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Decreasing Humidity in Concrete Facades after Water Repellent Treatments

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Abstract

One of the tallest buildings in Stockholm is The Scraper (after skyscraper) built in 1959. The building is 81 m high and the facades are covered with precast concrete elements. The elements have several problems related to high moisture content. To replace all the facade elements would be expensive and the Swedish Cement and Concrete Research Institute was commissioned to find a method to save the old ones. The choice fell upon water repellent treatments in order to lower the humidity and a test was initiated with measurements of the RH (relative humidity) and temperature inside the elements (40 mm from the surface).
Three sites on the building were chosen for the test. The first was on the ground level facing west, the second one on the roof facing north and the third one on the roof facing south. Three facades elements were treated with isooctyltriethoxysilane twice on the same day whereas two remained untreated on each test-site.
The results are presented as average values on each test-site and they show that the RH could be lowered by 20 % under the right circumstances. The conclusions are based on two testing periods in 2003 and 2004, respectively.

Keywords: humidity measurements, expanding clay minerals, water repellent treatment, silanes

1 Background

One of the tallest buildings in Stockholm is The Scraper (after skyscraper) built in 1959. For 45 years it was used by the Swedish Tax Agency which of course gave it the more commonly used name “The Tax-Scraper (Skatteskrapan)”, see Figure 1. The building is 81 m high and almost 50 m higher than the surrounding buildings resulting in its extreme exposure to rain and wind. The dominant wind direction for Sweden is southwest. However, Stockholm is situated on the east coast and the wind direction is not as pronounced as on the west coast giving all the facades of the Scraper a similar climate exposure.

The facades are covered with precast concrete elements. In 1993 cracks were discovered in these elements in the proximity of the anchorage bolts and in 1998 when a more thorough investigation was conducted, problems with corrosion of the steel reinforcement as well as of the anchorage bolts was discovered. In addition to this, several facade elements were found to have buckled outwards. The carbonation depth had reached the reinforcement bars in some places and the chloride content was high enough to initiate corrosion.

In 2003 the city of Stockholm decided that they would repair and rehabilitate the Tax-Scraper for student apartments apart from other uses, giving it the new name “The Student Scraper”. To replace all the facade elements would be expensive and the Swedish Cement and Concrete Research Institute was commissioned to find a method to save the old ones. The choice fell upon testing a water repellent treatment with the purpose of investigating if it could lower the humidity inside the elements and thereby stop the corrosion and the expansion of clay minerals (part of the aggregate in the concrete) which was the reason for the outward buckling of the elements.

Figure 1: Photo of the 81 m high “Tax Scraper” in Stockholm (http://sv.wikipedia.org).

2 Theory

Porous materials will always contain a certain amount of water. For concrete, which is a porous material, several durability problems are related to the moisture content inside the pores. The expansion of water, when it turns to ice, can cause severe freeze damages in concrete if the pores are saturated. The alkali silica reaction (ASR) depends on the access of water and so does the corrosion of reinforcement. These problems are all linked to the degree of moisture saturation in the pores. Moisture is not always the main reason for the problem but it is one of the most important parameters for an increased rate in the deterioration mechanism.

The importance of keeping the moisture below a certain critical level is well illustrated on the right hand side of Figure 2 when considering the corrosion of steel reinforcement as the limit of service life for reinforced concrete. The corrosion rate is highly dependent on the moisture content inside the pore system, in this figure represented by the RH (relative humidity) measured inside a reinforced concrete element. As one can see, the corrosion rate reaches its maximum at around 97% RH. The limited access of oxygen lowers the rate above this value and a decreased humidity lowers the rate below [1].

