Research focused on low carbonation of concrete under old cement-based render

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Introduction

Carbonation of concrete is a slow process during which the atmospheric CO_2 reacts with the compounds of the cement matrix, especially with portlandite. Speed of carbonation is governed mainly by diffusion and depends on the quality of concrete (the amount and type of cement used, water to cement ratio, used admixtures, etc.), environmental conditions (relative humidity, wetting and drying cycles, temperature, etc.) and amount of CO_2 concentration in the surrounding air. Based on many research projects and experience it could be stated that the better is the concrete quality, the lower is the speed of carbonation. However, during the study of 100 years old bridges in Slovakia, it was observed, that in some cases, also the poor quality concrete could have negligible carbonation. It has been found that a dense PRC applied 100 years ago was able to prevent the underlying concrete from carbonation. This unexpected result was observed on several bridges from the beginning of the 20th century when a PRC applied to the concrete surface was a common practice to enhance the aesthetic properties of a bridge. However, this PRC has proven a feature to be also an effective carbonation barrier. During in-situ research of a 125 years old Monier type concrete bridge in 2014, it was first observed that a thin PRC (2-3 mm thick) protected the underlying concrete from carbonation. Repeated measurements in 2015 proved the previous results with in-situ (by the phenolphthalein pH indicator) and later also by laboratory measurements (thermal analysis). In the next years, other bridges were found from the beginning of the 20th century, with the same results.

Figure 1. The carbonation depth of concrete at the places with a thin layer of PRC at the surface – sample selected from the measurements performed in 2018 (Bridge in Sládkovičovo).

Figure 2. The carbonation depth of concrete at the places where the render was missing – sample selected from the measurements performed in 2018 (Bridge in Sládkovičovo).

Figure 3. The carbonation depth of concrete at the places with a thin layer of PRC at the surface – sample selected from measurements performed in 2019 (Bridge in Rimavská Sobota).

Figure 4. The carbonation depth of concrete at the places where this render was missing – sample selected from measurements performed in 2019 (Bridge in Rimavská Sobota).

Measurement methods and results

In-situ measurements consisted of the following steps:

- The surface with the PRC was cleaned and permeability measurements with Torrent method were performed;
- Permeability was measured directly at the places, from where drilled core samples were taken. By this means it was possible to correlate the permeability measurements with measurements of carbonation depth;
- After drilling the core sample, it was properly cleaned with water pouring in the direction from the top of the cylinder to avoid contamination of the carbonated layer by non-carbonated concrete dust particles. After cleaning, the sample was wiped and a 1% solution of phenolphthalein was applied to its surface, again in the direction from the outer surface of the cylinder.

By this procedure, the carbonation depth was measured in-situ at all drilled core samples, which were then taken to the laboratory for further chemical analyses by TG-DTA method.

In-situ investigation, as expected, showed some relationship between the permeability measured on the PRC and the carbonation depth of the underlying concrete. Most of the measured places appeared to be almost impermeable (measured results by the Torrent permeability tester were below $0{,}01 \times 10^{-16}$ m²) and at these places, the underlying concrete showed negligible carbonation depth (max. 2 mm) even after being exposed to XC3 exposure class for more than 100 years. In some cases, negligible carbonation was measured also in cases, where permeability results were a bit higher. It was also observed, that even a small crack (crack width below 0,05 mm) caused higher permeability results and also a higher carbonation depth at this location. The results of these in-situ measurements are presented in tables 1, 2, and 3 for different, more than 100 years old bridges.

