The performance of cement-based coatings for drinking water reservoirs: a case study

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Abstract. Drinking water reservoirs are often made of cementitious materials. The inorganic mineral phases exhibit a similar chemical composition as the natural rocks. This enables the concrete in contact with drinking water to be a safe material with respect to the human health. The carbonate or the free-CO2 content of the water control the extent of the concrete deterioration. To increase the durability, cement-based mortars are applied as a coating. In this work, the damage on site and in laboratory, such as bubbles, cracks and microcracks formation, leaching effects and detachments of three cement-based coatings were investigated. The coating systems exhibited conventional mechanical parameters, such as the compressive and flexural strength, but a different behavior with respect to the cracks formation. This fact was dependent from the coating thickness, application features, water content, superplasticizer dosage, environment parameters and mortar quality. The damage was less related to the mechanical properties, in particular the compression strength. The coatings generally exhibited a dense compact microstructure. The addition of superplasticizers promoted the segregation of the aggregates. The fine particles were concentrated along the surface layers, which in turn, were more susceptible to the environmental changes. The coatings adhesion strength was always above 2 N/mm² for the coatings tested in laboratory. A reliable and acceptable adhesion that increased the durability.

1 Introduction

Cementitious materials, such as mortars are used in many applications. They are applied for injection systems, to seal cracks or to protect steel anchorage from corrosion. In these cases, the material has to be sufficiently fluid to reach and fill all the small air voids around the steel bars. Mortars are also often used as a restoration material for facades, where the modulus of elasticity of the supporting concrete layer needs to be higher than the sprayed mortar. This allows a better adhesion of the mortar and reduces the crack formation on the surface. In addition, mortars are known for anchoring bolts [1, 2]. They are also used for industrial pavement applications, where high mechanical properties and load bearing capacity are required. In these latter systems, the resistance to abrasion caused by vehicles movement and a high durability are also fundamental aspects. The single or multi-layer mortars need to fulfill many technical requirements. A reliable strength value must be reached in structural components. The self-leveling capability is a factor that needs to be considered during the application on site, while the surface aesthetic finishing must guarantee a satisfactory homogeneity with respect to the color, the porosity and all visual aspects [3]. In the recent years, superplasticizers have implemented their control on the quality of the fresh and the hardened state of mortars [4]. These latter are widely added to the cementitious materials in different percentage depending upon the chemical composition of the additive. In addition, setting condition, water type and the temperature may also influence the final properties of the mixtures [5]. In fact, a strong relationship exists between these latter parameters, the microstructure, the mechanical, physical, chemical properties and the durability. The mixing and the ingredients may also affect the deterioration of the material. Efflorescences [6] may occur during the service life. These can be caused by the leaching of the external surface and the salt enrichments. They often do not have a direct consequence on the main properties of the material, but an adverse influence on the visual impact of the surface.

2 Experimental

A visual inspection of the reservoir was carried out. Furthermore, laboratory samples were prepared to better understand the damage reasons. A mortar base mixture with a conventional water content 3.5 l water pro 25 kg binder was mixed (MA). In addition, a mortar with a higher water content (MB), with a conventional water content and superplasticizer addition 1% (MC), and with a conventional water content and a higher superplasticizer content (MD) were prepared. The mortars were applied on a cementitious support. Mortar MA was applied with a toothed spatula with 8 mm thickness on four specimens. Lately, on each sample a new layer of MA, MB, MC and...
MD, was applied with different thickness: one sample with 8 mm, another with 16 mm. For each set and thickness two specimens were prepared. After 48 hours one sample was cured at 20 °C and 50 % R. H. (dry curing), the other sample at 20 °C and 95 % R. H. (humid curing). The adhesion strength was measured in two zones. Five tests on each sample were carried out on cylindrical specimens with a diameter of 50 mm [7].

3 Results and discussion

3.1 Reservoir mortar degradation

The thickness of the mortar coatings was variable from 0.5 to 6.1 mm for the self-leveling thin layer to 7.2-16.5 mm, for the underlying layer. The piles and the walls did not exhibit degradation (Fig. 1 upper image). On the contrary, cracks and bubbles were observed on the pavement (Fig. 1 lower image).

Fig. 1. Pile and walls (upper image) and pavement damage (lower image).

The microstructure of the base concrete exhibited siliceous-feldspar based aggregates with a maximum diameter of 4.0 mm. A good adhesion with the mortar was seen (Fig. 2 upper image). The levelling mortar exhibited a thickness between 5.7 and 6.8 mm. More binder and less aggregates with a maximum diameter 1.4 to 4.4 mm were observed. Cracks were detected across the entire thickness. The latter mortar exhibited a good adhesion with the additional levelling mortar (Fig. 2 middle). This latter had a thickness from 4.6 to 5.8 mm. The matrix was more dense than the previous mortar. Silica fume was added to cement. The thickness was variable. Occasionally 5 µm fine cracks were detected, as well as more pores with a maximum diameter between 1.0 and 1.3 mm. The levelling mortar of the third layer was in partial contact with the water proofing mortar (layer 4). The thickness was 8.4 to 10 mm. It exhibited a polymer modified cementitious matrix with aggregates with a maximum diameter of 900 µm to 1.8 mm. The cracks width varied from 40 - 100 µm to 3.7 mm (Fig. 2 lower image).

