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The carbonation and chloride penetration along highway concrete structures in a South alpine space

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Abstract. Reinforced concrete structures are subjected to atmospheric agents during time. The cyclic exposure to natural parameters such as temperature, wind, rain and snowfall may emphasize the detrimental effect on structures. The different types of infrastructure may also be exposed to artificial phenomena such as, salt spreading, splashing of salt containing water or leaching effects. These phenomena contribute to the degradation of cementitious material, and the main induced mechanisms are carbonation and chloride ingress into the structures. Many types of structure such as tunnels, underpasses, walls, bridges and manholes have been investigated along a 11 km long highway close to the Alps in their South part. The aim of the study was to clarify the extent of carbonation and chloride ingress, as well as their relationship over a 40 year period. The mean climatic parameters were also registered over the years. Generally, the structures exhibited a different behaviour. The carbonation was maximal in tunnels and underpasses. A generalyl high chloride content was found for all artefacts, well beyond the 0.025 % referred to the concrete mass up to 0.400 %. The tunnels exhibited both high mean carbonation and chloride content, while all other structures indicated a slight correlation between high chloride content and low carbonation. These latter parameters were also influenced by processes such as leaching, splashing and indirect exposure to the degrading agents

1 Introduction

A major concern in the degradation of civil engineering infrastructure is the corrosion of reinforced concrete [1]. Deicing salts spread along the transportation ways during winter promote an increase of the chloride content within the structures. This is responsible for the depassivation of the oxide protection film on the rebars and causes corrosion [2]. The ingress of the chloride ions is particularly promoted by drying-wetting cycles [3]. Aside from the chloride induced rebar deterioration, carbonation is an additional detrimental process for reinforced concrete degradation. The pH reduction of the cementitious material causes rebar corrosion in the presence of oxygen and moisture. In tidal zones, both carbonation and chlorides may be present, because of the relative high humidity [4]. Although the general presence of high humidity may reduce the carbonation effects [5].

Nonetheless, both phenomena in bridge abutments in cold regions [6] and an increased degradation of the structure were also reported [7]. In a relatively cold climate, particularly present in the South Alps, the cyclic exposure of the infrastructure to temperature variation, wind and humidity is a major concern. In winter, a high amount of salts are spread along highways. This study focuses on the chloride presence and carbonation of different highway structures such as tunnels, walls, bridges, underpasses, and manholes, along an 11 km long route close to the Alps. The aim of the work is to find out the relationship between the carbonation and the chloride penetration within the different type of structure.

2 Experimental procedure

The South Alpine climate of the last 40 years exhibited a mean winter temperature (Jan-Feb-March) of -0.7°C, a mean summer temperature of 13.8°C and a mean temperature variation during the year of 17°C. The mean rain / snow fall during winter was 82 mm and in summer 154 mm. All artefacts were oriented along the North-South axis. Concrete cores were drilled from different 40 year-old highway components: two tunnels, five walls, sixteen bridges, thirteen underpasses and five manholes. The carbonation front (minimum, maximum and average) was determined by using a basicity indicator i. e. phenolphthalein [8]. The chloride content was determined with 10 mm steps down to a depth of 40 mm [9].

3 Results and discussion

The mean carbonation of the different artefacts varied significantly between 1.7 to 11.6 mm. In some cases, the values reached peaks up to 40 mm. The lowest data were observed for the walls and the manholes (mean

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carbonation 2.9 mm, Std. 2.1), while the highest were seen for the tunnels and underpasses (Fig. 1).

