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Resistance to carbonation of mortars for repairs of reinforced concrete structures

Study of cementitious mortars modified and unmodified with polymers

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ABSTRACT

This research sought to quantify the performance of acrylic polymer (As) in some of the properties of cementitious mortars. For this purpose, cementitious mortars modified and unmodified with this type of polymer, capable of satisfying the current European regulations for repair materials, more so when speaking of carbonation, were prepared. The resistance of mortars to accelerated carbonation was analyzed, with capillary absorption and oxygen permeability (given their interdependence with carbonation) being studied, and, being structural repair mortars, their mechanical strength was also assessed.

Ten cementitious mortars with CEM I 42.5 R were prepared, having been grouped together in two different sets: the experimental program of cementitious mortars modified with acrylic polymers (PCM of As), with a mass cement:sand ratio of one part of cement to three parts of sand (1:3), with the dosage of the polymer varied in relation to the cement (0, 10, 15 and 20%); the experimental program of cementitious mortar (CM) with quantities of cement relative to sand being 1:2, 1:3 and 1:3,5, alternating the addition of silica fume in the mortar. Aside from the observations with the electron microscope, all the tests in the hardened state were conducted after 28 days, the test specimens remaining in distinct cure conditions in each program.

KEYWORDS:

Cementitious mortars modified with polymers; cementitious mortars; acrylic polymers; silica fume; carbonation; mechanical strength; durability.

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1. INTRODUCTION

1.1. PRELIMINARY REMARKS

Repairs of reinforced concrete structures first emerged in the 20th century. Their usage around the world over the decades strengthened their position as one of the best options for civil engineering. For engineers and builders, reinforced concrete was considered a 'miraculous' material, for its ability to be molded and for its apparent indestructibility. However, a great amount of reinforced concrete structures reached their service life, and others showed signs of premature degradation, resultant from either mistakes in construction or in their projects, as well as deterioration of the concrete (mechanical, chemical and physical reactions) and on the steel reinforcing (carbonation and chlorides), as well as from a lack of maintenance.

The repairing of reinforced concrete structures is a reality in the universe of Portuguese building contracts. Not infrequently, the reparations themselves are flawed, there being several reasons for their failures. These reasons can be best observed in specific repairs, where the mortar-concrete interface's behavior is critical. In these repairs, cementitious mortars (CM) are the most commonly used, as well as cementitious mortars modified with polymers (PCM).

Especially because they are less costly, CM have been widely applied in the repair of concrete structures. The addition of silica fume to cementitious materials influences their properties in two ways: physically (reducing the permeability of the paste, reducing the size of pores and total porosity of the paste), and chemically (reducing the calcium hydroxide, $\text{Ca}(\text{OH})_2$, contents of cement pastes and consequently their alkalinity, since silica fume reacts with $\text{Ca}(\text{OH})_2$ to form calcium-silicate-hydrate (C-S-H)).

In general, the inclusion of polymers affects the fresh properties of cementitious mortars, by enhancing the workability, by extending the setting times and by causing heavy air entrainment in the absence of antifoaming agents. Also, the addition of polymer may lead to conferring further properties to hardened mortars, such as higher tensile and flexural strengths, adhesion, waterproofing and chemical resistance – with no improvement in compressive strength (Ohama, 1995), (Ribeiro et al., 2008). These improvements in the hardened state can be associated to the presence of polymer film in the cementitious comatrix.

1.2. SCOPE AND METHODOLOGY OF THE INVESTIGATION

The main objective of this study was twofold: on the one hand, to prepare cementitious mortars modified and unmodified with acrylic polymer capable of satisfying the current European regulations for repair materials (EN 1504-3), specifically in what concerns carbonation; on the other hand, to quantify the performance of acrylic polymer on some of the properties of cementitious mortars.

The resistance to carbonation was the property that underlied the development of this work. Capillary absorption and oxygen permeability (given their interdependence with carbonation) were studied and, as the mortars in case are structural repair mortars, their mechanical strength was also assessed. This assessment confirmed the beneficial effect of polymers on the tensile and flexural strengths of cement mortars, while not resulting in any improvement of the

compressive strength. Other properties, however, are also of importance in the context of repair mortars, specifically: substrate adhesion capacity, restriction of shrinkage and expansion, and adequate elasticity modulus.

In the preparation of the mortars, the imposition of using only powdered materials was set, in order to allow for easy large-scale production of pre-dosed mortars that require only the addition of water, *in situ*.

In this work, ten cementitious mortars were studied, having been grouped in two different sets: the experimental program of cementitious mortars modified with acrylic polymers – program A, or PCM of As; and the experimental program of cementitious mortar – programs B, C and D, or CM.

