THE USE OF POLYMER CEMENT MORTAR IN THE REHABILITATION OF SERVICE STAIRS IN LISBON, PORTUGAL

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Abstract

Sixty-year old reinforced concrete service stairs were strongly affected by corrosion of their reinforcement, clearly showing the effect of carbonation of concrete.

This structure represents a construction solution particularly used in the 40s to 50s of the twentieth century in several Lisbon areas. It was used for giving access to the patio and for evacuation in case of emergency and, normally, was located in the back of the building.

The complete replacement of the carbonated concrete cover was achieved by a high quality polymer cement mortar (PCM), of styrene-butadiene polymer dispersion.

This paper describes the different activities undertaken during the rehabilitation, the problems encountered during the works and, finally, the lessons learnt from this project.

1. INTRODUCTION

Repair of concrete structures has been representing an increasing proportion of the activity of the construction industry. However, the high diversity of repair products is not always accompanied by quantitative information on the performance properties for the appropriate selection to the intended use.

In order to know and to better understand the service performance of repair products, upon completion of concrete repair works, these products must be regularly inspected and tested.

This case study aimed to select a repair work, in which it was possible to monitor the over-time performance of applied products, and comprised tests in situ and in laboratory. A conventional concrete structure was chosen, with repair methods also conventional, but of which the monitoring during and after repair was feasible. This study is part of a research project, jointly subsidized by the Foundation for Science and Technology (FCT), which enables the long-term monitoring of repair works, and is expected to continue over time.

The structural element of this study consisted of the exterior service stairs belonging to the building located in Lisbon, Conde de Monsaraz street, Penha de França. It is a hybrid building characteristic of the 40-50 decade with a mixed structure of masonry and reinforced concrete, having five floors above ground and a half-buried one, with exterior service stairs made of reinforced concrete that connect the posterior approaches. The façade wall of this building is made of stone masonry, the interior walls of brick masonry and the floors are made of reinforced concrete massive slabs, with stairs and balconies of reinforced concrete.

Due to the advanced deterioration of the structure and to the owner's interest in rehabilitating the entire building, works were undertaken which included the repair of the exterior service stairs. These works had three-month duration and represented a total investment of approximately Euro. 20,000 for a lifetime of 20 years.

2. ASSESSMENT OF THE CONDITION OF THE EXTERIOR STAIRS

2.1 Visual inspection

The first stage of the repair works consisted of assessing the defects and their causes and of evaluating the ability of the concrete structure to perform its function.

Figure 1: Left side view of the stairs

Figure 2: Front/right side view of the stairs

Mention must be made of the most relevant aspects observed in the visual inspection:

- the absence of cover on the underside of the flight and landing was widespread and the remaining plaster was delaminated or micro cracked (Figs. 1 and 2);
- reinforcement corrosion and delaminated concrete was much less in the piers and beams than in flights, landings and guards (Figure 3);
- the worst deterioration of concrete was in the last two landings (Figs. 1 and 2), as they are the most vulnerable ones to the action of rain, sun, wind. The concrete was, in general, micro cracked around the coarse aggregate and the loss of steel-area on reinforcement due to corrosion was high, jeopardizing the ability of the structural element to perform its function (Figure 4);
- the absence of a constructive detail, intended to avoid the runoff of water on the underside of the landings, has caused and accelerated the reinforcement corrosion due to the consequent increase in the relative humidity of the concrete (Figure 4).

2.2 Tests in situ

To assess the condition of the existing concrete and of the reinforcement and to identify the causes for defects in the structure, *in situ* tests were performed before the beginning of repair works.

A high variation in the cover thickness was observed, which ranged from 5 mm to 53 mm, as well as in the thickness of the plaster, ranging from 8 mm to 25 mm.

The carbonation depth in the piers reached 64 mm and involved the whole element in the guards. For this reason, most of the reinforcement was subject to a corrosion process with a reduction in its cross-section.

Figure3: Deterioration of landing (underside)

Figure 4: Deteriorated concrete in the final landing

2.3 Causes and extent of deterioration

It is considered that the concrete deterioration derived from insufficient cover or lack of it and from the chemical loss of alkalinity, as a result of the reaction with atmospheric carbon dioxide (carbonation). In fact, the concrete of this structure has not been designed for a service life of 60 years.

3. REPAIR WORKS

3.1 Preparation of concrete

Weak, micro-cracked, delaminated and carbonated concrete was removed by mechanical percussion and with high pressure water and sand blasting (<60MPa). In order to maintain the structural integrity of the stairs, the concrete removal was kept to a minimum. However, in the two last flights, the slabs were all demolished and reconstructed due to the advanced degree of deterioration, which jeopardized the ability of the structural element to perform its function and, therefore, temporary supports were carried out.

