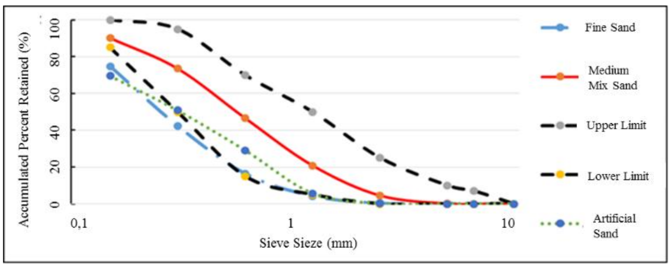

Figure 3. Gradation Curve Fine Sand, Medium Mix Sand and Artificial Sand

A. Adhesion Test

The adhesion results found in Fig. 4, demonstrate that wall 1, the only mortar coating with lime, shows a greater resistance to water penetration, better water retention, better workability, better flexibility to absorb small displacements, autonomous reconstruction of cracks and a better adhesion of the elements [21]. Mortar coating containing lime fulfill more uniformly and satisfactorily the entire surface of the substrate, providing greater adhesion [3].

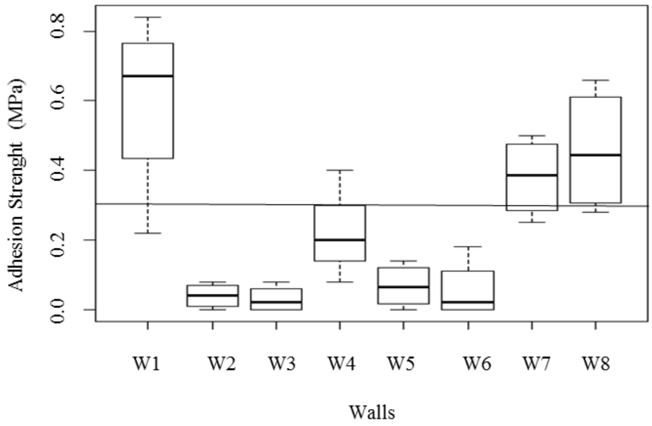

Figure 4. Adhesion results in mortar coating

TABLE I. Report of Fine Sand, Medium Sand and Artificial Sand.

Properties	Fine Sand	Medium Sand	Artificial Sand	NBR 7211:2005
	Results	Results	Results	Results
Specific Mass (g/cm³)	2,832	2,968	2,62	Not specified
Powder Content (%)	6,80	3,70	15,16	≤ 3,0%*
				≤ 5,0%**
Water absorption (%)	4,40	4,70	-	Not specified
Clods of Clay (%)	-	0,29	0,00	≤ 3,0%
Unitary Dry mass (kg/dm³)	1,244	1,373	1,52	Not specified
Organic and Humic impurities	Clearer	Clearer	<300 ppm	Clearer
FM	1,384	2,356	1,55	Not specified
D_{max}	1,2	2,4	2,0	Not specified

The results found in Wall 2 are below the limit, the only difference between Wall 1 and Wall 2 is the absence of lime, which is responsible for the satisfactory results of Wall 1. The engineer who as present in the field reported that the mortar was applied on a day, which the temperature was above 30 °C. Ref. [22] provides that if the environment is with temperatures above 30 °C, the mortar should be wet cured for at least 24 hours thereafter by continuous water spray. However, the coating did not undergo moist cure. A mortar in contact with the substrate loses part of the kneading water, which penetrates the pores and cavities of the substrate, where the hydration products of the cement, mainly ettringite, precipitates acting as a link between substrate and mortar coating [3]. The high temperature and the low humidity of the air contributed for a fastest kneading water evaporation [23], it would influence in the loss of adhesion because the substrate needs water of mortar coating constitution to undergo the mortar anchorage mechanism and so the adhesion [24]. This high water loss also resulted in a powder coating, result observed on the day of the adhesion test. It is necessary to emphasize that, besides the fall of resistance, all the fractures were between the roughcast and the plaster, corroborating with the lack of adhesion to the substrate. The plasticizer additive 1 has the purpose of obtaining a higher resistance with a reduction of the ratio water/cement for the same workability compared with a mixture without additive, or the purpose to improve the workability in order to throw it in inaccessible places [23]. It does not contribute to reduce the loss of water to the atmosphere, being indicated a water retainer additive.