2. EXPERIMENTAL PROGRAM

2.1. MATERIALS

- Cement - ordinary CEM I 42,5 R Portland cement was used.
- Aggregates - the aggregate used was a natural siliceous sand, with $D_{max}=4,75$; $D_{min}=0,30$ and fineness module of 3,17 (according with EN 933-1).
- Silica fume (SF) – it was used only in CM, with 5% in mass of cement dosage.
- Redispersible polymer powder – it was used only in PCM. Infrared spectroscopy identified acrylic-styrenated copolymer as a main component.
- Expansive admixture – it was used only in CM, with the objective of minimizing the drying shrinkage effect. An 8% in mass dosage of cement was adopted.
- Superplasticiser admixture – a superplasticiser was used in the dosage of 2% in mass of cement, in order to use lower quantities of water to reach the desired consistency. In addition, the Data Sheets for the silica fume and the expansive admixture recommend the usage of a superplasticiser.
- Air entrainment admixture – there was a need to resort to an air entrainment admixture to match the air content of the A1 and A0 mortars.
- Water – the water dosage was adjusted as the polymer and cement dosage was changed, in order to maintain the consistency by flow.

2.2. MORTAR FORMULATION

The experimental program of cementitious mortars modified with acrylic polymers (PCM of As) was conducted using a mass cement:sand ratio of one part of cement to three of sand (1:3) and the dosage of the polymer was varied in relation to the cement – with P/C ratios of 10, 15 and 20% for the A1, A2, and A3 mortars, respectively. All mixes were prepared to have the necessary consistency for a practical application, namely, to exhibit a consistency by flow of $100\pm 10\%$. This program included a reference mortar (A0), with the same air content and water:cement mass ratio of the PCM with a P/C=10% (A1), so as to isolate the polymer's action and evaluate its impact on mortar properties. The air entrainment and superplasticiser

admixtures were used, respectively, to equalize the air content and the consistency by flow of PCM A1.

Table 1 – Mortar mixes of PCM

Materials	Mortar mixes (kg/m ³)			
	A0	A1	A2	A3
Sand	1349,4	1250,6	1255,7	1234,1
Cement	449,8	416,9	418,6	411,4
Polymer As	-	41,7	62,8	82,3
Water	164,9	152,7	130,2	123,4
Air entrainment admixture	0,04	-	-	-
Superplasticiser admixture	2,3	-	-	-
Cement:sand ratio	1:3	1:3	1:3	1:3
Consistency by flow, %	87	106	97	100
W/C	0,37	0,37	0,31	0,30
P/C, %	0	10	15	20

In the other experimental program, the addition of silica fume, as well as the mass cement:sand ratio in cementitious mortars (CM) unmodified with polymers were alternated. Specifically, three different mass cement:sand ratios were analyzed (1:2, 1:3, 1:3,5, respectively for the B, C, and D subprograms). Intrinsically in each subprogram, two mortars were formulated (1 and 2) with the same dosage of binder. In mortars 1 silica fume was added, unlike in mortars 2. For the calculation of the mass binder:sand ratio, the binder included the dosage of silica fume and of cement (Cement+SF:Sand). All mixes were prepared to have the necessary consistency for a practical application, as in program A.

Table 2 – Mortar mixes of CM

Materials	Mortar mixes (kg/m ³)					
	B1	B2	C1	C2	D1	D2
Sand	1194,2	1242,6	1349,5	1406,6	1398,3	1439,1
Cement	597,1	652,4	449,4	492,3	399,9	431,7
Water	194,1	201,5	208,5	206,8	216,7	220,2
Silica fume	29,9	-	22,9	-	19,6	-
Expansive admixture	47,8	52,2	36,4	39,4	32,1	34,5
Superplasticiser admixture	11,9	13,1	9,0	9,9	8,0	8,6
(Cement+SF):sand ratio	1:2	1:2	1:3	1:3	1:3,5	1:3,5
Consistency by flow, %	107	108	97	102	93	102
W/C	0,33	0,31	0,46	0,42	0,54	0,51

In cementitious materials modified with polymers, wet cure must not be resorted to, because it slows or inhibits the polymeric particles' agglutination and, consequently, the polymer film's formation in the cementitious matrix. Therefore, two different curing conditions were considered, namely:

- Curing of PCM – Demould after 24 h and wrap in film for 48 h. Then, unwrap and cure for 25 days in a standard laboratory climate of (21±2) °C and (60±10) % RH;
- Curing of CM – Demould after 24 h. Then, cure under water at (21±2) °C for 27 days.

2.3. TESTS ON MORTARS

The flow consistency of mortars was determined according to section 10.3 of ASTM C 109. The air content was determined according to method B of ASTM C 231. The mortar's fresh density was measured according to EN 12350-6. Detailed results of the testing of the fresh mortars are available in Table 1, in the Appendix.

All the tests of hardened mortar were conducted after 28 days. The mortar's strength was determined in accordance to EN 196-1 and EN 12190, using prismatic specimens with dimensions of (4x4x16) cm, and each strength value is the average of 3 samples of the same batch. The capillary absorption was measured in accordance to EN 13057. To evaluate the oxygen permeability, the LNEC E 392 specification was used. The resistance to carbonation was measured according to EN 13295. Detailed results of the testing of the hardened mortars are available in Table 2, in the Appendix.

