

Evaluation of the mechanical performance of different coating mortars types after an accelerated aging process

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Abstract

There are different types of mortars, which are essential elements of façades for protecting the inner building materials. Therefore, there is an increasing worry about the durability of these mortars in the civil construction sector, raising studies about this topic, and developing tests to evaluate durability issues, such as the accelerated aging procedures, for instance. The aim of this paper was to assess (quantitatively and qualitatively) the effect of accelerated aging process on the behavior of different coating mortars. Three mortars were characterized and evaluated in this research: M - Mixed mortar (made of cement and hydraulic lime); P - Mortar with Plasticizer only; and WP - Mortar with Water-retaining and Plasticizer. Each mortar was initially characterized for: density, water absorption, porosity and modulus of elasticity. Then, they were evaluated before and after accelerated aging process (adapted method of the Brazilian standard ABNT NBR 15575-4:2013) for: compressive, flexural and tensile bond strength, and pathological manifestations. The procedure of simulate the aging of mortars is important to properly define the proportion of materials, focusing on the durability of the façades, since their behavior through the years and under usual environmental conditions can be predicted. From the results it was noticed low variability in density, porosity and water absorption, between the three evaluated mortars. After the aging process, WP had low variation in mechanical performance, P increased its tensile bond and flexural strength, and M increased only its tensile bond strength. In conclusion, the simulated aging caused significant changes in the properties of the coating mortars, being the WP mortar the most suitable for coating application. Thus, this study also contributes to the evolution of knowledge about mortars with admixtures.

Keywords: Mortar, Hydraulic Lime, Chemical admixtures; Accelerated aging, Mechanical properties

INTRODUCTION

The façade is the element of the building sealing system that is most attacked by aggressive agents (Souza et al., 2016). They generally cover the entire surface of the building and present various components such as: mortar, painting or some other coatings (ceramics, ornamental rocks, polymers, wood, among others), besides frames, drips and movement joints (Santos et al., 2014; Madureira et al., 2017). An efficient project will provide an adequate dimensioning of these elements and their interfaces, based on the building dimensions, utilized materials and environmental conditions (climate, rains, winds, and aggressiveness) (Santos et al., 2014; Madureira et al., 2017; Pereira et al., 2020). Currently, for economic and environmental reasons, there has been a growing concern with the durability and service life of buildings, since the cost of repairs is high and it generates wastes (Lordsleen Jr. and Maorais, 2015). Thus, it is evident that the correct diagnosis of pathological manifestations in the building is very important (Torres et al., 2014; Silva Neto et al., 2020), in order to investigate them (efflorescence, vesicles, molds, detachments or cracks), allowing to propose an appropriate intervention (Santos et al., 2014; Silva Neto et al., 2020).

One of the main factors of degradation of coating mortars is the high-water absorption capacity, which can promote the transportation of deleterious agents through them (Santos et al., 2014; Santos et al., 2019a). Therefore, the low permeability of

mortars to water, salts, sulphates or any harmful substance, is associated with higher durability of the coating (Sicakova et al., 2017). Besides, the degradation of the façade can be generated by gases, such as CO₂, which in the case of mortars with lime can even generate a beneficial effect of increasing strength and closing pores, due to the reaction of this gas with the Ca(OH)₂, present in the cementitious matrix. However, when in excess, as in large urban centers, and together with other agents (salts, sulphates, among others) they can originate acids, which when they are associated with rain, cause deleterious reactions and deterioration (discoloration, powderiness and detachment) of the coating mortar (Pereira et al., 2018). There are also particles dispersed in air, that are originated from clay minerals (dust) and soot (exhaust pipes and tires of automotive), which in the event of rain are taken to the façades (Chew and Tan, 2003). These particles tend to penetrate with the water in the pores of the coating mortar, generating stains and, in some cases, even detachment due to the increase in the volume of clay minerals in the presence of water. Associated with chemical and physical agents, there are also microorganisms that take advantage of places with little sunlight and high moisture for the proliferation of their colonies, which can release chemical compounds that generate detachments and powdery mortars (Gaspar and de Brito, 2008; Gomoio et al., 2016).

Although the previous effects are important, it is noticed that the use of an impermeable layer (when it is a good quality mortar) tends to improve and guarantee an adequate service life to the coating. However, climatic effects, such as thermal variations caused by rain and sun, are almost impossible to prevent (because they are natural factors), causing expansion and shrinkage in the coatings (Ravindrarajah and Mansour, 2009; Alves and Rachid, 2016). Thus, it is necessary to know the material and environmental conditions in order to make an adequate specification, design and construction, avoiding the cracks and detachments, that are the main pathological manifestations (Abreu et al., 2004; Silva Neto et al., 2020).

In view of this, in recent years, standards have been developed aiming to simulate these variations, whose parameters vary in each region depending on climatic conditions (Cao and Chung, 2002; Izaguirre et al., 2011; Fu et al., 2011) assessing the mortar durability through freeze-thaw test. However, in countries like Brazil, freeze and thaw do not have an impact as significant as high temperatures, humidity, biological agents and ultraviolet radiation (Oliveira et al., 2014; Sentena et al., 2018). Thus, as from 2013 (ABNT, 2013) a test was structured that simulates 10 cycles of heating by high temperatures (80°C) and cooling by sprinkling water to validate elements used in building façades. The Brazilian standard differs in some aspects from the testing methods of foreign standards; for example, the maximum temperature of the exposed surface of the specimen: in NBR 15575 (ABNT, 2013) it is (80 ± 3)°C, in ETAG 004 (EOTA, 2008) it is (70 ± 5)°C and in ASTM C1185 (ASTM, 2016) and ISO 8336 (ISO, 2009) it is (60 ± 5)°C. Related to the temperature measurement method, the Brazilian standard (ABNT, 2013) specifies the measurement by means of thermocouples directly attached to the external surface of the sealing element, while in ASTM (ASTM, 2016) the thermocouples are connected to painted metal plates, which are attached to the surface. There are already studies (Oliveira et al., 2014) questioning the Brazilian's parameters, claiming that there are few cycles, insufficient time and low aggressive temperatures.