Wall 3 presents a similar ratio to Wall 2, and also presented a lower result that can be related to the loss of kneading water for the environment, equally the previously justification. A single factor that differentiates Walls 2 and 3 is the increase of fine content from 40% to 50%. The increase in this content weakens the adhesion of the mortar because these fines can fill the pores that the cement hydration compounds should filled, which are responsible for the anchorage [3]. In addition to the already explained factors, the Wall 3 presented a lower result compared to Wall 2 because of the increase of fines.

Wall 4 used the artificial crushing sand with high powder content. These fines, due to their high specific surface area, require a greater amount of kneading water to obtain a proper workability [3]. Walls 2 lost a lot of kneading water to the environment, this water demand due to the fine content could have been enough to Wall 4, verifying that it achieved a satisfactory anchorage because its fracture was 100% in the mortar coating. If it had a suitable cure, probably the coating would pass the lower limit established by [1] of 0.3 MPa.

The Wall 5, made with the industrialized mortar, showed a rupture in the roughcast/plaster, demonstrating that this wall presented a poor adherence mechanism. A possible cause would be the loss of kneading water to the environment, since the supplier recommends moistening and curing. However, this wall should have presented results similar to Wall 1, because in its composition have hydrated lime and selected sand [2].

The Wall 6 presents a similar mixture to the Wall 3, with lower additive content. The results were similar on both walls. The cause may be the loss of water to the environment and consequent anchorage deficiency. A possible improvement can be associated to the reduction of the additive, because the additive promotes better workability with a smaller amount of water, and its reduction increases the water required for the same workability.

The Wall 7 has a similar mixture to Wall 4, with reduction of the content of cement. It reached a satisfactory adhesion result, but the rupture was between roughcast and the coating. Verifying that despite achieving satisfactory results the reduction of the cement affected the anchoring of the coating, comparing with the rupture in Wall 4, which was 100% in the mortar. This reduction is associated with a partial replacement of the cement by the sand, as the reduction of the fines ratio requires less kneading water to obtain a suitable workability. It makes the adhesion deficient, because increasing the amount of water reduces the resistance [23]. The rupture of the coating occurs between roughcast and plaster, but Wall 4 did not present this behavior. It is possible to link that the reduction of water affected the anchoring effect explained in the Wall 2, so it might have lost more water than it should.

The wall 8 has the same mixture of the Wall 4, however the wall 8 attends to the adherence limit [1] and the Wall 4 does not. Although it is the same material, the application of the plaster used by the mason, or the environmental conditions were not exactly the same, otherwise both walls would fulfill the requirements. The mortar must be plated with energy and flatted [2], but human energy cannot be always the same. Another factor is that the humidity of the building's facade are different [25] and the Wall 4 and the Wall 8 were not in the exactly same place. The incidence of the sun might have been lower in Wall 8, which leads the wall to lose a smaller amount of kneading water and increases the adhesion resistance.

B. Macroscopic Analysis

Another way to analyze the coatings is the digital microscope images shown in Figs. 5, 6 and 7.

Fig. 5 presents the surface of the coatings, in it can be analyzed all the walls studied.