To support this research, observation of mortars' microstructures were performed, with a scanning electron microscope (SEM) and X-ray spectroscopy. After testing the compressive strength, small samples of the broken surface were collected, and coated with a gold layer. In order to remove the inorganic portion, some samples (particularly PCM) were treated, after the coating, with HNO₃ during 5 hours and were subsequently washed thoroughly with water and dried at 40 °C.

3. RESULTS AND DISCUSSIONS

The flow's consistency values are illustrated in Figure 3.1 and Figure 3.2, for PCM and CM, respectively, to keep flow constant.

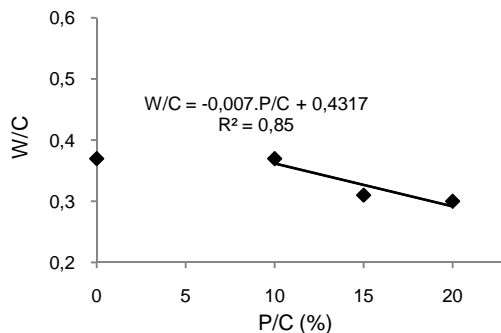


Figure 3.1 – W/C ratio of PCM As

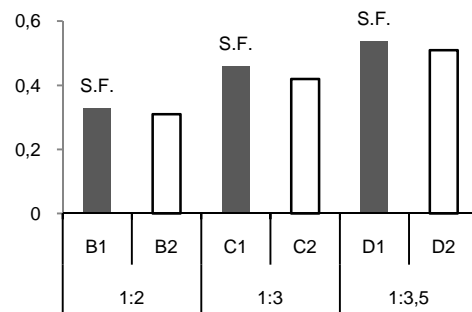


Figure 3.2 – W/C ratio of CM

In PCM, in order to maintain the consistency by flow (100±10%), the dosage of water decreases with the increase in acrylic polymer dosage. The As polymer acts as a superplasticiser because of the dispersed effects of surfactants present on the surface of the polymer's particles, associated with air bubble entrainers and with the spherical polymer particles, leading to an improved dispersion of cement and to an increased workability of the fresh mixture with a lower requirement of mixing water. In CM, to maintain the flow, it was necessary to increase the dosage of water with the decrease in the dosage of cement in the mass cement:sand ratio.

Mortars with silica fume required greater amounts of water to keep the same flow. In the mortars with the mass cement:sand ratio of 1:3, the acrylic polymer used in PCM was more effective in the reduction of water dosage ($W/C=0,3$) than the superplasticiser used in CM ($W/C=0,4$), used in the dosage of 2% in mass of cement. In CM, the $W/C=0,3$ ratio was only reached in mortars with a mass cement:sand ratio of 1:2.

The air content values for PCM are illustrated in Figure 3.3. The air content of CM was only determined in B1, B2 and C1, being respectively of, 3,9%, 4,0% and 4,5% (the standard range of air volume variation in cementitious mortars, is of 3 to 5%). It is considered that the ratio of $P/C=20\%$ of As is very near to the saturation point of the polymer. The air content was higher in PCM than in CM (approximately three to four times higher), but without putting the viability of PCM as mortars for repair in question. The air content of PCM decreased linearly with the increase in the P/C ratio.

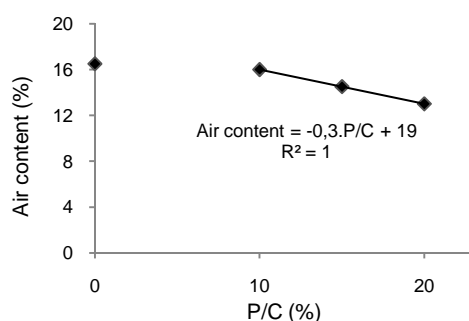


Figure 3.3 – Air content of P/C

The fresh density of mortars is presented in Figure 3.4 and Figure 3.5, respectively, for PCM and CM. In PCM, the increase of fresh density with the increase of P/C was evident - being expected because of the lesser incorporation of air in the mortars. In the CM, the reduction of the fresh density's values with the transition of the 1:2 ratio to the 1:3,5 ratio was notorious, especially due to the reduction of the cement dosage and the increase of added water. The CM with SF in their constitution presented a slight increase in the fresh density, for the same ratio. Since the fresh density is greatly influenced by the air content of the mortar, the fresh densities of the PCM of As ($<2000 \text{ kg/m}^3$) were far lower than the fresh densities of the CM.