Corrosion was present in most of the reinforcement bar exposed or embedded in carbonated concrete. After carbonated concrete removal, preparation of reinforcement consisted of removing rust and cleaning the dust and deleterious material by water and sand jets, which did not exceed a pressure of 18MPa, and of subsequently painting an adhesion promoter coating on the whole circumference of the exposed reinforcement. In the cases where high loss of steel-area was observed on reinforcement, additional reinforcement was fixed by anchoring to the concrete substrate with an epoxy based product (*Soldepox Ref.906*). Coating reinforcement consisted of a CEM I cement paste modified with an acrylic copolymer (*Regicril Ref. 412*).

3.2 Application of repair mortar

In order to assess the behavior in service and over time of repair mortars, a comparison was made between two cement mortars, which were modified with the two most marketed polymers in Portugal.

Therefore, for the concrete restoration, two polymer cement mortars (PCM) were used: one with an acrylic-styrene polymer, PCM of As (*Pavicril Ref.415*) and another with a styrene-butadiene polymer, PCM of SB (*LATEX EMULSION*). The cement was CEM I 42.5 R and the polymers were aqueous dispersions with total solids of 35% As and 23.5% SB, respectively, according to EN 480-8. The sand was a mixture of two natural siliceous sands with a smaller amount of sand with high clay content (the more yellow sand), passing in a sieve with an aperture size of 5mm. To reduce plastic cracking of PCM, polypropylene fiber was added (*Fibril ® F*) using the dosage recommended in the technical information of the product (1 bag of 600g/m^3 of PCM). The volumetric trace of the PCM was 1 cement: 2.7 sand: 0.2 polymer, for a solid polymer/cement mass ratio (P/C) of 6% for the As polymer and of 4% for the SB polymer.

Both PCM were manufactured in situ and applied using the spraying equipment for plaster (Fig.5). The consistency of PCM was adjusted to obtain a projection without formation of voids and with a minimum loss of material by rebound (Fig.6).

At the site, a slump of 12.5 ± 2.5 mm was adopted (Fig. 7), which corresponded to a consistency by flow of 107 ± 5%, according to ASTM C 109 (Fig. 8). It should be noted that the correlation line between the two methodologies ($Consistency_{ASTM\ C\ 109}$ [%] = 2. $Slump_{In\ place}$ [mm] + 82) was previously determined in laboratory.

The PCM composition enabled its application in a simple layer finishing with strikeoff (Fig. 6). The thickness of PCM ranged from 30 mm to 50 mm.

Figure 5: Spraying PCM of SB

Figure 6: Aspect of layer before finishing

Figure 7: *In situ*, slump of PCM of AS

Figure 8: Lab: consistency by flow of PCM

Curing of PCM was not necessary because the weather was rainy and foggy. Twelve hours after the application of PCM, the finishing layer of plaster was spread on followed by the application of a surface painting (*membrane CINOFLEX*).

For comparison purposes a current mortar was also prepared used. Current mortar was made *in situ* with cement type CEM II/B-L 32.5 N, with the same silica sands, but with a large amount of the yellow one, which contains a higher clay content (clay to provide the necessary thixotropy to mortar), and the same polypropylene fiber, with equal volumetric trace. Slump was 10 mm, corresponding to a flow consistency of 102% according to ASTM C 109.

In order to prevent the draining of water on the underside of the landing a hollow out was performed along all the edges (Fig. 9), which serves as a pickaxe.

4. IN SITU QUALITY CONTROL

In situ quality control was focused on the properties of concrete substrate, on the acceptance of repair products, on the conditions before and during its application and on final hardened and long term properties of the PCM of As and SB. Quality control was carried out using in situ tests and observations, based on Table 4 of EN 1504-10.

Adhesion bond strength of PCM was evaluated according to EN 1542 (Pull-off Test, dry state). The tests were done at 7 days, due to the need of plaster and finishing paint applications. Before core drilling, a rebar detector (Covermeter) was used to avoid cutting existing or additional reinforcement.

To assess the porosity of PCM, in particular by gas permeability, tests were carried out *in situ* with Torrent equipment, according to Swiss standard SN 505 262/1 (Fig.9). However, it was not possible to test the PCM, as the roughness of PCM surface was high.

Figure 9: Torrent test in PCM of As

During PCM application, prisms were moulded to measure both the flexural and the compressive strengths at 28 days, respectively, according to EN 196-1 and EN 12190, and each strength value is the average of three samples from the same batch. The halves of the prisms resulting from flexural and compressive strength measurements were cut in order to use the sections without microcracks for the carbonation resistance measurement of PCM at 1% CO_2, in accordance with EN 13295. Lateral faces and the broken surface of these sections without microcracks were protected with an insulating coating (epoxy resin) so that the access of CO_2 occurs only on the surface of the broken surface. Each value is the average of three samples.