An important issue little discussed in researches is the characteristics of the coating mortars used in this test (Souza, et al., 2020a). Since, in most cases, it is only stated which mortar was used, but its properties, important for an adequate characterization of this material, are not reported (Oliveira et al., 2014). Furthermore, there is a diversity of mortar types available in the market, which can be prepared in the construction site or industrialized. Considering this, mixed mortars (using cement and hydraulic lime as binders) and those with chemical admixtures are currently utilized, in the latter generally contain only plasticizer to guarantee the fluidity of the mortar and sometimes some fine materials for the purpose of improving the cohesion (Haddad et al., 2016; Santos et al., 2018). These types of mortar are very different and often is not suitable for the places applied as coating materials, which tends to generate several pathological manifestations (Santos et al., 2019b; Souza et al., 2020b).

The novelty of this paper is related to the contribution for the evolution of studies involving coating mortars with chemical admixtures, focusing on how the aging of this building material influences the mechanical properties and the appearing of pathologies. To do so, this research proposes subjecting the mortar samples to thermal cycles of high temperatures, similar of equatorial regions as Brazil. Besides, differing from the other researches about this topic, this paper previously characterizes the different mortars, aiming to correlate these characteristics to their behavior after the thermal cycles.

Given this scenario, the aim of this paper was to assess (quantitatively and qualitatively) the effect of accelerated aging process on the behavior of different coating mortars. In this research initially the three mortars (mixed, with plasticizer, and with water-retaining and plasticizer together) were characterized (porosity, density, water absorption, water retention and modulus of elasticity) and then the effect of the accelerated aging on their mechanical performances (compressive, flexural and tensile bond strength) was studied. In addition, a qualitative assessment of the pathological manifestations (cracks, displacements and powder) was performed.

2. MATERIALS AND METHODS

2.1 Materials

The materials used were Brazilian Portland Cement CP II-F 32 (ordinary cement with 10% limestone powder addition, equivalent to the cement ASTM type II) with specific mass of 3.1 g/cm³ and unitary mass of 1.7 g/cm³, which do not has reagent additions that could affect the admixtures and hydraulic lime effects (Table 1). The Brazilian hydraulic lime used has specific

mass of 2.8 g/cm³, unitary mass of 0.8 g/cm³, and a certification of 0% of non-hydrated oxides (Table 1). The water used come from the Brazilian water supply. The natural sand of quartz composition come from the riverbed, it is well graded and its mainly characteristics are shown in Table 2.

The cement: sand ratio adopted for mixture with admixtures (P – Plasticizer and W – Water retaining) was 1:5 (by volume), in accordance with the prescription from Santos' methodology (Santos et al., 2018) which considers the amount of binder according to the voids between the aggregates. The proportions of admixtures were based on the maximum percentage of use by weight of the cement recommend by the manufacturer, as in Table 3. The cement: hydraulic lime: sand ratio (M - Mixed) used were 1:1.08:4.41 (by volume), intending to establish a similar proportion between mortars with and without admixtures, being the only difference between them the replacement of hydraulic lime by admixtures. The amount of water was settled experimentally until the spread diameter on Flow-Table (ABNT, 2005a) reached 260 ± 10 mm (Table 4). This study choose M, because it is a proportion with sand, cement and hydraulic lime without any admixture as it is usually used in civil construction (Gulbe et al., 2017); P, because it is a proportion with sand, cement and a lignosulfonate plasticizer commonly used in admixture mixes for mortars (Hartmann et al., 2011); and WP, because Souza (2019) results showed that using the combination of the admixtures adopted, this proportion obtained the most suitable result. So, the three samples could provide a good comparison parameter.

Table 1: Cement and lime characterization

Material	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	CaO (%)	MgO (%)	LOI (%)	D ₁₀ (µm)	D ₅₀ (µm)	D ₉₀ (µm)
Cement	18.97	4.21	2.81	64.52	2.01	5.21	5.3	22	63
Lime	1.88	0.26	0.22	49.35	26.45	21.74	0.47	4.28	30.84

Table 2: Fine aggregate characterization

Characteristic	Value
D ₁₀ (µm)	297
D ₅₀ (µm)	590
D ₉₀ (µm)	1150
D _{max} (mm)	2.4
Fineness Modulus	1.995
Specific gravity (kg/dm ³)	2.584
Bulk Density (kg/dm ³)	1.283

Table 3: Admixtures characteristics

Admixture	Density (Kg/l)	Maximum (%) ^a	Form	Chemical base
Plasticizer (P)	1.18	1.0	Liquid	Lignosulfonate
Water retaining (W)	1.00	1.5	Liquid	Acrylic Polymer

^a Maximum percentage of solid by weight of cement, recommend by the manufacturer

Table 4: Mortar proportions – by volume

Mixture	Cement	Lime	Sand	Water	Admixture
Mixed (M)	1.00	1.08	4.41	1.82	-
Plasticizer (P)	1.00	-	5.00	1.67	0.0085
Water retaining + Plasticizer (WP)	1.00	-	5.00	1.77	0.0075 (W) 0.0042 (P)

2.2 Methods

This research intended to analyze the effect of climatic agents as the effect of the sun and the rain on external mortar coating. To do this, mortars were characterized: density in hardened state, porosity, water absorption and elasticity modulus. Posteriorly, thermal cycle was used to age the coating and the following experiments were made: compressive, flexural and tensile bond strength and pathologies (cracks or detachments) were analyzed through visual and microscope superficial inspections.

2.2.1 Mixture and molding

With all the mixtures adjusted, the mortars studied were made with an inclined axis mixer. First, the dry materials (cement, sand and hydraulic lime when it was necessary) were mixed for 30 seconds. After, the water-retaining agent then the plasticizer, previously diluted in part of the kneading water, were added, for the mixtures containing admixtures, each one separately. Subsequently, the amount of water left was added. The mixing procedure continued for more 3 minutes, having the mixture procedure 3 minutes and 30 seconds in total. The sequence of admixtures addition adopted, intended to generate a more workable mix and a good air retention.