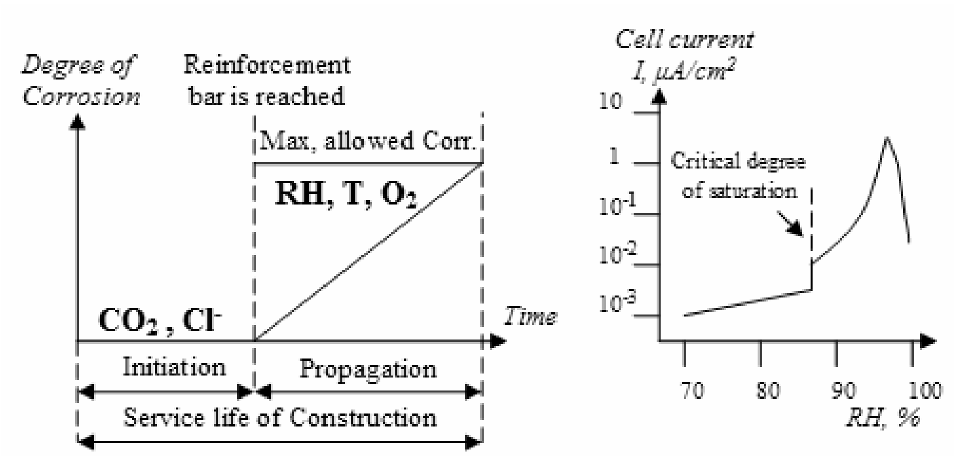

Figure 2: On the left: Corrosion model after [1] that describes the factors which affect the time to initiation and the time of propagation. On the right: The corrosion rate as a function of RH for a concrete specimen with w/c-ratio 0.9 (after [1]). The experiments were conducted on carbonated concrete.

In new-cast concrete, the reinforcement is protected from corrosion by the alkali environment. This may, however, slowly be altered by carbonation or chloride ingress. The initiation time on the left hand side in Figure 2 is affected by carbonation and/or chloride ingress. The diffusion rate of carbon dioxide and thus the carbonation rate is low when the moisture content is high. A summary of investigations conducted on carbonation rate as a function of RH is given elsewhere [2]. The conclusion obtained was that a maximum in carbonation rate is reached at around 70% RH. This value varies with the porosity of the concrete and for a dense concrete the maximum is reached at 10 to 20% lower RH.

On the other hand, transport of chloride ions into the concrete requires on a continuous water phase in the pore system. The maximum rate for chloride diffusion is reached at saturation while below 50 % RH it is close to zero according to some studies [3]. The authors of [4] suggest that the diffusion coefficient (as a function of RH) for chloride ingress can be described by an S-shaped curve which reaches its maximum at full saturation. After the initiation of the corrosion process, moisture, temperature and the access of oxygen are the decisive factors for the corrosion rate.

The reason for using a water repellent agent was to change the surface layer properties of the concrete thus influencing both the transport and fixation of moisture. In the right situation, the application of the water repellent would substantially reduce the moisture level in the concrete.

3 On-site measurements of humidity

Before the whole building could be treated with a water repellent agent, measurements during two test periods were conducted in order to predict the outcome of a full scale treatment. The first period was in 2003, mid April until mid June; and, the second one was in 2004 during the same part of the year. The product Wacker 1701 (isooctyltriethoxysilane) was used for the tests and applied to three different parts of the building. The elements were treated twice the same day (2002-08-08) with the same product (0,4 l/m^2). The penetration depth was unfortunately not measured after this treatment. However, a similar test treatment on the building performed in 2002-04-09 gave an average result of 13 mm.

Three facades elements were treated. Two remained untreated on each test-site. The first was on the ground level facing west, the second one on the roof facing north and the third one also on the roof but facing south. The results presented are average values on each site, the temperature is the average of the five facade elements.

The measurements were performed at a depth of 40 mm from the facade surface. Therefore a 16-mm diameter hole was drilled to a depth of 40 mm. A plastic tube was placed inside the hole to seal off the walls before the sensor was mounted. Moisture and temperature sensors type Humi-Guard (Nordisk Industrifysik AB) were used in the setup. The sensors were mounted 2003-04-11. In 2003, the measurements were manually performed while in 2004 a monitoring campaign was executed using the system Betongdatorn version 5.0 (Skanska AB) which includes data loggers as well as computer software. The measurements were done at the same places during the two periods. Problems occurred with the sensors positioned on the elements facing south during the test period in 2003 on both reference elements and these results are therefore not included in the analysis.