Fig. 2. Good contact between the base concrete and the levelling mortar (upper image). Continuity contact between levelling mortar (layer 2) and additional mortar of the third layer (middle image). Discontinuity contact between layer 3 and 4 mortars. Nicols // (lower image).
The water proofing self-levelling mortar of the layer 5 exhibited a thickness around 3.8 - 4.0 mm. A high matrix content and aggregates with a maximum diameter between 100 - 300 µm were seen. This latter mortar was likely applied fresh on the fresh layer 4 (Fig. 3 upper image). The water proofing mortar of the layer 5 exhibited vertical and pseudo-horizontal cracks in the inferior part (Fig. 3 middle image) as well as vertical cracks in the upper part (Fig. 3 lower image).

The adhesion strength on the pavement was measured in a time superior than 28 days. The depth and the rupture mainly occurred within the support. Nonetheless, some data were relatively low, below 1 N/mm² (Table 1).

Table 1. Reservoir mortar system: adhesion strength values.

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<thead>
<tr>
<th>Dimension</th>
<th>Adhesion strength</th>
<th>Depth and rupture type</th>
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<tr>
<td>cutting depth</td>
<td>Adhesion strength</td>
<td>Depth and rupture type</td>
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<tr>
<td>[mm]</td>
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<tr>
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<td>50.2</td>
<td>0.7</td>
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<td>29</td>
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<td>27</td>
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3.2 Laboratory vs. reservoir mortars

The laboratory mixes were prepared by varying the main ingredients, in particular the water, the superplasticizer content, the curing and the thickness. This was done to identify the possible causes of the damage seen in the reservoir. The adhesion strength values were compared between the laboratory samples (tested after >19 days) and the one’s tested on site (> 28 days). The adhesion strength on the reservoir exhibited four specimens out of five to fail within the support and one along the interface mortar/support. The values ranged from 0.35 to 1.31 N/mm² (four specimens). The fifth specimen showed 1.26 N/mm². The laboratory adhesion strength between the water proofing mortar and the support exhibited values between 2.1 and 2.7 N/mm².

The laboratory sample products tended to crack formation. The cracks were eliminated through workability and the surface finish with the trowel. The curing conditions were decisive with respect to the crack formation. The cracks formed regardless of the temperature [5]. They formed with different opening width in the dry condition cell. In the humid cell condition, cracks were seen only in the specimens with high mortar thickness. The increase in the mixing water dosage promoted the cracks development in the dry condition. Despite the general positive effect of superplasticizers [4], their inappropriate use, such as a too high dosage, promoted the crack formation, while the application of a thickness higher than 10 mm triggered the crack formation as well. On the other hand, no bubbles were observed in the laboratory mixtures. The addition of the superplasticizer induced the aggregate segregation and a major concentration of the binder and fine aggregates to the surface. Therefore, the mortar coating was more sensitive to the curing condition. The layers with a thickness above 8-10 mm, activated the cracking in both the reservoir and in the laboratory mortars. In addition, the change of mortar thickness in the reservoir was also a critical zone with respect to crack formation. Bubbles in the reservoir mortars were likely due to the superplasticizer addition during mixing and the air production within the cementitious material. This also
depended on the mixing procedure on site. They were not caused by air or water vapour exited from the underlying concrete support.

In the laboratory samples there was a negative influence of water and superplasticizer dosage as well as the self-levelling mortar thickness variation with respect to the crack formation. The curing condition also influenced the crack presence in both laboratory and reservoir mortars. The cracks were especially observed in the reservoir mortars, where an air flux through the openings occurred during the works (Fig. 4). The laboratory mortar mixture coating MA applied with a conventional thickness (sample left in the image 4a and 4b) and with a superior thickness (sample right in the image 4a and 4b) cured in the humid cell condition did not exhibit a significant crack formation (Fig. 4a e 4b on the left). In the dry cell curing condition the sample with a superior thickness started to exhibit cracking (right sample in all image). The mortar mixture coating MB blended with a higher water dosage showed a significant cracking only with the superior thickness in both the humid (Fig. 4c on the right) and dry curing condition (Fig. 4d on the right).

The mortar coating MC added with a superplasticizer showed only a slight crack formation with a conventional thickness, while a significant cracking with a superior thickness in both humid (Fig. 5a on the right) and dry curing condition (Fig. 5b on the left). The mortar coating MD with a higher superplasticizer dosage exhibited a slight cracking with conventional thickness and a significant cracking with a superior thickness in both humid (Fig. 5c on the right) and dry curing condition (Fig. 5d on the right). The absence of silica fume with a less dense mixture and the maximum diameter aggregate reduction from 2 to 1.2 mm promoted the crack formation in the laboratory samples. Nonetheless, the measured adhesion strength values on the support were always superior to 2 N/mm² [7]. A general good value. The superplasticizer addition induced a higher segregation of the fine particles on the surface with a higher curing susceptibility. The curing susceptibility was also seen within the reservoir mortars.

Fig. 4. Mortar MA and MB plates cured in the humid and dry condition. The sample on the right of every image indicated the specimen with a superior thickness.

Fig. 5. Mortar MC and MD plates added with a superplasticizer and cured in the humid and dry condition. The sample on the right of every image indicated the specimen with a superior thickness.

4 Conclusion

Cracks and bubble formation on the mortar coating was due to the use of self-leveling mortar with a significant thickness variation. The adverse influence of water and superplasticizer dosage, thickness and environmental curing condition on the cracks formation was seen. The cracks formation was promoted and increased with the superplasticizer addition. The underlying cementitious support was not carefully prepared in order to allow an uniform thickness application of the mortar coating. Consequently, a mortar with variable thickness was present. In addition, the presence of an air current through the reservoir openings promoted the local formation of cracks. The adhesion strength between the support and the first mortar layer was good. Therefore, the removal of the superior layer could be done easily in order to restore the situation. On the other hand, the addition of superplasticizer to the self-leveling mortar must be re-evaluated.

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References