For measuring the oxygen permeability, followed by capillary absorption and open porosity at atmospheric pressure, according to Cembureau Recommendation, EN 13057 and RILEM Recommendation CPC 11.1, respectively, cylinders were moulded, which were cut into 50 mm thick pieces, and each value is the average of six samples from the same batch.

5. RESULTS AND DISCUSSION

Table 1 presents the average values obtained in tests performed on PCM of As and SB and on current mortar.

Table 1: Results of tests on PCM of As and SB and on current mortar

PCM of As	**PCM of SB**	**Current mortar**
Flexural strength at 28 days, MPa		
5.7	7.7	4.0
Compressive strength at 28 days, MPa		
21.5	41.5	19.2
Adhesion bond strength at 7 days, MPa		
1.1	1.2	Test not performed
Oxygen permeability, $x10^{-16}$ m^2		
5.110	0.543	29.320
Capillary absorption coefficient, $kg.m^{-2}h^{-0,5}$		
0.565	0.230	2.581
Open porosity, %		
21.0	17.9	20.5
Carbonation resistance at 1% of CO_2, mm		
90 days in the chamber		28 days in the chamber
19	7	10
Change in mass in the carbonation chamber, g		
90 days in the chamber		
+ 1.3	+ 0.6	Test not performed

6. RESULTS AND DISCUSSION

The compressive strength of PCM of SB (41.5MPa) fulfils the value specified in EN 1504-3 for the R3 structural class of repair products (≥25MPa), although not reaching the value specified for R4 structural class (≥45MPa). R3 class was considered to be the most suitable class for repairing concrete stairs due to its low concrete strength. The PCM of As had a value 3.5 MPa less than that specified for R3 class (21.5MPa), which, in this case, is considered to have resulted mainly from the polymer action in the delaying of cement hydration process [MS Ribeiro, 2008]. The low strength value of current mortar is probably associated with the lower strength class of the cement used and with the higher clay content contained in the sand mixture.

The average of adhesion bond strength at 7 days was 1.2 MPa, a value that, at 28 days, is likely to be very close to the value specified in EN 1504-3 for R3 structural class at 28 days of repair products (≥1.5 MPa).

The oxygen permeability of the PCM of As is high (≥ 1.0 $x10^{-16}m^2$) [1]. The value is an order of magnitude higher than that of PCM of SB. These results are consistent with the values obtained in the carbonation resistance, which were higher than the value obtained on concrete reference samples (1.5mm), according to EN 1766. Based on Table 3 of EN 1504-3, PCM of As and SB are not suitable for protection against carbonation unless the repair procedure includes a surface protection system with proven protection against carbonation. The plaster and the finishing paint applied may improve in order to fulfill the durability requirements of EN 1504-2, but this was not tested.

The oxygen permeability of current mortar was an order of magnitude higher than that of PCM of As. The carbonation depth of current mortar at 28 days was also high, probably due to the use of CEM II.

The capillarity coefficient of PCM of SB fulfils the value specified in Table 3 of EN 1504-3 (≤ 0.5 kg $m^{-2}h^{-0,5}$), whereas the value obtained in the PCM of As is slightly higher than the specified value. The current mortar had a coefficient of capillary an order of magnitude higher than that of PCM of As.

Open porosity, i.e, the water absorption at atmospheric pressure, mainly reflects the macropores volume ($r(m) \geq 10^{-4}$) and part of the capillary pores ($r\ (m) \geq 10^{-7}$).

The mass increase of samples during the accelerated carbonation test is due the formation of calcium carbonate [MS Ribeiro, 2004].

7. FINAL COMMENTS

PCM production is as easy as production of current cement mortars, and its production control is also easy to perform.

PCM do not require the addition of water reducer admixtures because polymers have also this function. However they also act as air entrainers and setting retarders.

The polymers in PCM provide the thixotropy need for repairs, which makes the application easier than current cement mortars. It makes possible to reduce the use of sand with high clay content.

The cost of using PCM is not significant in the total repair cost.

The PCM of SB showed a better performance than the PCM of As, and it was observed that polymers are more effective in reducing capillary than permeability, which is in accordance with others works [1]. It is assumed that this action results from the lining of the capillary pores by the polymer film, which changes the surface tension in the pores and reduces capillary suction, rather than from changing the capillary structure or from its obstruction.

Once again, it was observed that polymers improve adhesion to concrete and decrease the carbonation depth. On the one hand, as polymer addition makes mortar more deformable (by reducing its modulus of elasticity) the adhesion strength will be less weakened over time, thus increasing the mortar bond. On the other hand, the polymer may acts physically by coating the hydrated $Ca(OH)_2$ crystals, in such a way that it delays their reaction with CO_2 and, by changing the mortar porometry, it hinders the diffusion of CO_2.

Under the FCT project, this repair will be continuously inspected by *in situ* tests to assess the over time performance of applied PCM. Therefore, this study is expected to proceed by using the results obtained from further tests performed on these PCM in the medium and long term.

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