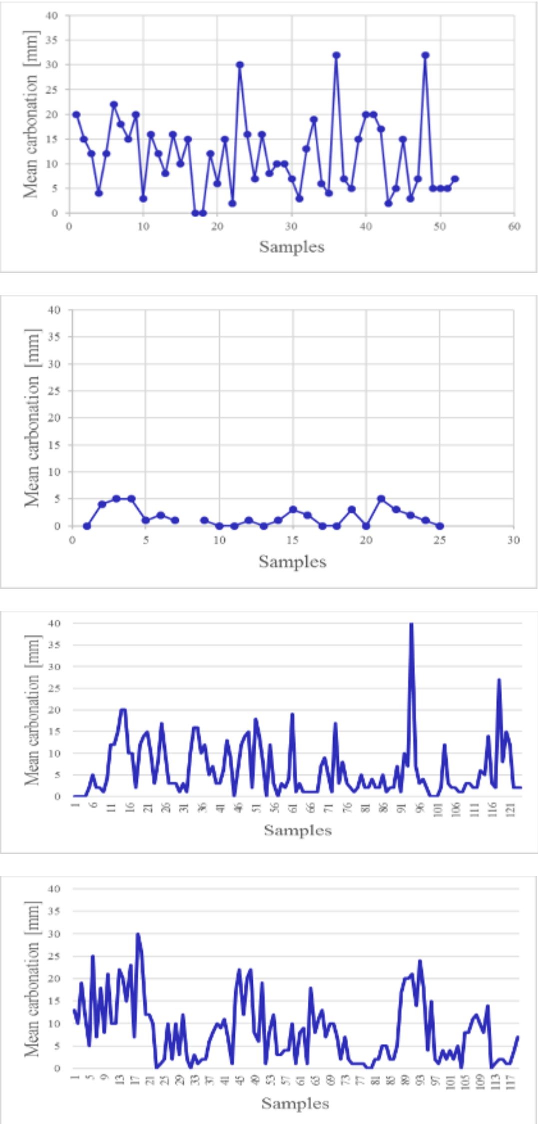

Fig. 1. Carbonation of tunnels (Graph1 highest: mean 11.6 mm, SD 7.3), walls (Graph2 high: mean 1.7 mm, SD. 1.7), bridges (Graph3 low: mean 6.2 mm, SD, 6.4), underpasses (Graph4 lowest: mean 8.5 mm, SD. 7.1).

The artefacts exhibited a similar orientation with respect to the geographic parameters. The surface effects and the degree of direct or indirect exposure to the atmospheric agents of the artefacts may account for the variability of the carbonation measurements. Nevertheless, in regions where there was a direct exposure to rainfall or with a high presence of water, the carbonation tended to be generally low. This was particularly observed for the walls. The carbonation was high at 20ºC and a relative humidity of 65 %, but also for sheltered parts [7].

During winter, the concrete structures are subjected to cold weather, with icing periods especially during nights. To decrease the water freeze point of the daily melting snow, relatively high amount a salts are spreaded on the highway lanes. This fact result in the general high content of chlorides in all artefacts down to 40 mm depth (Fig. 2). Furthermore, the drying-wetting cycle is known to accelerate the chloride penetration in cementitious materials [3]. The South-Alpine clima emphasizes the cyclic exposition of the artefacts to the variable atmospheric condition.