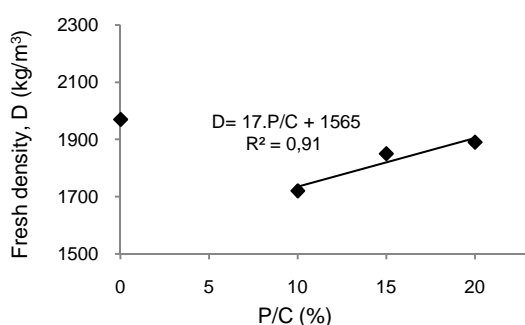


Figure 3.4 – Fresh density of PCM

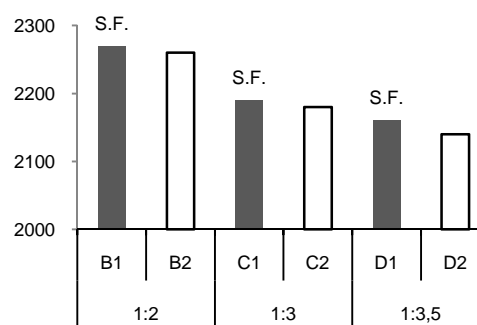


Figure 3.5 – Fresh density of CM

The results of flexural strength of PCM and CM are presented, respectively in Figure 3.6 and Figure 3.7.

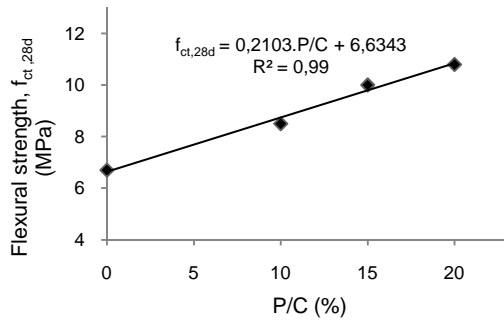


Figure 3.6 – Flexural strength of PCM

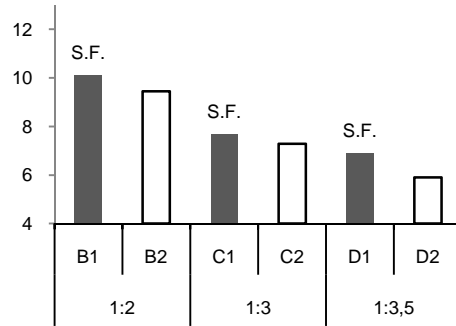


Figure 3.7 – Flexural strength of CM

The flexural strength of PCM increased linearly with the increase of the mass P/C ratio. The beneficial action of polymers on flexural strength may be related to two simultaneous phenomena: atrophy of hydrated $\text{Ca}(\text{OH})_2$ crystals and lower microcrack density in the paste, specifically in the paste-aggregate interface. It was verified that PCM A1 showed an increase of 20% in flexural strength when compared with the A0 reference mortar, with the same air content and mass cement:sand ratio, which reveals the effectiveness of the polymer in the increase of flexural strength.

In the CM, the loss of flexural strength was noticeable when the ratio between cement and sand is decreased and the W/C ratio is increased. The CM that incorporated SF showed flexural strength slightly higher than that of the mortars with the same mass cement:sand ratio without the addition.

It was in flexural strength that the effect of the polymer was most noticeable. The PCM A1 (P/C=10%) showed greater flexural strength than the CM with the same mass cement:sand ratio, C1 and C2. The PCM A2 (P/C=15%) matched CM B1, which is a mortar with more cement. Finally, the PCM A3 (P/C=20%) showed the most flexural strength of all mortars, reaching a gain of 30% when compared to the CM C1, with the same mass cement:sand ratio.

The results of compressive strength of the mortars are indicated in Figure 3.8 and Figure 3.9, respectively, for PCM and CM.

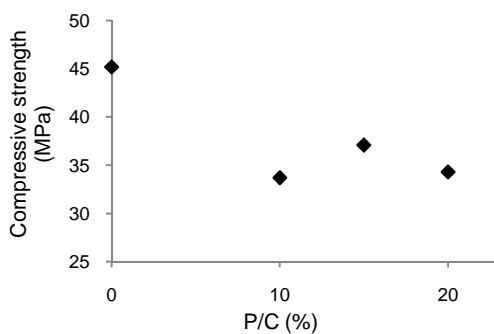


Figure 3.8 – Compressive strength of PCM

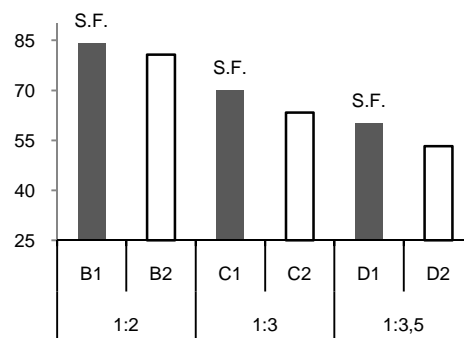


Figure 3.9 – Compressive strength of CM

The compressive strength of PCM was harmed by high levels of air content. It was considered that this reduction was due to the polymers' delaying of the process of cement hydration and increase of the mortar porosity (Ohama, 1995), (Ribeiro et al., 2008). According to EN 1504-3, all of the PCM of As can be classified as being of resistance class R3 ($25 \text{ MPa} < f_{c, 28d} < 45 \text{ MPa}$). In the CM, the loss of compressive strength (as with flexural strength) was noticeable when the ratio between cement and sand was decreased and the W/C ratio was increased, and the mortars with SF produced better results. In accordance to EN 1504-3, all of the CM can be classified as being of resistance class R4 ($f_{c, 28d} > 45 \text{ MPa}$).