The molding of cylindrical (porosity and water absorption) specimens (5x10) cm was in two layers with 12 strokes each one. The prismatic (compressive and flexural strength) molding was in two layers with 30 falls of the settlement table each one. The application of the coating mortar on prisms (40x40x160) mm was over rolled industrial roughcast. The designed mortars were applied on the roughcast of prisms (40x40) cm with the assistance of proper worker, to evaluate the tensile bond strength before

and after the wetting and drying cycle. All the samples stayed indoors, with an average temperature of (25 ± 3) °C and relative humidity of 60% for 28 days before being tested.

2.2.2 Mortar characterization

In the characterization procedures, the coating mortar was evaluated by the hardened state density (ABNT, 2005b) with six cylindrical samples (5x10) cm, measured with a 0.1g precision weight balance and they were obtained through mass and volume ratio. The water absorption by immersion and open porosity (ABNT, 2005c) used six cylindrical samples (5x10) cm, for each mixture, the samples, was remained for 24h in electrical furnace at (100 ± 5) °C, when it was verified mass stability, for these experiments a 0.01g precision weight balance was used. Water absorption by immersion was obtained by gradual immersion of the specimens in water in three steps until complete immersion, masses of saturated and saturated dry surface samples were recorded. The elastic modulus (ASTM, 2019) determined by MKII Erudite equipment used the forced resonance method and the result was obtained by the average result obtained in six tests of an oven dried (10x20) cm sample. The theoretical porosity (P_t) were calculated with Equation 1.

$$P_t = 100 \times \{1 - [\mu_h / ((mc + ms + ma + mw)/vc)]\} \quad (1)$$

Where P_t = theoretical porosity (%); μ_h = hardened state density (g/cm^3); mc = mass of cement (g); ms = mass of sand (g); ma = mass of admixture (g); mw = mass of water (g); and vc = certain volume (cm^3).

The water retention test was performed according to the Brazilian standard NBR 13277 (ABNT, 2005d). This method quantifies the water retained in the mortar after suction by paper filter discs positioned in the fresh mortar under a standardized weight for 2 minutes, the masses were measured with a precision scale of 0.01g.

2.2.3 Thermal cycle adapted from the Brazilian standard NBR 15575-4

The thermal cycle was used to age the coating, simulating the incidence of sun and rain on an external coating. The method in the Brazilian standard NBR 15575-4 (ABNT, 2013) is to submit the coat to an average temperature of 80 °C for 1 hour and right after this period the heated side must be cooled by aspersion of water. This need to be repeated for 10 times to end the whole experiment. The method used in this research differs from the standard method because of the sample dimension. The standard dimension is a wall (1.20 x 2.10) m and the sample used were a prism of (40 x 40) cm.

The tensile bond strength before the aging cycle was conducted on one mixed proportion and 10 different proportions with chemical admixtures (plasticizer, water retaining and air entraining) as seen in Souza's study (Souza, 2019), in which it was evidenced that the best combination for tensile bond strength without compromising others properties were the combination WP (50% water retaining and 50% plasticizer in relation to the maximum percentage solid by weight recommended by the manufacturer). Because of this, for the aging cycle, it was adopted the mixed mortar with hydraulic lime M, widely used, the ideal mortar WP (Souza, 2019) and the commonly used mortar with chemical additive with only plasticizer P. These three proportions suffered the aging cycles established in Brazilian standard NBR 15575-4 (ABNT, 2013), only adapting the dimension of the sample to (40x40) cm.

The tensile bond strength (ABNT, 2019) were evaluated with Pull-off tester Z16-DYNA Proceq, after and before the experiment to test the differences. If any pathologies appear it must be noted. The mortar temperature was manually controlled by gauging through thermocouples installed at strategic locations as demonstrated in the scheme of Figure 1 (a). The experiment consists to submit the three samples, at the same time, to 10 heating and cooling cycles with the aid of a radiant panel and sprinkling of water through a hose. Each cycle consists of heating to 80 °C → keeping 80 °C for 1h → cooling to room temperature (Figure 1 (b)).

The flexural strength and the compressive strength (ABNT, 2005e) were conducted in normal and aged samples, using adapted aging method from the Brazilian standard NBR 15575-4 (ABNT, 2013). It was used three prisms (4x4x16) cm molded according to the Brazilian standard (ABNT, 2005e). One cycle of the aging experiment consists of waiting the electric furnace to reach (80 ± 5) °C and after that the prisms were placed in the furnace where they stayed for 1h. After this heating period the prisms were subjected to water blast cooling until they reached ambient temperature (25 ± 5) °C. This process was repeated 10 times in total to complete the experiment. The prisms were broken in Flexural strength test with loading rate of (50 ± 10) N/s in EMIC DL 30000 N. Afterwards, the compression experiment was performed, with a loading rate of (500 ± 10) N/s also in EMIC DL 30000 N.

Powdery behavior and pathologies (cracks or detachments) were analyzed through visual and microscope superficial inspections. Microscope images were made of the surface of specimen (40x40) cm for each mixture with a digital microscope with up to 1600x magnification.