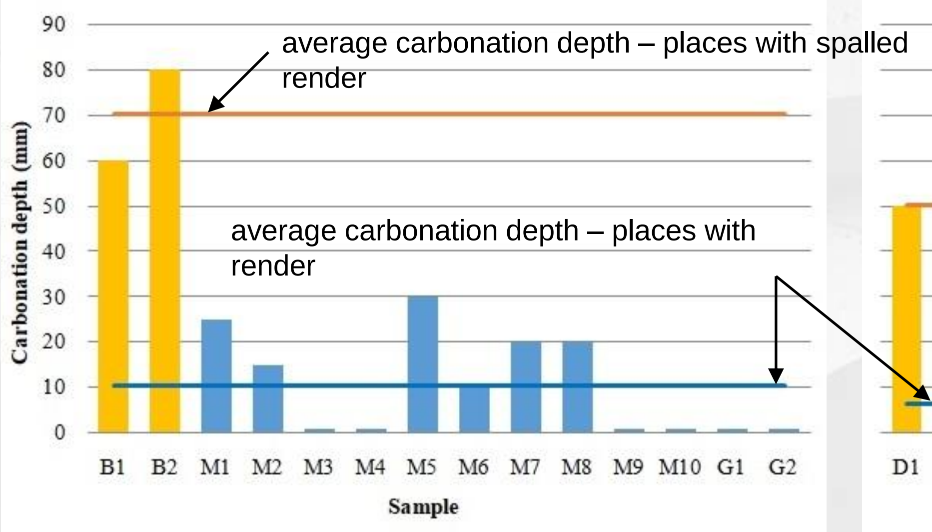


Figure 5. Results of in-situ measurements of carbonation depth at the Bridge in Sládkovičovo.

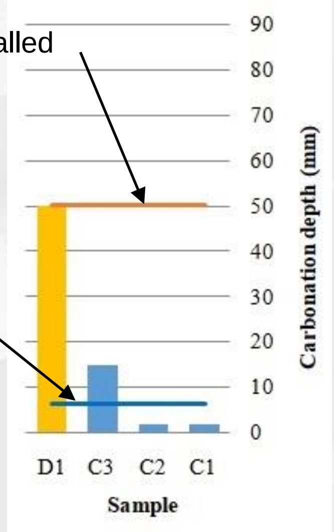


Figure 6. Results of in-situ measurements of carbonation depth at the Bridge in Rimavská Sobota.

It might be kept in mind that no chemical admixtures or additions, were used at the manufacture of the PRC at the time of the bridge construction 100 years ago. It is stated, that the observed low carbonation depth of underlying concrete can be explained by the protective effect of a thin cement render layer only, which is at some places almost non-permeable for CO_2. At the places, where the PRC was of good quality, carbonation of the underlying concrete was negligible (less than 2 mm, even 0 mm). Even at the places where the concrete was covered by a lower quality cement-based render it had much lower carbonation depth than concrete at the places where the protective render coat spalled over time.