The addition of polymer was detrimental to compressive strength. When comparing PCM and CM, with the same mass cement:sand ratio (1:3), CM showed gains of between 40 to 50% regarding compressive strength.

The results of capillary absorption of mortars are presented in Figure 3.10 and Figure 3.11, respectively, for PCM and CM. Detailed results are accessible in Table 2, in the Appendix, where results of the sorption coefficient can be accessed.

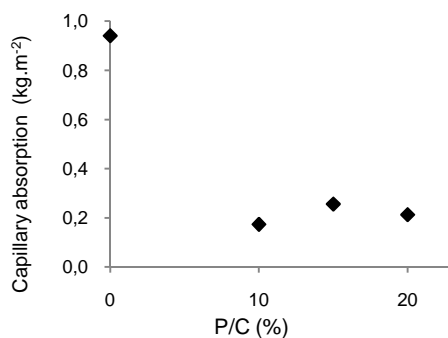


Figure 3.10 – Capillary absorption of PCM

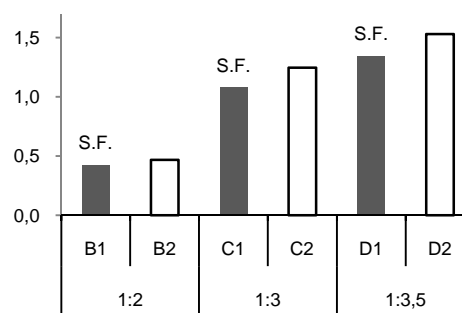


Figure 3.11 – Capillary absorption of CM

The PCM A1 (P/C=10%), with the same air content and W/C than the reference mortar A0 (P/C=0%), absorbed 1/5 of the water within 24 hours, which reveals the effectiveness of the polymer in the reduction of capillarity. The rise of the P/C ratio from 10% to 15 and 20% slightly increased the water absorption after 24 hours, a fact which can be justified with the lower level of air content in these PCM. In practice, the polymer As increased the closed porosity of the PCM, reducing capillary suction via the sectioning of the capillary pores. In addition, the polymer film contained in the cementitious matrix also prevented water absorption by the capillaries of the cement paste, by obstructing them.

In the CM, as expected, the capillary absorption increased with the reduction of the cement dosage and with the increase of the W/C ratio, accompanying the lower compactness of the mortars and the increase of the capillary pores' density. The CM that contained SF showed a lower absorption of water by capillarity than the CM without the SF (with the same mass cement:sand ratio and a similar W/C ratio).

The beneficial effect of the addition of polymer in the capillary absorption of cement mortar was confirmed. The PCM sorption coefficient was an order of magnitude lower than the sorption of CM, regardless of the mass cement:sand ratio adopted.

The results of the oxygen permeability coefficients are indicated in Figure 3.12 and Figure 3.13, respectively, for PCM and CM.

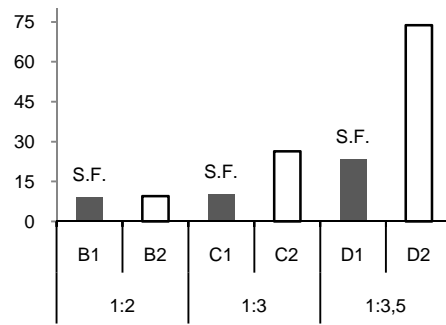
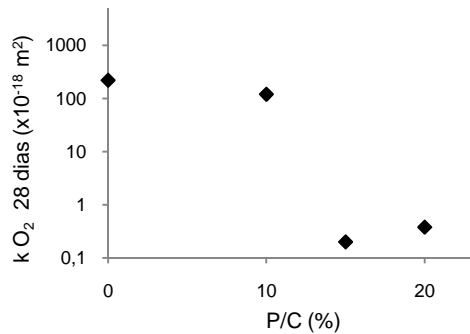


Figure 3.12 – Oxygen permeability coefficient of PCM Figure 3.13 – Oxygen permeability coefficient of CM

The PCM A1 (P/C=10%) with the same air content and W/C than the reference mortar A0 (P/C=0%) showed a lower oxygen permeability coefficient (k_{O_2}), of half, which reveals the effectiveness of the polymer in reducing the mortar's permeability to gases. The rise of the P/C ratio from 10% to 15 and 20% reduced k_{O_2} drastically. The reasons for this reduction were the lower volume of voids, as well as of the percentage of micropores accessible to the gas, by obstruction of the polymer film spread over the cement matrix.

The k_{O_2} in CM increased with the decrease of the cement:sand ratio, and with the increase in the W/C, as in the case of capillary absorption. The CM that incorporated SF showed better results than mortars with the same mass cement:sand ratio, without the addition.

The PCM A2 and A3 presented very low k_{O_2} , lower by an order of magnitude than the more impervious CM, B1 and B2, in which the mass cement:sand ratio was 1:2.