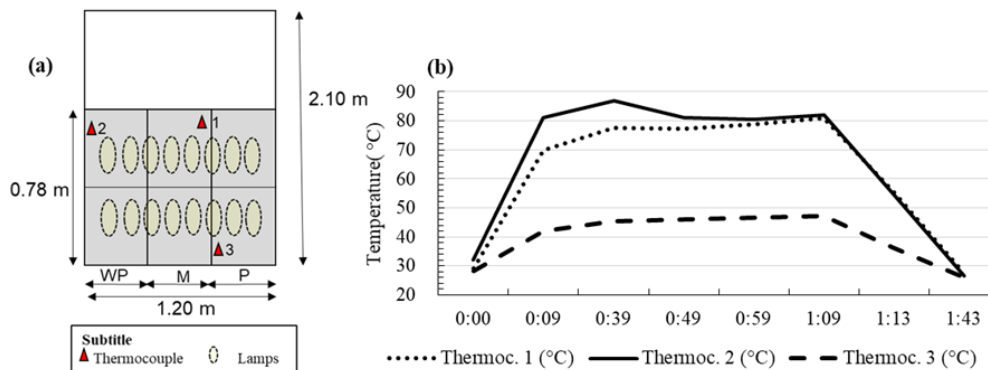


Fig. 1: Apparatus installation (a), Thermocouple temperature exemplification through time according to installation based on NBR 15575-4 (b)

2.3 Statistical analysis

The software that was used for statically analyzing the data was Excel developed by Microsoft. It was performed only basic analysis to verify the variability of the obtained results.

3. RESULTS AND DISCUSSIONS

3.1 Mortar characterization

According to the obtained results for density in hardened state of the produced mortars, it was not noticed a great variance between them (maximum of 2.3% higher in relation to M). The values were 1.75, 1.79 e 1.74 g/cm³, for the mortars M, WP e P, respectively. As the quantities of solid materials in the three mortars were similar (Table 4), their densities in the hardened state were conditioned by their porosity. However, the low variations in the porosity (open and theoretical, Figure 2) were not enough to generate great variations in the densities of those mortars. Nevertheless, taking into account the requirements for external coating mortars presented by Santos (2014), all three produced mortars, which attend the minimum density limit of 1.40 g/cm³, all being higher.

Regarding to the open porosity of the analyzed mortars (Figure 2), it was found a trend of reduction of this property, comparing the mixtures WP (-8.38%) and P (-3.24%) with M. It was due, mainly, to the fact that the water/cement ratio of the mixtures reduced when the chemical admixtures were incorporated. The mortar P, which presented the lowest water/cement ratio, compared with M (1.67 against 1.82), was also which reached the smallest value of open porosity (26.24%), 9.7% smaller. When comparing mortar WP (27.12%) with M (29.06%), the reduction of porosity was of 6.7%. Such reductions are fundamental to the durability and mechanical performance of these mortars (Khudhair et al., 2018).

Considering the evaluation of the theoretical porosity of the mortars, Figure 2, it was observed an inverse behavior to the open porosity, with values of 15.19, 15.89 and 17.10%, for M, WP and P, respectively, which means that even though the mortar M had showed a smaller quantity of pores, these are more connected, allowing the penetration of water, being evidenced by the greater open porosity (29.06%). The mortars with chemical admixture had percentage increases in relation to, with values of +4.62% for WP and +12.59% for P in relation of M.

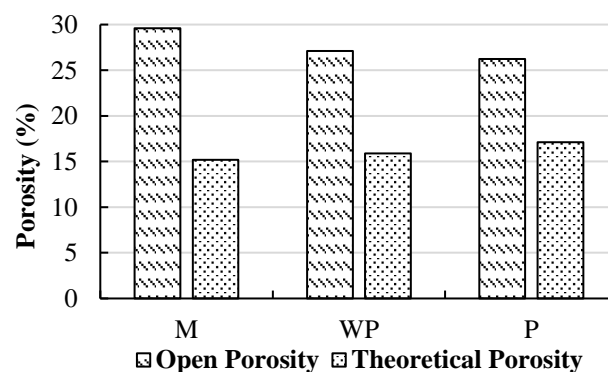


Fig. 2: Open and theoretical porosity results

Consequently, as there was a reduction of the open porosity, also there was a reduction of the water absorption capacity (Figure 4) of the mortars with chemical admixtures, with maximum reduction of 8.7% in the mortar of plasticizer (P) compared with the mixed mortar (M). In the case of the mortar with water-retaining admixture and plasticizer together, this reduction was of 5.3%. It perceives that the presence of hydraulic lime promoted a refinement of the pore sizes (Figure 3) and a greater

capillarity/conductivity of them, increasing the open porosity and the water absorption, on the other hand, the chemical admixture generated a greater theoretical porosity, which means that it generated pores, but they are isolated.

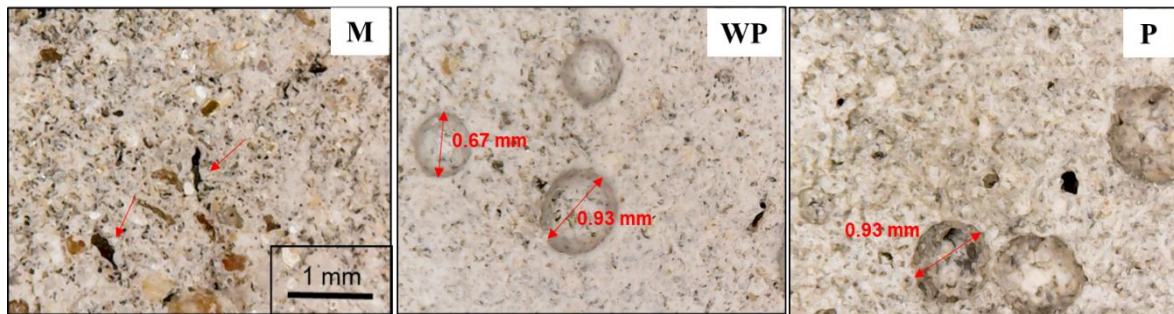


Fig. 3: Image of mortar porosity

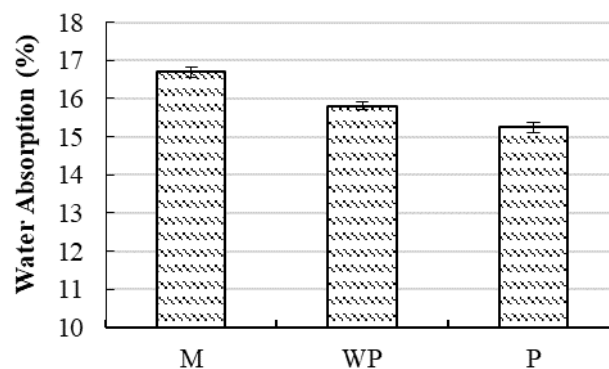


Fig. 4: Water absorption results

Concerning to the modulus of elasticity (Figure 5), it was observed the higher modulus of elasticity (28.9 GPa) was found in the mortar with plasticizer only (P), which corresponds to 15.5% higher than modulus of elasticity of the mixed mortar (M). This behavior is related to the lower open porosity of P, once the utilization of lignosulfonate-based plasticizer provided a reduction of the water/cement ratio, leaving the mixture more compact. It corroborates with the statement of Haddad et al. (2016), which says that the modulus of elasticity is inversely proportional to the mortar's porosity.