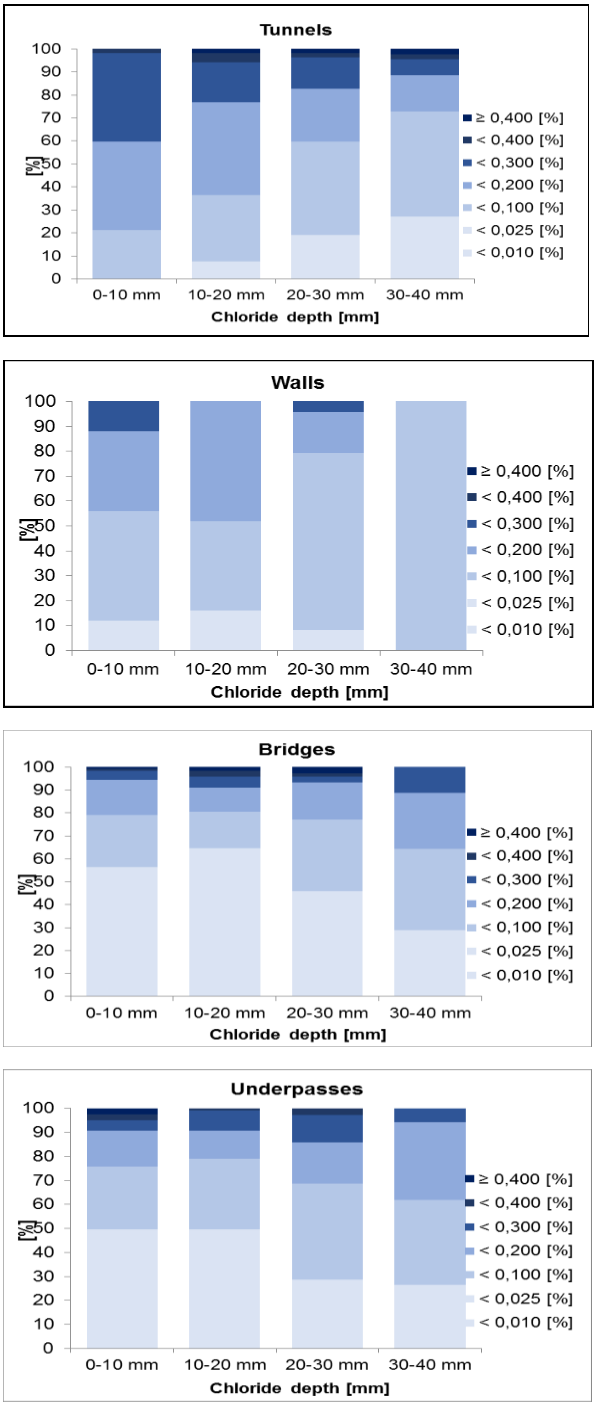

Fig. 2. Chloride content at different depth in tunnels (Graph1 highest), walls (Graph2 high) Bridges (Graph3 low), underpasses (Graph4 lowest).

It is generally accepted that, chloride content higher than 0.025 % referred to the concrete mass is detrimental for the rebar corrosion [10]. The chloride ingress within cementitious materials takes place through a diffusion process. It requires the presence of water. On the other hand, direct exposure to rainfall, may expose the artefacts to chloride leaching. This phenomenon can occur at the surface. Consequently, a trend with slightly higher content with depth is observed for the bridges, underpasses and walls, while the highest content for the tunnels may be accounted for a sheltered effect with a poor chloride leaching process. In spite of possible chloride enrichments at the carbonation front. Chloride may also be enriched due to the Chloride splashing effect taking place on tunnel walls. For all structures, especially for tunnels, contents higher than 0.400 % are observed on the surface within the first 10 to 20 mm depth. On the other hand, for bridges and underpasses, high content up to 0.400 % are also found with depth down to 40 mm.

In the South Alpine space, the correlation between the carbonation and the chloride ingress is not always clear. In tidal zones, the high humidity may promote both phenomena [4] or reduce the carbonation [5]. The presence of water, necessary for the chloride transport, reduces the penetration of the CO_2 gas within the concrete. So that both processes cannot be present simultaneously. For tunnels the correlation between carbonation and chloride content is very slight (Fig. 3).

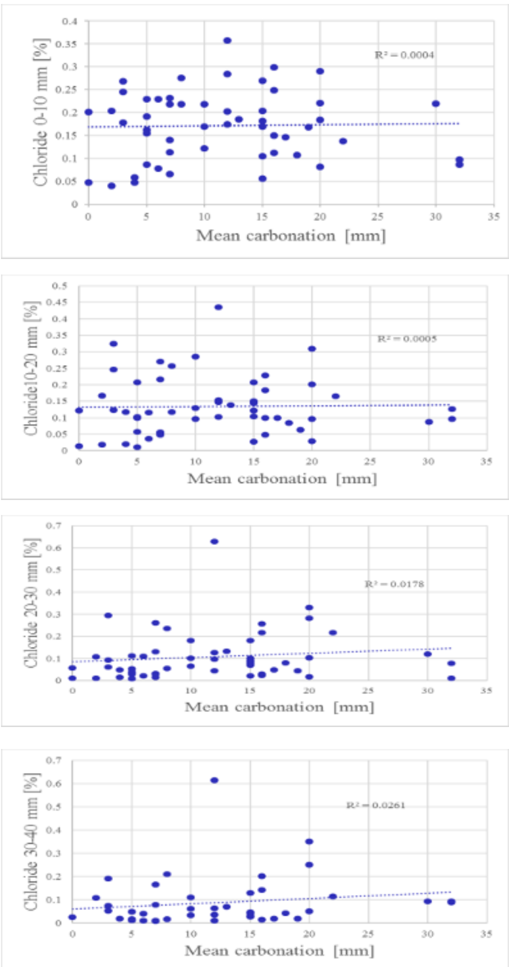

Fig. 3. Correlation Chloride content ([%], 0-10 mm (Graph1 highest), 10-20 mm (Graph2 high), 20-30 mm (Graph3 low), 30-40 (Graph4 lowest) and mean carbonation depth [mm] for the tunnels.