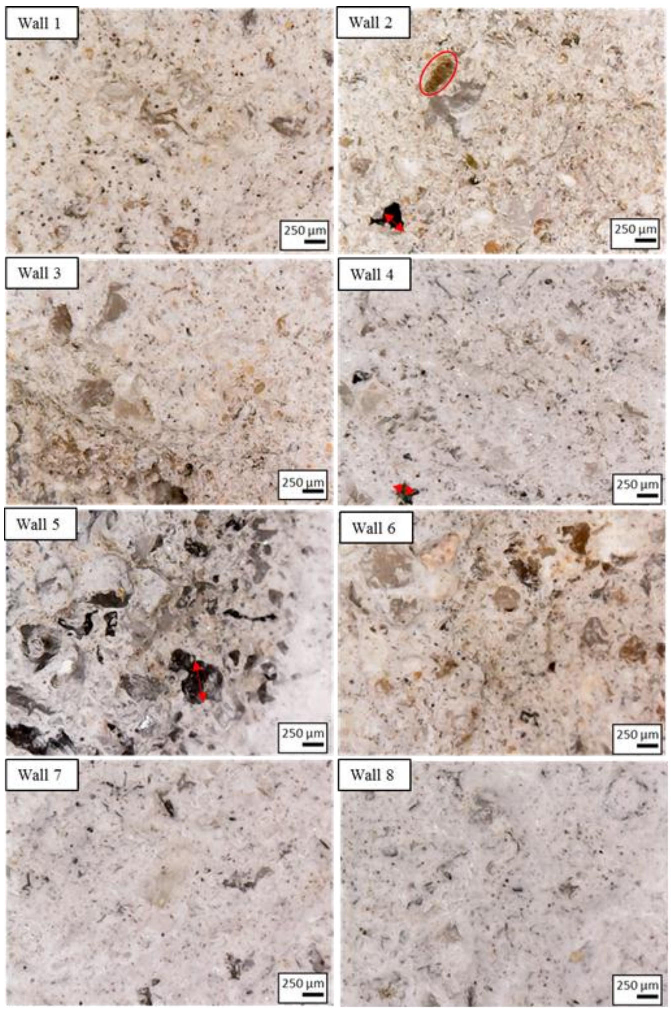

Figure 5. Digital microscope images of the surface of the coatings

With the Fig. 5, we can infer that the mortars with lime allow a better finishing due to more plastic conditions and penetration of the fluid substances constituent of the binder in the reentrances [21]. Therefore, wall 1 has small, rounded pores, a lime-containing coating characteristic.

In Wall 2, we can see a presence of more irregular pores because of the absence of lime. It is even possible to see a pore of diameter approximately 300µm, a significant size in comparison to the others observed. Another factor observed is the aggregate particles, the presence of sub-round and angular particles. Angular aggregates result in better adherence [23]. Brown spots, indicating the presence of the aggregate, also observed in Wall 3, however less than Wall 2, which could indicate the use of a thinner aggregate. A rough surface is in the lower corner, indicating that the amount of water might be not sufficient. The Wall 2 also has pores of considerable diameter, which may be points of weakness in coating.

The Wall 4 differs from previous ones by the use of artificial sand, acquiring a surface more uniform and a gradation of the aggregate more appropriate, as observed. The pores are smaller than Wall 2 and 3, more equally to Wall 1, however Wall 4 has no lime in its constitution. Concluding that because of this greater uniformity of the coating, it almost achieved satisfactory results.

The visual result found on Wall 5 is the most unsatisfactory and totally out of expected. Being a mortar ready to use with lime, additive and selected sand, it could have had similar result than Wall 1, but that did not happen. The Wall 5 has a greater amount of pores, and the largest pore is around 500µm in diameter. This amount of pores is very high and might be associated with the result of adhesion found, lower than expected for an industrially controlled mortar.

The Wall 6 presented a similar constitution to the Wall 3. The Wall 6 still has pores, but in less amount than Wall 3, besides it presents a uniform surface. The reduction of the amount of plasticizer decreases the workability of the mass. Therefore, for adequate workability it should increase the amount of water. Concluding that the increase of the amount of water favored the surface finish.

The Walls 7 and 8 acquired the necessary resistance for external coating, which can be inferred to the lower amount of pores found in both walls. However, analyzing Walls 7 and 8, Wall 8 presented less porosity than Wall 7 and better adhesion. In others words, the reduction of cement affected the adhesion strength, but not in a worrying form because both walls presented satisfactory results. Comparing the Wall 8 with the Wall 4, which have identical structures, the Wall 4 showed larger pores and a consequent decrease in resistance compared to the Wall 8.

Fig. 6 represents fracture points on each wall due to the adhesion resistance test. In the Wall 1, the presence of the aggregate, that was not so noticeable in the surface image, is observed. The aggregates have several diameters, which characterize a continuous gradation curve [3] with less fines. Aggregates present in the rupture image mean broken aggregates, which are indicators of high resistance, or, in large numbers, indication of a weak aggregate [23].