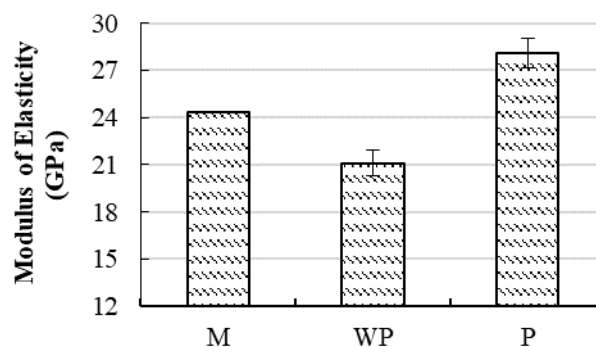


Fig. 5: Modulus of elasticity results

On the other hand, the mortar WP, even showing a lower porosity than the mortar M, did not showed an increasing in the modulus of elasticity, but a reduction 13.2% (21.11 against 24.33 GPa). This behavior is related to the fact that the hydraulic lime had showed a better water retention effect than the water-retaining admixture (88.51 against 93.31%, as it can be seen in Figure 6), benefiting so the hydration reactions of the cement. As stated by Izaguirre et al. (2011) the water-retaining agents maintain the mixing water in the mixture for a longer time, improving the hydration reactions of the cement and consequently benefiting its mechanical behavior.

According to CSTB (1993), modulus of elasticity higher than 12 GPa presents a high susceptibility of cracking and it would be bad to the coating absorbing deformations of the substrate and/or thermal variations, and considering the results, all samples would show high susceptibility of cracking. Attention must be paid to the methods utilized to measure the modulus of elasticity, because the CSTB (1993), although having a comparison table, it is based on the modulus obtained by the ultrasonic method, and in this research, it was used the forced resonance method. It was opted for this method, because of its sensibility to this type of mortar, however there are no parameters yet to fundament this relationship of cracking.

It is possible to see in works, as of Santos et al. (2018), that a mix proportion with a cement content around 10% (by volume) tends to show lower results of modulus of elasticity. In this study, it was opted for using a cement content that generates mechanical results close to those commonly seen in the admixture mortars utilized in the conventional market. Thus, it generated an expressive increase in the modulus of elasticity of all analyzed mortars.

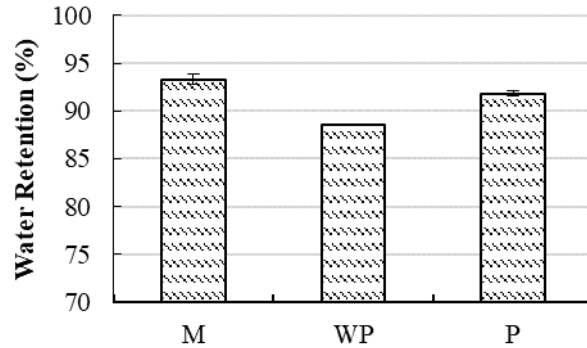
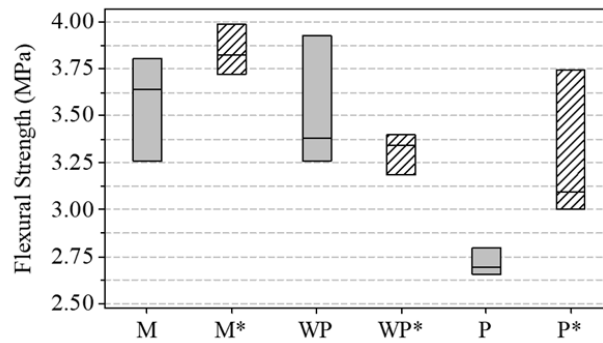


Fig. 6: Water retention results

3.2 Wetting and drying cycles

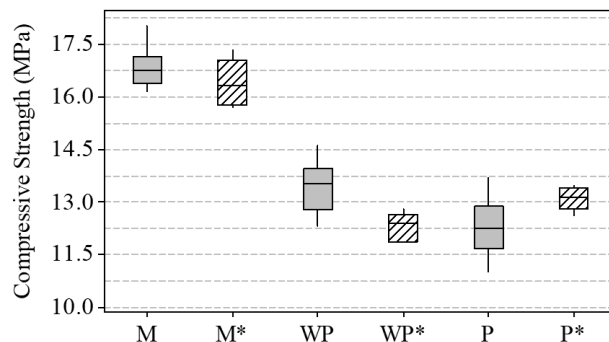
3.2.1 Flexural strength

The first test performed with the samples before and after the adapted aging method was the flexural strength, according to the Brazilian standard NBR 13279 (ABNT, 2005e) (Figure 7). Through the data dispersion chart it is possible to observe that, before the wetting and drying cycles, the median of the mixed sample (M – 3.64 MPa) is only 7% greater than that of the sample with two types of chemical admixtures (WP – 3.38 MPa). Furthermore, not only the mixed mortar (M), but also the one with two types of additives (WP), showed a high variability of results, besides both had a minimum value of 3.26 MPa. Thus, the results of M and WP, despite having different medians are practically equal due to variability and cannot infer any variation due to the difference in constituents. On the other hand, comparing mortar P with M, and WP before aging, the variation is more visible. M has a median 35% greater than P (2.69 MPa) and WP has a median 25% greater than P. It is observed that the samples M and WP achieved results well above P in relation to flexural strength, which can be a differential factor in choosing the type of material to use.



