THE AIR PERMEABILITY, CARBONATION AND CHLORIDE CONTENT ALONG A CONCRETE HIGHWAY UNDERPASS

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Abstract

In reinforced concrete structures carbonation and chloride ingress are two main phenomena that induce rebar corrosion. Agents such as CO_2 gas or water containing chloride enter the cementitious material mainly throughout the pore system. The air permeability was measured with a non-destructive rapid test method. The aim of the present work was to identify a relation between the carbonation, chloride ingress and the permeability to air of a reinforce concrete underpass. Concrete cores were drilled from a 40 years old in service highway underpass located in the South alpine region. The carbonation values were between 11-25 mm after 40 years exposure to the atmosphere. They corresponded to the conventional carbonation rate, in spite of the cyclic exposure condition of the artefact. In general, the wing wall east and west exhibited lower values as compared to the shoulders. This also indicated the importance of the geometry, orientation and exposition of the structure. The chloride content were generally well beyond 0.025 % referred to the concrete mass. This was due to the location of the structure close to the Alps at 1000 meters above sea and the spreading of the deicing salts during winters. The chlorides were leached from the concrete surface, so that higher contents were sometimes found with concrete depth. A correlation existed between the carbonation (CO_2 entrance) and the permeability to air. The higher the permeability, the deeper the carbonation. At concrete depths 0-20 mm chloride ingress and carbonation seemed to be antagonist phenomena. They could not occur simultaneously to a great extent. When humidity is present, gas penetration is lowered. While from 30 to 40 mm chloride ingress, transport and carbonation appeared to be both present. Keywords: concrete, air permeability, carbonation, chloride

1. INTRODUCTION

In cementitious artefacts the material quality and the rebar concrete cover thickness largely control the extent and the velocity of infrastructure surface damage. The concrete permeability controls the entrance of substances such as gases or liquids. Transport takes place by diffusion with concentration gradient (CO_2 in air), or by capillary adsorption with chloride containing water adsorbed. In low and moderate strength concrete, the air permeability is greatly affected by curing [1]. It is also known that, the air permeability is affected by the concrete moisture content, which is not always homogeneous within the material [2]. Air contains CO_2 gas, which induces carbonation within the cementitious material, and the rate of carbonation increases with the concentration [3]. The process reduces the pH of the pore solution [4] resulting in uniform rebar corrosion. Another detrimental agent for reinforced concrete is chloride. Alternating wetting and drying cycles promote the ions ingress, in particular within the first 40 mm from the surface. The content can be higher than the sea water concentration after 10 years exposure [5]. chloride induces localized rebar corrosion and a limit of 0.025 % referred to concrete mass is set for reinforced concrete structures [6]. In tidal zones, a relatively high humidity is present. The humidity might reduce the entrance of gases, such as CO2 within the material. Therefore, chloride might enter the structures, while a reduction in the gas entrance might be detected [7]. Nevertheless, it was found that, both carbonation and chlorides may be present, because of the relative high humidity [8]. Furthermore, both phenomena were present in bridge abutments in cold regions [9].

The objective of the work is to identify a relationship between the air permeability, measured with a non-destructive technique directly on site on the artefact, the carbonation and the chloride content of a still in service 40 years old highway underpass.

2. EXPERIMENTAL

The in service highway underpass 40 years old located at 1000 meters above Sea is analyzed. In the last decades, the mean temperature of the January-March period was -0.7 ºC. The mean temperature of the June-August period was 13.8 ºC. The mean rain / snow fall of January-February-March was 82 mm, while the mean rain / snow fall in the period June-July-August was 154 mm. The sheltered underpass is located in a South alpine clima, close to the Alps.

The air permeability is measured with a Torrent permeability Tester, a rapid non- destructive method [10]. The equipment consists of a test chamber with an external ring applied on concrete surface. An under pressure is created. During the measurement, the external ring pressure is maintained the same as the pressure in the test chamber. Within the test chamber the pressure variation with time is registered (air flux from concrete to test chamber). The air permeability is calculated from the pressure change with time. The test chamber allows a unidimensional air flux. The air comes only from the internal part of the concrete cover (Fig. 1).