In the surface levels the correlation is poor and no particular trend can be observed. With lower depths from 20 to 40 mm a slightly more marked increase in the carbonation and high Chloride content appears to occur. On the contrary, the underpasses exhibit a general slight trend with high Chloride content and low carbonation (Fig. 4).

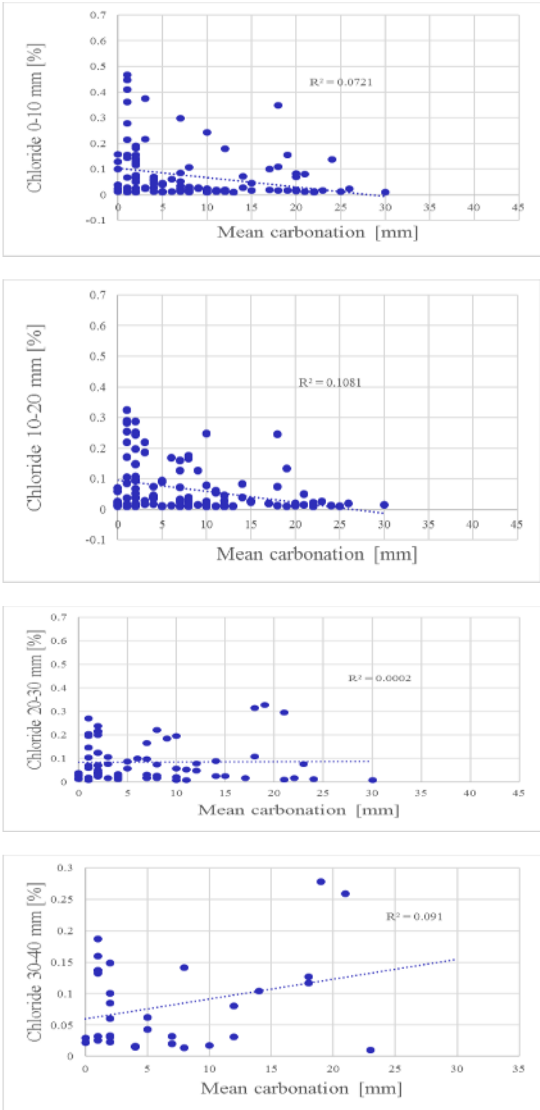

Fig. 4. Correlation Chloride content ([%], 0-10 mm (Graph1 highest), 10-20 mm (Graph2 high), 20-30 mm (Graph3 low, 30-40 (Graph4 lowest) and mean carbonation depth [mm] for the underpasses.

A similar behaviour can be seen for the bridges. As for the underpasses, these latter are partially sheltered structures (Fig. 5).