*Aged sample
M - Mixed mortar; WP - Water retaining agent and plasticizer; P - Plasticizer

Fig. 7: Flexural strength results



*Aged sample
M - Mixed mortar; WP - Water retaining agent and plasticizer; P - Plasticizer

Fig. 8: Compressive strength results

The plasticizer is widely known for reducing the mixing water keeping the consistency and thus, reducing porosity and increasing mechanical strength (Khudhair et al., 2018). It was observed that the plasticizer obtained the lowest open porosity, but the highest theoretical porosity of the sample, despite being like the others, thus, it can be associated with the lower flexural result in flexion. It is also believed that part of the mixing water retained by the water retaining and the hydraulic lime may have reacted to form hydrated cementitious compounds, favoring the strength gain of these samples. Since the plasticizer used less water than the other samples, it remained with unreacted compounds.

After thermal cycles (heating in an oven and water spray), flexural tests were also performed on flexion and a change in behavior was observed (Figure 7) between the samples. The sample M (3.83 MPa) obtained a result 15% greater than the median of the sample WP (3.34 MPa) and 23% greater than the median of the sample P (3.09 MPa). WP obtained a median only 8% greater than P and due to the variability of the results it is not possible to infer change between the two compounds. Therefore, after the thermal cycle, M mortar continues with the highest results of tensile by flexion, showing to be less influenced by it.

Comparing the samples before and after the thermal shock, it is observed that only the WP sample remained practically with the same results, decreasing its median by only 1.7%, which means that the thermal shock did not affect the flexural strength. However, due to the lower variability in results, it appears that there was a slight drop in the result, but not very sensitive. Sitarz et al. (2018), showed in their study that flexural strength reduces about 7% after heating to 400 °C, mainly due to Portlandite's water loss. From this, it is concluded that the temperature elevation to 80 °C is not sensitive to internal chemical changes in the sample that can considerably affect its strength. Another important factor, which could be related to the degradation of the specimens is the porosity (Zeng et al., 2012), which in this study did not influence the results. In addition to the expansion and retraction of the sample's constituent materials (Zeng et al., 2012), at the microscopic level, the expansion and stress differences may occur due to the different expansion coefficient of the materials (Temoche-Esquivel and Barros, 2018), which also had no great influence on these results. Visually, no cracks were observed in the specimens before and after the adapted aging cycles.

Therefore, it was observed that instead of the thermal shock causing the dropping in strength, it favored it, generating gains of 9.3% (M) and 13.9% (P), in relation to samples before the aging cycles. It is possible that the sprinkling of water promoted hydration of non-hydrated compounds that remained in the sample (Temoche-Esquivel and Barros, 2018), reason that justifies the low result of the flexural strength of P sample before the aging process and the consequent later gain. As a result, the sample can become more resistant and less deformable, compared with samples without aging (Jing et al., 2018).

3.2.2 Compressive strength

After the flexural strength tests, the resulting half of the samples were subjected to compressive strength experiments according to NBR 13279 (ABNT, 2005e), for both aged and non-aged samples, the results are on Figure 8. According to NBR 13281 (ABNT, 2005f) all the tested samples are classified as high compressive strength mortar coating ($P_6 \geq 8$ MPa).

It is possible to see in Figure 8 that the mortar M (16.74 MPa) obtained the highest compressive strength result, 24% higher than WP (13.53 MPa) and 36% higher than the median of P (12.27 MPa). Following the tendency of theoretical porosity, being the sample with lowest theoretical porosity (M) the one that obtained the highest compressive strength, followed by sample WP and the lowest value was of P. As mentioned in the results of flexural strength experiment, although the plasticizer is responsible for decrease the porosity (Khudhair et al., 2018), on this samples it obtained the highest theoretical porosity, relating directly to its drop in compressive strength. It is also important to stand out, as mentioned in Santos (2014), the binder/aggregate ratio usually stays around 0.33. However, M mortar had a ratio of 0.47 and additivated mortars WP and P had a ratio of 0.2, explaining the high compressive strength achieved for M, as the median of WP is 10% higher than P. One more time, the least amount of water used in the preparation of this sample, because of the use of plasticizer, might turned difficult for it to react with all the hydration compounds, resulting in the lowest compressive strength of the three samples. In addition, the cure process of the coating mortar was exposed to the environment, and not underwater as concretes, which could facilitate the evaporation of water to the environment. In M and WP cases, the hydraulic lime and the water retaining agent were efficient in retaining water against the evaporation.

After the aging cycle and the flexural strength experiment, it was performed the compressive experiment, results are also presented in Figure 8. M had a median 32% higher than WP and 24% higher than P, and comparing M with WP the median of P was only 6% higher than WP. Through results variability, it can be seen that this variation is sensitive on three samples, opposite of flexural strength, which we could not infer differences. After increasing the temperature and the subsequent water blasting, the water ends up entering through the micro cracks and pores, which may arise, producing more hydration products, then improving the compressive strength of the sample (Liang-Xiao and Cong, 2020).

Analyzing the aging samples, it is possible to observe that sample M (16.32 MPa) decreased its compressive strength by 3%, however due to the sample variability results, after and before the aging cycles, it is not possible to infer differences. Sample WP (12.38 MPa) decreased by 9%, and only sample P (13.14 MPa) increased the compressive results by 7%. In both results, WP and P presented sample's result differences, before and after aging cycle. However, the variation of the results was small, and as in P, the compressive strength increased instead of decreasing, due to the thermal cure of the non-hydrated compounds (Liang-Xiao and Cong, 2020). The results of compressive strength of samples subject to thermal shock may increase or decrease until heating up to 400 °C, comparing with samples without aging, only when it reaches 600 °C that it is possible to observe considerable drop in

strength (Shumuye et al., 2019). Initially, between 80 °C and 105 °C, only evaporable water in the sample is removed, generating more voids thus a greater porosity in the samples (Shumuye et al., 2019; Hagen, 2013), this could be associated with the drop in compressive strength of sample WP.