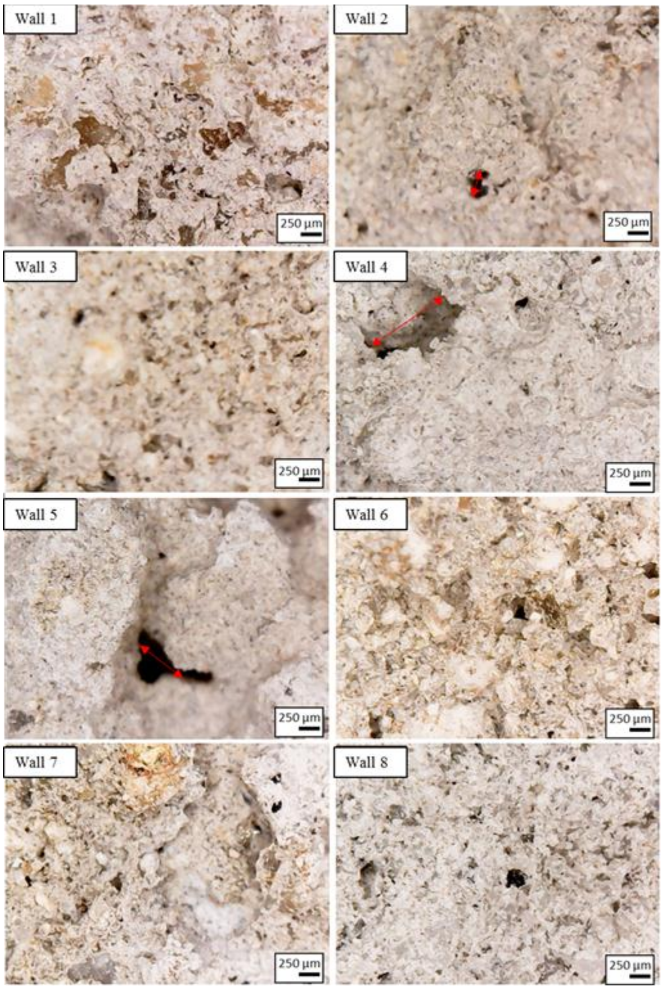

Figure 6. Digital microscope images of the coating disruption

Nevertheless, the Walls 2, 3 and 6 had similar sand composition and did not present a high amount of ruptured aggregate, so this observation is not associated to the weak aggregate. The rupture image of the Wall 2 presents a similar structure to the surface image, without the evidence of aggregates with larger diameter than the group.

The pores presented in the fracture of Wall 3 had not considerable dimensions. Visually it distinguished of Wall 2 due to greater occurrence of pores, being able to infer that the increase of fines increased the porosity of the coating.

The Wall 4 had in its constitution the substitution of natural sand for artificial sand. A color homogeneity indicates that this composition must have a maximum diameter inferior than Walls 1, 2 and 3, made with natural sand, confirmed by the gradation curves of the sands. The Wall 4 has a large pore, approximately 400µm in diameter, but with reduced depth. This occurrence might be associated with a possible lack of water to incorporate properly the mass.

In the surface image of Wall 5, it is possible to observe many pores with a considerable diameter. In the rupture image of Wall 5, the pore focused has approximately 700µm. This pore has a smaller diameter than that found in Wall 4, but might be more damaging due to its depth. Pores that occupy a large area represent a site without adhesion and it will result in the decrease of the resistance of the mortar analyzed.

The Wall 6 uses natural aggregate and its brown coloration becomes present again. The walls 6 and 3 have the same components ratio, only the amount of plasticizer that changes, but visually both are similar.

The Wall 7 shows a yellow coloration in the upper corner of the photo, which is not characteristic of other walls that have artificial sand in the composition. Wall 7 in relation to Wall 8 has a lower uniformity, and the only difference between them is the lower proportion of cement used in the Wall 7. The Wall 8 is visually very similar to Wall 4; they have the same components ratio, so this observation was expected. However, the Wall 8 has smaller pores than the Wall 4, which could associate with the greater adhesion resistance of the Wall 8.