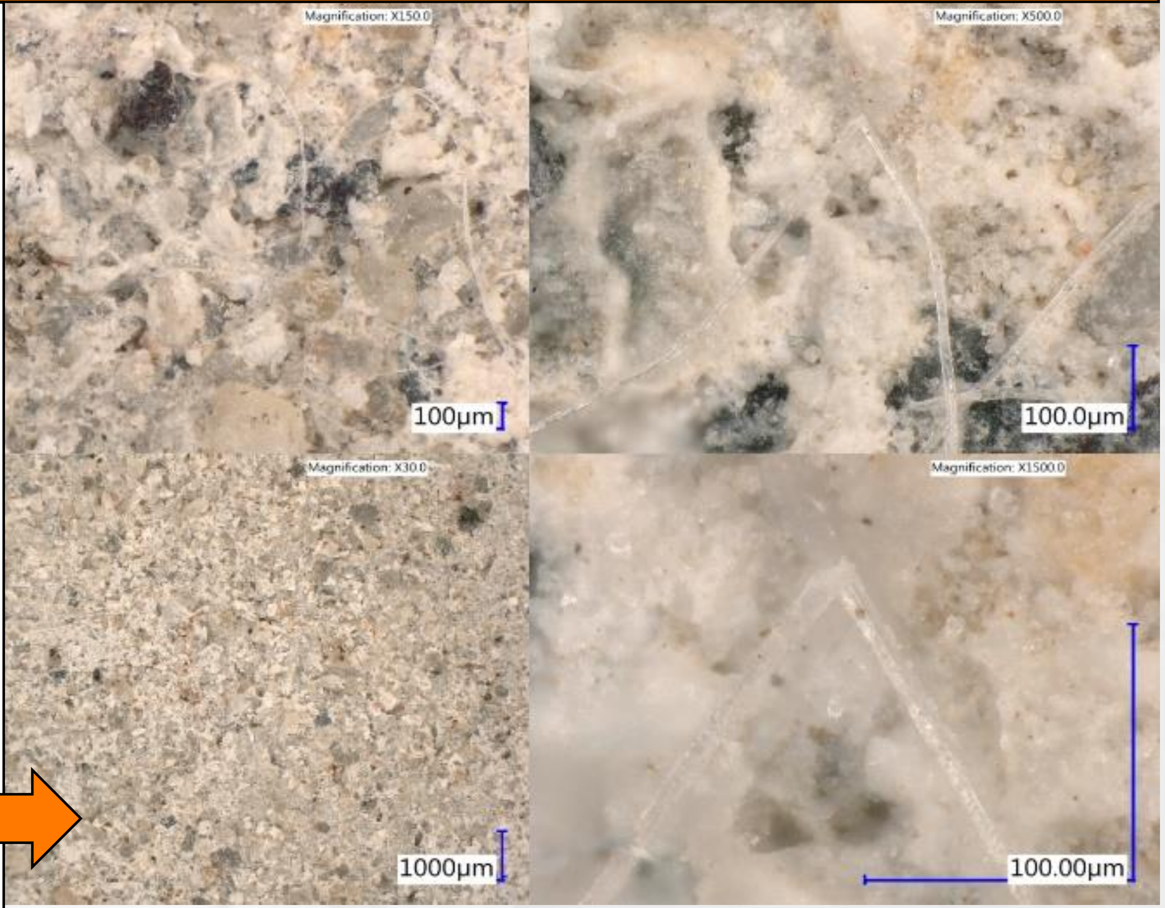
Conclusions

The possible explanation of the extremely low permeability of the cement render and thus its superior protection of the underlying concrete could be summarized as follows:

- The in-situ measurements of carbonation depth, which were also demonstrated by thermal (TG-DTA) analysis showed, that a good quality thin cement-based render (PRC with a thickness of only 2-3 mm) can effectively protect the underlying concrete against carbonation.
- The study of permeability of the PRC indicates a close mutual correlation between the coefficient of permeability measured by the Torrent method and the carbonation depth of the underlying concrete.
- One of the possible explanations of the very low permeability of the PRC could be the self-sealing of the pore structure by carbonation products, which occur in the thin cement-based render. Self-sealing of the PRC open pore system is caused by the accumulated fine-grained carbonate alternates instead of coarse-grained carbonation products.

The reduced content of coarse-grained $CaCO_3$ in the original, old cement-based render, can be attributed to a narrow space capable for its formation. One can assume, that when carbonation products were forming, the spatial deficiency does not allow the growth. As a result, a narrow free space filled with the fine-grained carbonate can cause the observed significant reduction of permeability of the PRC, which at many samples was almost impermeable to air.

Images from the optical microscope at various magnifications show at first invisible, but at higher magnification demonstrable, the accumulated layer of predominantly fine-grained $CaCO_3$ within the cement-based render as seen in figure 8. Shining needles show also the presence of crystal-developed coarse $CaCO_3$ compressed within the render thickness. The fine-grained character of the formed dense, as if sintered, carbonates in confined spatial conditions inside the 2-3 mm thick render creates the best condition for the built limestone-based barrier with the ability to dramatically reduce CO_2 penetration into the underlying concrete over time.



Thank you for your attention!

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