The carbonation depths are illustrated in Figure 3.14 and Figure 3.15, respectively, for PCM and CM. It should be noted that the carbonation depth of the reference concrete was 1,2 mm, in accordance to EN 1766.

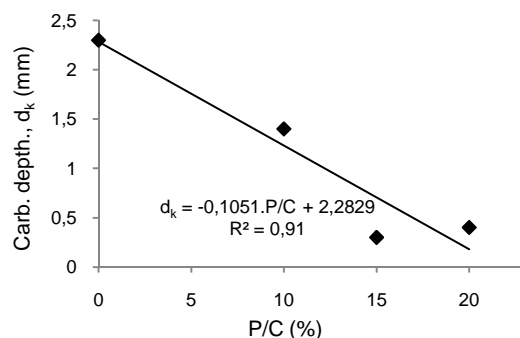


Figure 3.14 – Carbonation depth of PCM

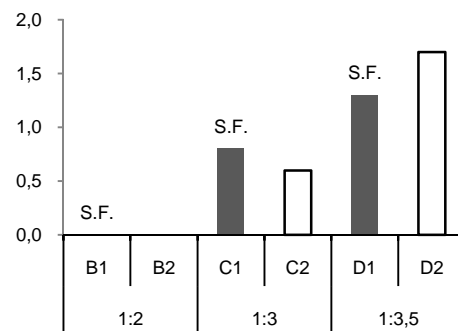


Figure 3.15 – Carbonation depth of CM

In the PCM of As, the linear decrease of the carbonation depth (d_k) with the increase of P/C was evident. The PCM A1 (P/C=10%) with the same air content and W/C than the reference mortar A0 (P/C=0%) showed a lower carbonation depth, by half, which reveals the effectiveness of the polymer in increasing the mortar's resistance to the process of carbonation. It is considered that the polymer As, aside from reducing the permeability to gases, tends to coat the crystals

resulting from the hydration of cement, including crystals of calcium hydroxide, via its polymer film – reducing its reactivity with the carbon dioxide dissolved in the interstitial solution. In accordance to EN 1504-3, only PCM A2 and A3 (respectively P/C=15% and P/C=20%) can be applied to structural repairs without requiring an additional coating to protect against carbonation, because they showed a carbonation depth lower than that of the reference concrete ($d_k=1,2$ mm).

In the CM, as expected, the carbonation depth increased with the reduction of the cement dosage and with the increase of the W/C ratio. In the CM with a mass cement:sand ratio 1:3, unlike in the other tests, the addition of SF revealed itself to be harmful to the resistance to carbonation. It can be related to the consumption of Ca(OH)_2 by the hydration of SF and the lower dosage of cement in these mortars. In CM B1 and B2 (mass cement:sand ratio of 1:2) there was no carbonation, but they have greater oxygen permeability than PCM A2 and A3, explaining the high amount of Ca(OH)_2 formed, due to the high cement of these mortars. In accordance to EN 1504-3, only CM D1 and D2 cannot be applied to structural repairs without requiring an additional coating to protect against carbonation.

Comparing the mortars of the same mass cement:sand ratio (1:3), the PCM A2 and A3 showed a lower carbonation depth than CM C1 and C2, by half, but all of these mortars showed smaller carbonation depths than the reference concrete.

As for porosity (Figure 3.16 and Figure 3.17), the following can be noted: a decrease in the volume of voids with the rise of P/C; the shapes of the air voids introduced both by the addition of the polymer As or by the air introducer (in A0) were rounded; the CM showed itself as being more compact and dense than the PCM, with a very reduced density of macropores ($\varnothing > 10^{-4}$ m).

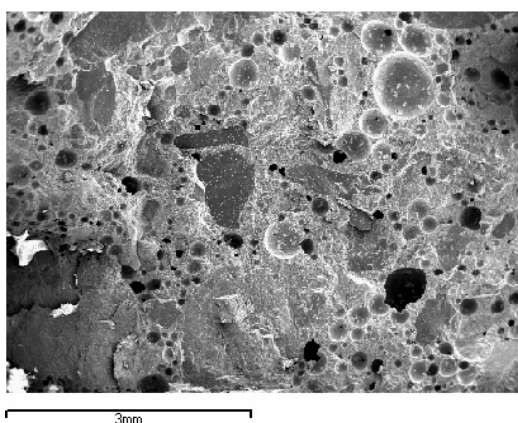


Figure 3.16 – Porosity of PCM A3, 20x

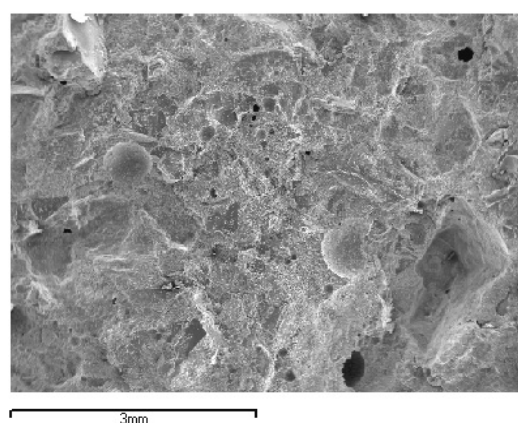


Figure 3.17 – Porosity of CM D1, 20x

The polymer film formed on the PCM A1 (Figure 3.18) and A3 (Figure 3.19) is disseminated in the cementitious matrix and coats the pores' surface, appearing as a cover, that when fissured is reminiscent of a rubbery material. The cementitious matrix and the pores have a glazed appearance. In PCM A3, the polymer film appears to have greater elasticity and thickness than the polymer film in PCM A1 and, consequently, greater will the coverage of the crystals be.