Figure1: Test chamber and external protection ring of the Torrent permeability tester.

To define the air permeability and the relation to the humidity, it is necessary to determine the electric specific resistance of the surface. This is done with a four electrode Wenner method. Between the external electrode a current (alternate current 50-1000 Hz) is applied and between the internal points a resistance is measured. The involved concrete depth corresponds to the electrode distance of 5 cm.

The carbonation front is determined on drilled concrete cores (diameter 50 mm) and the minimum, maximum and average values are presented by using a basicity indicator i. e. phenolphtalein [11]. Concrete cylinders are cut in 10 mm thick disks and pulverized and the chloride content is determined to a depth of 40 mm [12].

3. RESULTS AND DISCUSSION

The concrete is generally a high quality concrete used for highway structures with an expected life duration of at least 60 years. The carbonation values vary depending on the quality of the material and degree of exposition (temperature, humidity) of the parts of infrastructure, in particular shoulders or wing walls. The main values are located between 11 and 25 mm. The highest rate of carbonation occurs at relative humidity between 50 and 70 %. According to the conventional equation, the depth of carbonation in millimeters increases with the square root of time [13]. Assuming a carbonation coefficient variable between 3-4 and a time exposure of 40 years, the carbonation front may vary between 18 and 25 mm. Most measured values on the underpass vary exactly within this range, even though the equation applies with steady state condition. But on site, the condition are not stable and varies daily and upon winter or summer time. Nonetheless, on the artefact, the mean carbonation also assumes different values that changes from 1-5 mm to 26-30 mm. This is also accounted for a different exposition condition of the part of the artefact. The carbonation of the shoulder South is only slightly higher as compared to the shoulder North. The values of the wing wall east and west are generally lower as compared to the shoulders (Fig. 2).

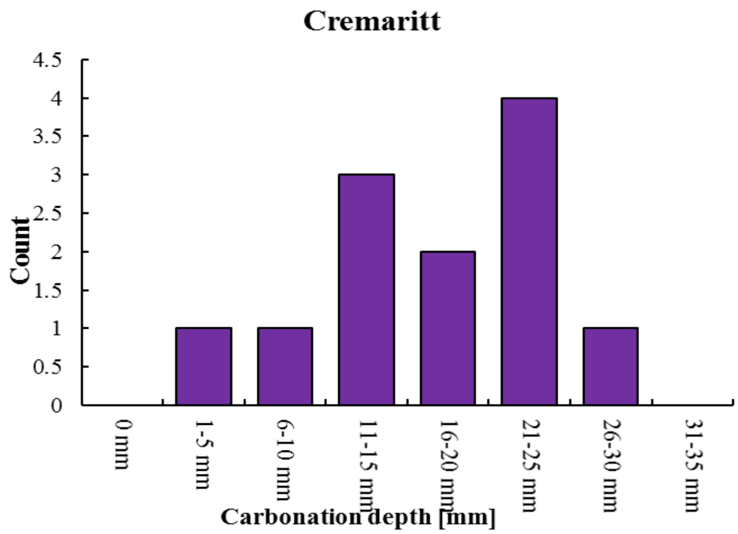

Figure 2: Mean carbonation distribution and occurrence on the underpass.

The region of the underpass is located close to the alps. During the winters, a relatively high amount of NaCl salt is spread along the highway. The underpass generally exhibits a high amount of chlorides exceeding to the limit established for reinforced concrete of 0.025 % referred to the concrete mass [6]. The underpass reaches values up to 0.400 % by concrete mass, and below 40 mm depth the chloride content was still higher than the established limit. The chloride content is higher at the surface compared to the deeper regions, but the total chloride presence can be higher with depth down to 40 mm. In particular high chloride total concentration is observed at depths between 20 and 40 mm. This is likely to be linked to the water leaching of the surface. (Fig. 3). It is also important to notice that, a variation of the chloride content and concentration is observed. This may be caused by a different exposition of the artefact to the degrading or atmospheric agents (insulation, wind, thermal excursions) and by the geometry of artefacts, snow accumulation during winter or different removal of the salt containing waters form the lanes.