3.2.3 Tensile bond strength

During the experiment, the three samples were subjected to 10 wetting and drying cycles and were evaluated regarding the appearance of any pathological manifestations. In the first cycle, the coating with mortar M presented four micro cracks visible with naked eye and a small detachment (Figure 9). In the second cycle, appeared another micro crack on M. In the third cycle, it was observed a powdery behavior of M and mortar detachment in the lower right corner of the prism. In the seventh cycle, sample M presented a new micro crack and a little mortar detachment of the roughcast, also in the lower right corner of the prism. In all other cycles there was no observation to be highlighted. In other words, only the coating with mortar M visually presented pathological manifestations to be considered.

As seen in Figure 9, the micro cracks were highlighted with lines and the detachments with circles. As presented by the highest value of elasticity modulus and compressive strength, mortar M was the more rigid of all of them and that justifies the appearance of micro cracks, due to its difficult to absorb deformation. However, the more appearance of cracks does not mean that the sample possess the lowest compressive strength (Shumuye et al., 2019), as seen in the previous topic. The tensile bond strength was analyzed before and after the aging cycle, through the prisms (40x40) cm, the tensile bond results and the rupture location are presented in Figure 10.

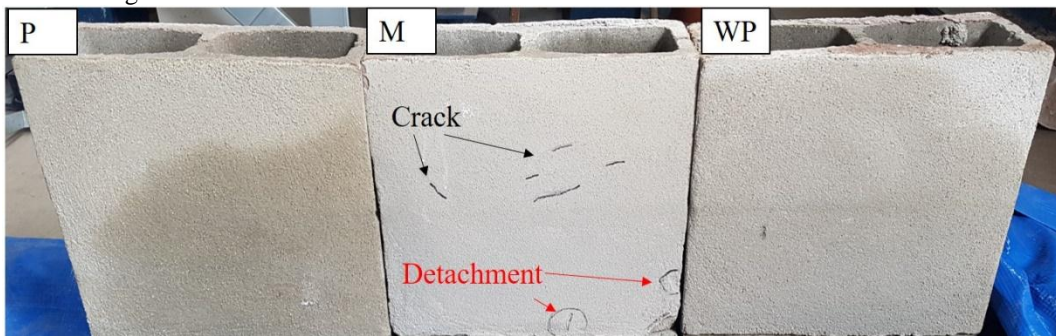


Fig. 9: Coating mortars after aging cycles of NBR 15575-4

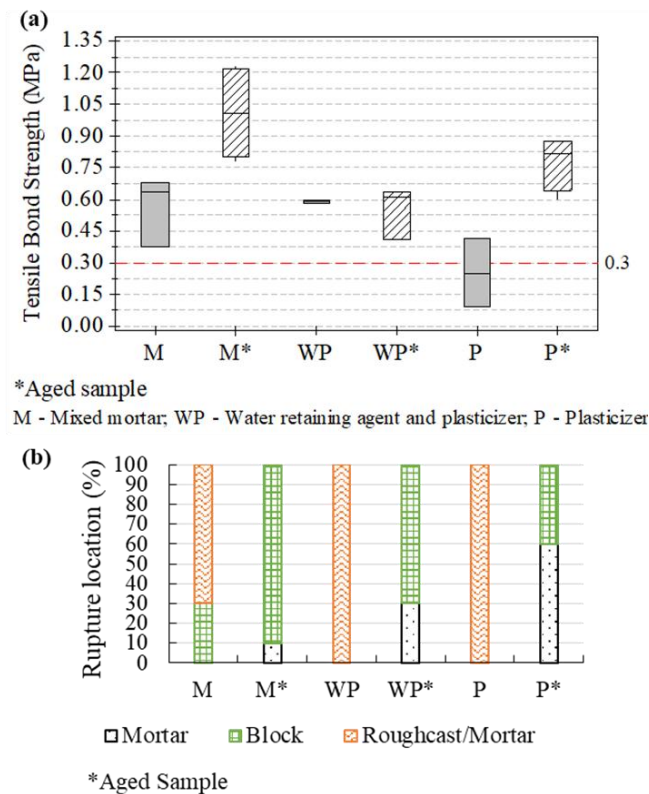


Fig. 10: Tensile Bond strength (MPa) (a), Rupture Location (b)

After doing the aging cycles according to the Brazilian standard NBR 15575-4 (ABNT, 2013), the experiment were performed again on all samples, Figure 10 (a). A change in the samples behavior was observed, M (1.01 MPa) remained with the highest result, 23% higher than P (0.82 MPa) and 65% higher than WP (0.61 MPa). A significant change in the rupture location was also observed, Figure 10 (b), it was observed only rupture in the block and in the mortar. The percentage of rupture in the block of samples M, WP and P were, respectively, 90%, 70% and 40%. Despite the strength gain of P the rupture location were mostly in the mortar coating, in other words the strength gain favored a better anchoring between the mortar and the roughcast making the mortar the fragile part of the group. Despite WP having the lowest result, M and WP had mostly of rupture location in the block, showing that the fragile part of the group was turned to be the prism in which the mortar are being applied. It is important to highlight that tensile bond strength results of 1.01 MPa (M) and 0.82 MPa (P) are extremely high results, as the Brazilian lower limit for mortar for external coating is 0.3 MPa. Despite mortar WP (0.61 MPa) having lower result compared with the other samples, it also has a satisfactory result for this property. It is also important to notice, that despite M presented micro cracks and detachments during the experiment, it was well adhered to the substrate. The hypothesis of the appearance of micro cracks was not related to the compressive strength loss (Shumuye et al., 2019) can be also applied for tensile bond strength, despite M was the only one to visually present pathological manifestations it was the sample with the highest result. The higher compressive strength and also the highest tensile bond strength may have affected the sample stiffness making it less susceptible to thermal solicitations generated during the experiment. These cracks and detachments must be treated with caution as they may allow water and deleterious agents percolation, reducing the service life of the façade.