In the paste-aggregate interface of PCM A1 (Figure 3.20) and A3, the polymer film to link the paste to the aggregate was clearly observed, appearing as rubbery material, as opposed to the observed in CM (Figure 3.21), with a hard appearance – and thus more fragile – which favors the propagation of cracks. With treatment, it was easy to observe the existence of bridges in the paste-aggregate interface.

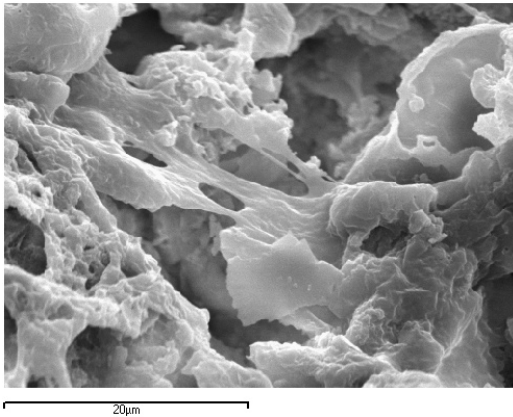


Figure 3.18 – Polymer film of PCM A1, with treatment, 3000x

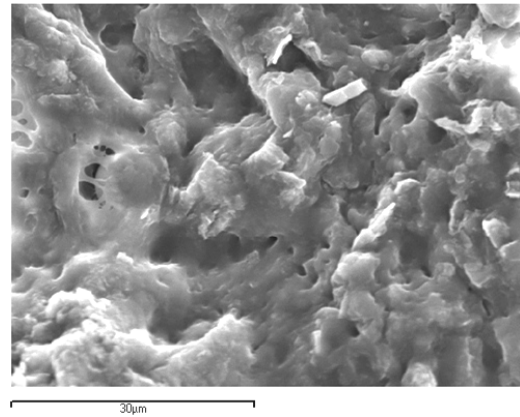


Figure 3.19 – Polymer film of PCM A3, with treatment, 2000x

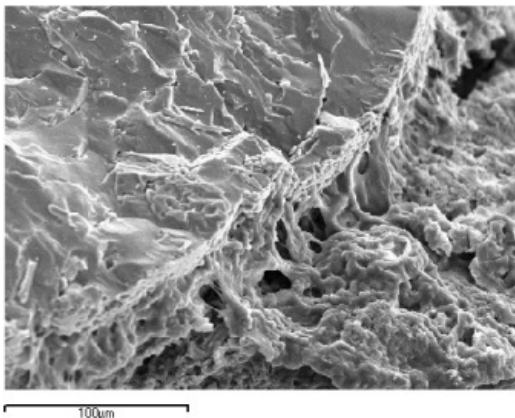


Figure 3.20 – Paste-aggregate interface of PCM A3, with treatment, 450x

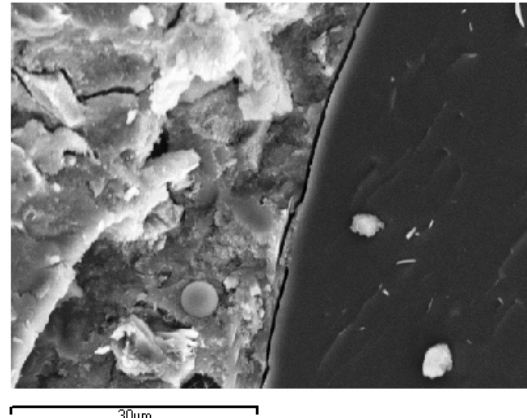


Figure 3.21 – Paste-aggregate interface of CM C1, 2000x

The existence of the polymer film coating the surfaces of PCM (Figure 3.22) seems to prevent the free growth of crystals formed from calcium. When these crystals break the polymer film, they tend to grow preferentially in the direction perpendicular to the surface. The CM B2 (Figure 3.23) and B1, because of their greater age and cement content, have a greater density of formed crystals, for which reason they revealed to be the mortars most resistant to carbonation. In comparing PCM A3 with CM C1, of equal age and mass cement:sand ratio, the difference of quantity and stage of development of the formed crystals was notorious.

It is considered that the As polymer may act in the resistance to carbonation in two ways, whether separately or simultaneously: physical effect, chemical effect, or physicochemical. The SEM program led to observing the physical effect of the polymer in resistance to carbonation: coating and atrophying the formed crystals, namely the calcium hydroxide ones.