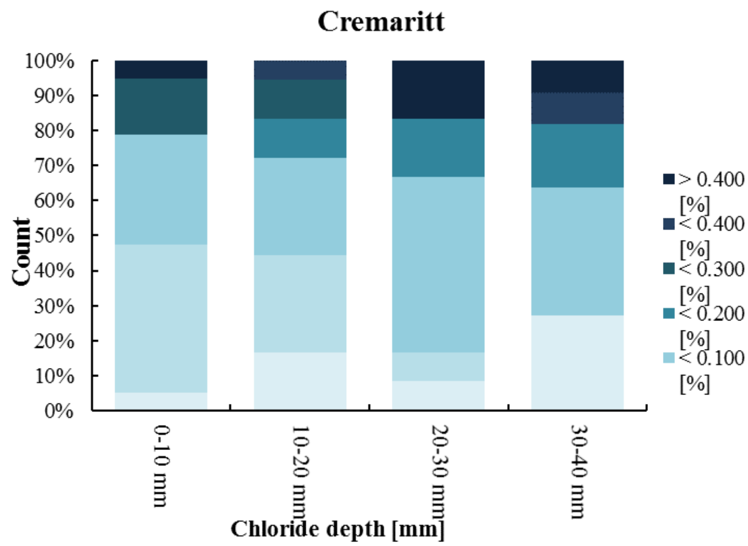

Figure 3: Chloride distribution with depth along the underpass.

The porosity influences the strength of cementitious materials, but also represents a preferential way for the substance to enter the concrete. The entrance of CO_2 gas has a detrimental effect on the rebar [3, 4]. In addition, the entrance of chlorides in concentration above 0.025 % referred to the concrete mass promotes the localized rebar corrosion [6]. A slight general correlation is observed between the air permeability of the cementitious material and the carbonation depth (Fig. 4). That means, the higher the permeability, the more air, i. e. CO_2 gas, can enter the concrete.

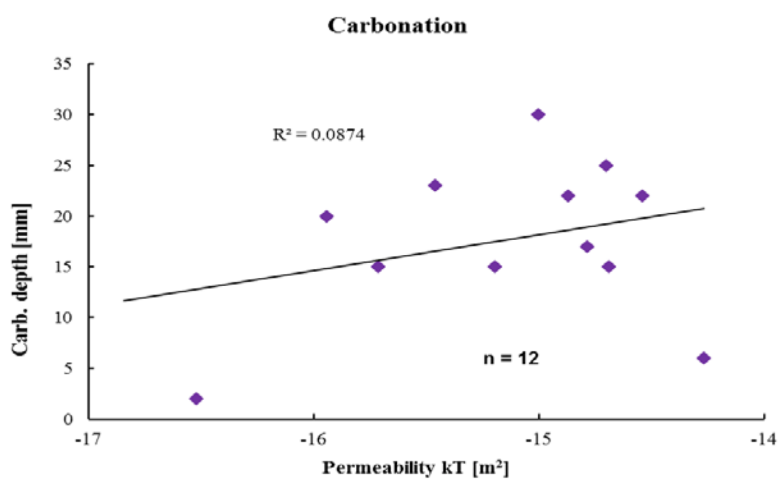

Figure 4: Correlation between carbonation depth and air permeability.

Contrary to the relationship between the air permeability and the CO_2 gas penetration, i. e. the carbonation depth, a negative correlation exists between the chloride content in the first 20 mm depth and the air permeability. This is particularly observed for the first 10 mm below the concrete surface. That means, low air permeability corresponds to high chloride content. This may correlate with the reverse relationship between carbonation and chloride ingress. Chloride is relatively present within the first 20 mm depth. Humidity is present and carbonation, i.e. CO_2 gas permeation, is lowered [7]. Between 20 to 40 mm the relation is more variable (Fig. 5). A slight trend with increased air permeability and chloride content is seen. This indicates that, at lower levels within the concrete, both phenomena, chloride ingress, transport and carbonation, may be detected [8, 9]. While in the upper levels, surface effects, such as water leaching, direct exposition to the atmosphere may also influence the phenomena.