It was possible to observe cracks recorded in Fig. 7. The coating of the Wall 3 also cracked, according to the engineer's report. Cracking is a function of intrinsic factors such as cement consumption, fines content, amount of kneading water and other factors such as the loss of water by atmospheric agents [26]. The Walls 3 and 6 have a higher amount of fine sand in their composition. The Wall 3 presents a crack almost imperceptible in the digital microscope. Ref. [26] argues that well-proportioned mortars have less resistant internal bonds, and internal stresses can be relieved in the form of micro cracks. Therefore, these coatings would be well proportioned, but it did not achieve satisfactory results, possessing other deleterious factors.

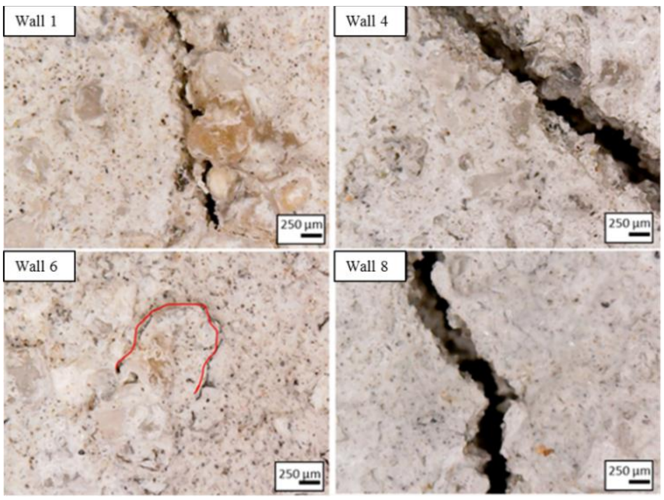

Figure 7. Fissures in the Coating

The excess of fines also generates a hydraulic retraction due to the greater demand of kneading water [26]. As observed in the gradation analysis of the artificial sand, contained in the Walls 4 and 8, the content of powdery materials is high, which can favor the cracking process.

Another factor, previously mentioned, would be cause of the cracking: the high temperature of the environment, because the unfavorable climatic conditions added to the inefficiency of the mortar in retaining water can result in a process that generates fissures [5]. Most of the coatings cracked, being the main cause the high temperature that all the coatings were. The lack of cure of the coating can also be a cause of cracking [5].

It is worth noting that cracks, considered as pathologies, are those visible to the naked eye at a distance of more than one meter, or those that are causing moisture penetration into the structure [27]. Hydraulic retraction cracks are only visible when wet and the water penetrates by capillarity and shows its trajectory [5]. In others words, these cracks would not be considered worrisome, because the Walls 1 and 8 passed and the Wall 4 almost passed the test of adhesion. However, it may be a clue that the quality of the mortar could be improved.

IV. Conclusion

From the bibliographical research and the results obtained, it is possible conclude:

- The Walls 1, 7 and 8 pass the adhesion test according to [15], having more than 60% of values above 0.30 MPa.
- The walls 7 and 8, which passed the test, have artificial sand. Inferring a better quality of the artificial sand and consequent gain of resistance.
- Lime gives the coating a much better adhesion resistance result, due to its characteristics, inferring the higher results on Wall 1.
- The walls 4 and 8 have the same constituents, but wall 4 did not pass the test. Indicating that the preparation and climatic conditions were more aggressive for this mortar.
- The wall 5 presented a very unusual and unexpected result for an industrialized mortar demonstrating that wetting the substrate and curing are imperative for this industrialized mortars.
- Although the walls 1, 4 and 8 presented cracks in the digital microscope image, they are not of concern because they have obtained the best results. The higher binder content improved the adhesion and, as expected, maximized cracking. An effective cure might reduce this to an acceptable standard.

It is possible to conclude that the preparation of the substrate, the base and the technique of application of the coating mortar are of vital importance to ensure the quality of the mortar. The demand to represent the worst situation ended up decreasing considerably the adherence resistances of the coatings studied, failing to meet an acceptable condition. The presence of lime compensates the lack of cure and wetting. In the mixtures with additives, it should need other formulations of additives, not only plasticizer, but also air entraining agent and water retainer for an efficient dosage and promotion of a quality coating mortar.

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