Analyzing the behavior change between the same sample, before and after aging cycles, it is noted that all samples increased their tensile bond strength, some more than others. M (1.01 MPa) increased its median strength after the experiment by 57.5%, WP (0.61 MPa) increased its median strength by 2.5% and P (0.82 MPa) increased its strength by 229%. With the results showed, it is possible to observe that P increase was much more superior than the others samples, ceasing to be a mortar with tensile bond strength value below the lower limit of 0.3 MPa, turning to be a mortar coating with high adherence. As in the flexural and compressive strength, it is believed that due to the lower content of water used to prepare the sample, according to Table 3, the sample did not managed to supply the necessary water to hydrate all binder compounds, mainly the ones responsible for the tensile bond strength and anchorage of mortar/roughcast. But, after the aging cycles it suffered a thermal cure (water to hydrate and temperature to accelerate the reactions) generating strength gains (Shumuye et al., 2019), as well as the others samples however in a lower percentage. These gains showed in the results can be directly related, firstly, with the sample that used less water (P) and, secondly, with the sample that has the highest binder content (M), WP results hardly changed, demonstrating that its binder compounds were already hydrated and it have a proper components proportion.

Analyzing the rupture location of all samples before and after aging cycle, Figure 10 (b), it is noticed the change in the rupture form in all samples. All samples presented mostly adhesive ruptures (roughcast/mortar) before the 10 cycles. After the cycles it changed to mostly rupture in the block, demonstrating that the tensile bond strength results gain were very favorable for all samples, as their strength were enhanced. It is important to highlight that mortar P had 60% of the ruptures percentage in the mortar, which despite of improving the anchorage with the substrate, weakened the mortar, and it may occurred due to thermal expansion or porosity increase.

Miranda and Selmo (2005), on their study, subjected mortars to the aging experiment as established by Brazilian standard NBR 15575-4 (ABNT, 2013) and they did not observe tensile bond strength loss. However, Esquivel (2009), did the experiment with 30 cycles, instead of the recommended ten, and noticed tensile bond strength loss on all studied samples, besides the change of ruptures to mainly adhesive ruptures. Oliveira (2014), on the other hand, evaluated the experiment in relation to the restrictions that the samples are subjected and their dimension, he noticed that samples with 1.20m length without lateral bonds are subject to lower tensions compared with samples with 2.40m length with lateral bonds. The samples with 1.20m did not showed any significant changes during the experiment. With all the exposed, it is possible to observe that the experiment recommend by NBR 15575-4 (ABNT, 2013) can be more improved on several items, so it can better represent equatorial climate conditions as the one in Brazil. This explains, as seen in this study and in the bibliography review, the lack of resistance drops with this experiment.

4. CONCLUSIONS

Due to the results exposed, this study concludes, about the mortar characterization, that density did not showed considerable variability on the three samples. Although, open porosity and water absorption index tended to a small reduction with the addition of chemical admixtures. This is justified due to the secondary effect of incorporating air in the mixture because of the use of admixtures, and the incorporated air contribute to pore isolation. The theoretical porosity increased, demonstrating that the mixtures generate large pores because of anhydrate excessive water leaving the sample, thus, although the pores are not connected, they are larger. This implied a similar behavior on elasticity modulus and water retention, mortar WP showed reduction on these properties, also because of the free water that leaved the sample in hardened state, which was not detected on water retention experiment, generating voids and the reduction in elasticity modulus, been the mortar more suitable in absorbing deformation.

Analyzing the aging experiment, it is possible to conclude that WP presented a good behavior, because it did not show pathological manifestations (cracks and detachments) and its mechanical results did not vary with this procedure. The mixed mortar (M) showed no significant variability on flexural and compressive strength, but it had significant gain on tensile bond strength (due to the hydraulic lime carbonation after aging), however it presented detachments and cracks, behavior of a brittle

mortar, which reduce the service life of the façade and could also maximize the possibility of deleterious agents and water entering in the mortar.

Mortar coating with only plasticizer (P), before aging, did not reached the Brazilian lower limit of tensile bond strength for external use (0.3 MPa). Although, after aging the samples, this mixture (P) gained flexural and tensile bond strength (reaching the parameter), this occur because of the water used to cool the samples after the heating process of the experiment, contributing to hydration reactions of cement, which was not possible during environment cure (25 °C and 60% air humidity) of mortars.

Given the results exposed, this study concluded that the mortar WP would be more suitable to use because of durability parameters, and the tensile bond strength results that did not fluctuate. Mortar P would only be suitable for use if an effective cure of the coating was performed, because, after the final finishing of the façade (paint or another type of coating), this mortar would be isolated, and the strength gain observed in this study would not occur, being this mortar not suitable to use on façades. Related to the mixed mortar (M), it appeared to be suitable for use if its proportion had lower binder content, reducing the stiffness and the possibility to appear pathological manifestations, as cracks and detachments.

Therefore, in this research it was reported how different types of mortar can behave through service life subject to high temperatures, similar of equatorial regions as Brazil. It also showed that the better use of admixture is the combination of them and not its individual use. This study contributes to the evolution of mortars with admixtures knowledge as it present how the mechanical properties are influenced due to thermal cycles and highlight the pathologies that may arise. Differing from the literature that usually study the ageing influence on mortars without admixtures and did not previously characterize the samples being study.

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Conflict of Interest

Authors declare no conflict of interest.

Authors' Contributions

Alessandra Tolentino Souza: Formal Analysis, Methodology, Writing, Writing-review and editing; Gilberto Alves da Silva Neto: Formal Analysis, Methodology, Writing, Writing-review and editing; Henrique Silveira Neto: Data curation, Investigation, Visualization; Rodrigo Barreto Caldas: Conceptualization, Validation, Resources, Supervision, Funding acquisition; White Jose dos Santos: Conceptualization, Validation, Resources, Supervision, Funding acquisition.

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