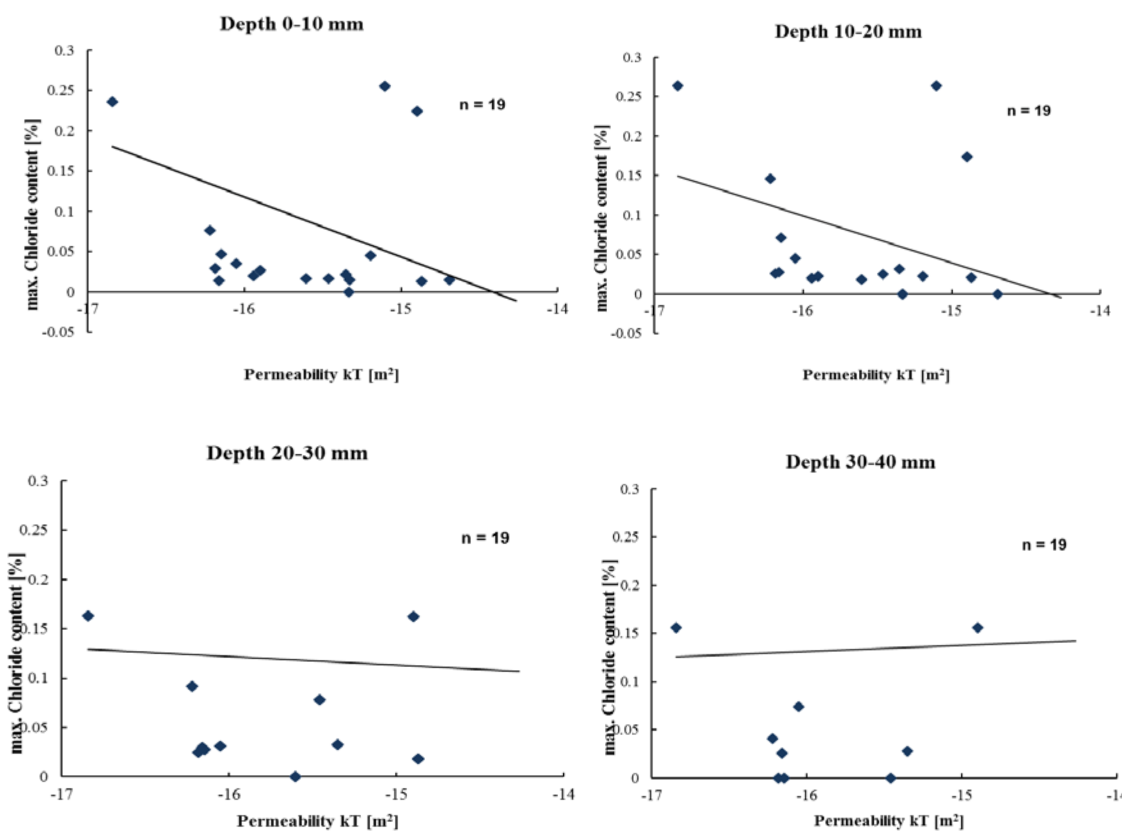

Figure 5: Correlation between chloride content with depth and air permeability.

4. CONCLUSIONS

The carbonation and chloride content of concrete cores withdrawn from a highway underpass have been analyzed and correlated with the air permeability. The carbonation values were between 11-25 mm after 40 years exposure to the atmosphere. They corresponded to the conventional carbonation rate, in spite of the non-steady state condition. In general, the wing wall east and west exhibited lower values as compared to the shoulders. The chloride content was generally well beyond the limit of 0.025 %, due to the location of the structure close to the Alps at 1000 meters above sea and the spreading of the deicing salts during winters. Sometimes the chlorides were leached from the concrete surface, so that higher contents were sometimes found with concrete depth. A correlation existed between the carbonation (CO_2 entrance) and the permeability to air. At concrete depths 0-20 mm, chloride ingress and carbonation seemed to be antagonist phenomena, while from 30 to 40 mm chloride ingress, transport and carbonation appeared coexisting.

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