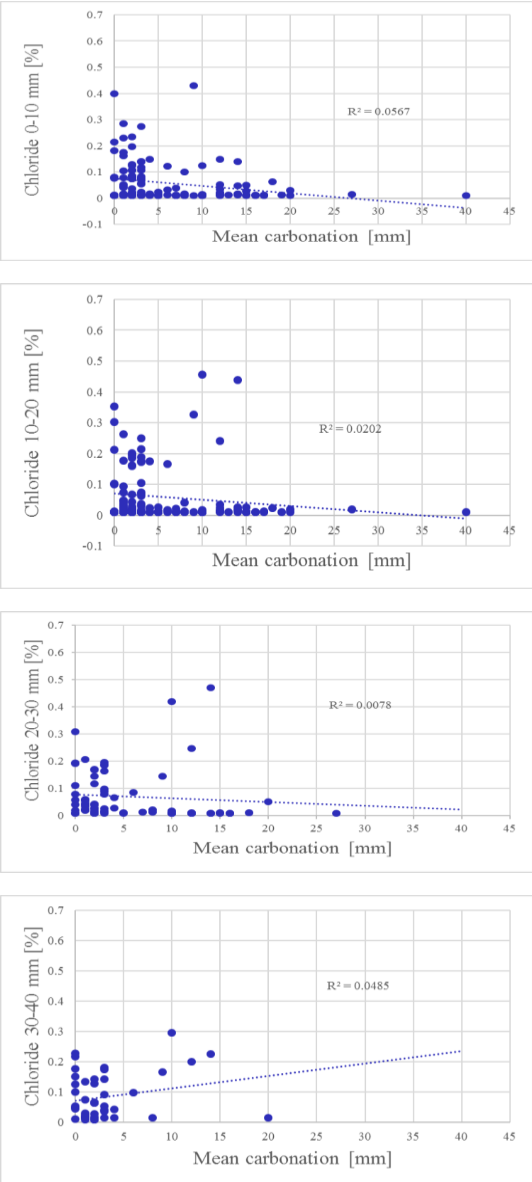

Fig. 5. Correlation Chloride content ([%], 0-10 mm (Graph1 highest), 10-20 mm up (Graph2 high), 20-30 mm (Graph3 low), 30-40 (Graph4 lowest) and mean carbonation depth [mm] for the bridges.

For the walls, the mean carbonation is generally low because of the direct exposure to rainfall and the high presence of water. Therefore, the correlation with the chloride content is difficult (Fig. 6). The same is valid for the manholes. So, again, only a slight correlation might be seen, with high chloride content and low carbonation.

Apart from the tunnels, where a high carbonation and high chloride content appear to take place, in all other artefacts this correlation is observed only at depth down to 30 to 40 mm. For all artefacts, except for tunnels, high carbonation does not appear to correlate with high chloride content. This is in spite of the variable atmospheric conditions, including the humidity, as compared to the tidal zones [4] or cold climates [6]. Surface effects such as chloride leaching must also be considered. This seems to be present for bridges, underpasses and walls. It is also important to notice that, on the same artefact, the exposition condition may also partially vary.

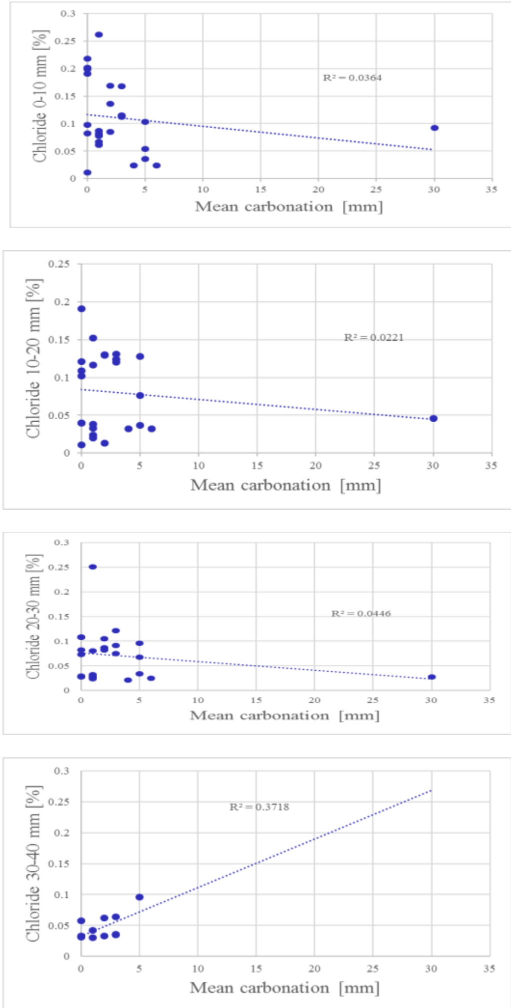

Fig. 6. Correlation Chloride content ([%], 0-10 mm (Graph1 highest), 10-20 mm (Graph2 high), 20-30 mm Graph3 low), 30-40 (Graph4 lowest) and mean carbonation depth [mm] for the walls.

3 Conclusions

The different concrete structures such as tunnels, walls, bridges, underpasses and manholes exhibit variable carbonation depending on the cyclic or sheltered exposure condition of the artefacts. It is maximal in tunnels and underpasses. The chloride content was generally greater than the limit of 0.025 % concrete mass to avoid corrosion and reached values up to 0.400 %. Tunnels also exhibited generally high chloride content caused by the cyclic high / low humidity and chloride splashing on the tunnel walls. High chloride content was present on the surface layers, but also in depth (bridges, underpasses and walls).This is due to the leaching and transport effects. Generally, a slight correlation existed between high chloride content and low carbonation (except for tunnels) as expected (more humidity, less carbonation). This relation is more seen in marine environment (general high humidity) less in alpine space.

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