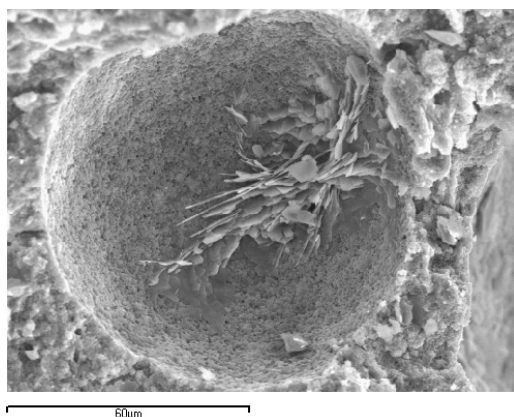


Figure 3.22 – Macropore of PCM A3, without treatment, 1000x

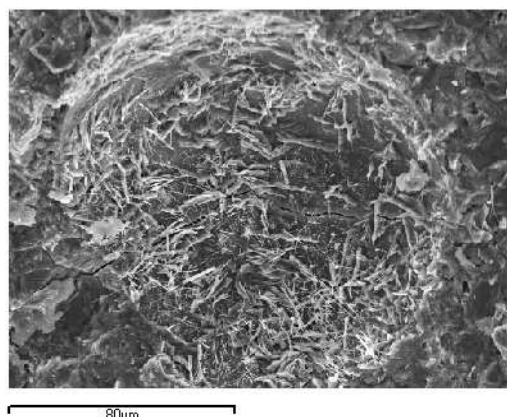


Figure 3.23 – Macropore of CM B2, 700x

4. CONCLUSIONS

The tests performed on the PCM of As confirmed that the polymer As decreases the compressive strength of cement mortar but increases its flexural strength. It is considered that the reason for this mechanical behavior of PCM is the polymer's action simultaneously on the atrophy of the growth in hydrated $\text{Ca}(\text{OH})_2$ crystals and on the reduction in the density of microcracks in the paste-aggregate interface, associated with the delay in the cement hydration and with the increase in the air content of PCM.

The polymer As also reduces the capillary absorption and oxygen permeability coefficient, both of them parameters which contribute to increasing the resistance to carbonation of cement mortar. It was observed that the addition of polymer As in P/C=15% ratio, reached the requirement of carbonation and class R3 of compressive strength, according to EN 1504-3.

The test performed on the CM demonstrated that a mass cement:sand ratio of 1:3,5 failed to meet the requirement of resistance to carbonation, but met the requirement of class R4 in compressive strength (>45 MPa) and satisfied the requirement of sorption coefficient capillary ($<0,5 \text{ kg}\cdot\text{m}^{-2}\cdot\text{h}^{-0,5}$). With a mass cement:sand ratio of 1:2, there was no carbonation.

The addition of silica fume, with the objective of increasing the compactness and reducing the segregation of the CM, contributed to improving the quality of the mortar's surface layer, thereby increasing the resistance to carbonation of the CM.

The observations of the microstructure of both the PCM by SEM were in line with the effects of the macropores being coated by polymers and crystalline atrophy (namely, hydrated $\text{Ca}(\text{OH})_2$ crystals inside the pores). The polymeric bridges at the paste-aggregate interface and the polymeric film's morphology in the cement paste were both observed.

5. REFERENCES

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APPENDIX

Table 1 – Results of the testing of the fresh mortars

Mortar	Cement:Sand (in mass)	W/C	Consistency by flow (%)	Air content (%)	Density (kg/m ³)
A0	1:3	0,37	87	16,5	1970
A1	1:3	0,37	106	16,0	1720
A2	1:3	0,31	97	14,5	1850
A3	1:3	0,30	100	13,0	1890
B1	1:2	0,33	107	3,9	2270
B2	1:2	0,31	108	4,0	2260
C1	1:3	0,46	97	4,5	2190
C2	1:3	0,42	102		2180
D1	1:3,5	0,54	93	-	2160
D2	1:3,5	0,51	102		2140

Table 2 – Results of the testing of the hardened mortars

Mortar	Flexural strength (MPa)	Compressive strength (MPa)	Capillary absorption (kg.m ⁻²)	Sorption coefficient (kg.m ⁻² .h ^{-0,5})	Oxygen permeability coefficient (x 10 ⁻¹⁸ m ²)	Carbonation depth (mm)
A0	6,7	45,2	0,941	0,192	219,00	2,3
A1	8,5	33,7	0,173	0,036	119,50	1,4
A2	10,0	37,1	0,256	0,028	0,20	0,3
A3	10,8	34,3	0,213	0,022	0,38	0,4
B1	10,1	84,2	0,423	0,086	9,08	0,0
B2	9,5	80,7	0,466	0,095	9,45	0,0
C1	7,7	70,1	1,080	0,220	10,30	0,8
C2	7,3	63,3	1,245	0,254	26,39	0,6
D1	6,9	60,3	1,344	0,274	23,45	1,3
D2	5,9	53,3	1,530	0,312	73,77	1,7