4 Results

The results presented are a summary of the humidity measurements described in the final report of the study [5]. Figure 3 shows the results from the manual measurements carried out in 2003. It is clear that the treatment decreased the RH in the elements compared to the reference one for both sites. However, since there were only six measuring points it is difficult to quantify the reduction in moisture content. Therefore, a data logger was used to continuously record temperature and RH during the test period in 2004. Nonetheless, the data in Fig.3 indicate that the RH could be lowered by 10 to 20 %. This would have a significant impact on the corrosion rate. A reduction of RH from 90 to 80 % would result in a reduction of the corrosion rate by a factor of approximately 10 as shown in the right hand side of Figure 2.

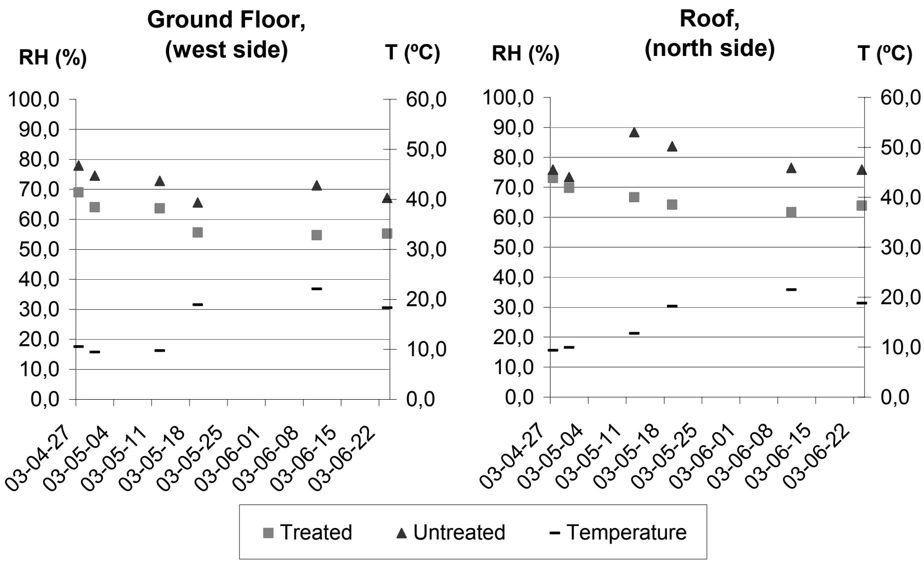

Figure 3: Results from the test period in 2003. The measurements indicate that the water repellent treatment has lowered the RH with approximately 10-20 %.

Figures 4 to 6 show the results from 2004. The second period gave almost the same results as the first one. The facade elements facing south as well as those facing west both have a significant decrease in RH caused by the water repellent treatment. The reduction is approximately 20 % RH during most of the period. However, the results from the north side, contrary to the results obtained in 2003, indicate a non measurable difference in RH, see Figure 6. The authors have not found a reason to explain these results.

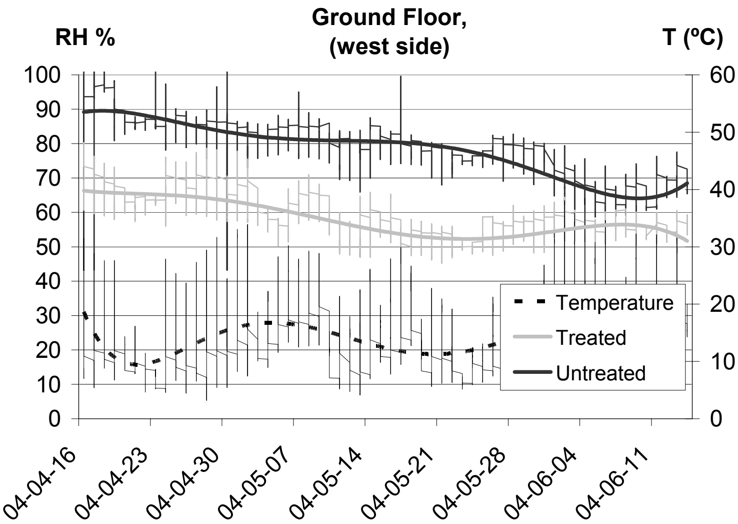

Figure 4: Results from the test period in 2004 on the ground floor.

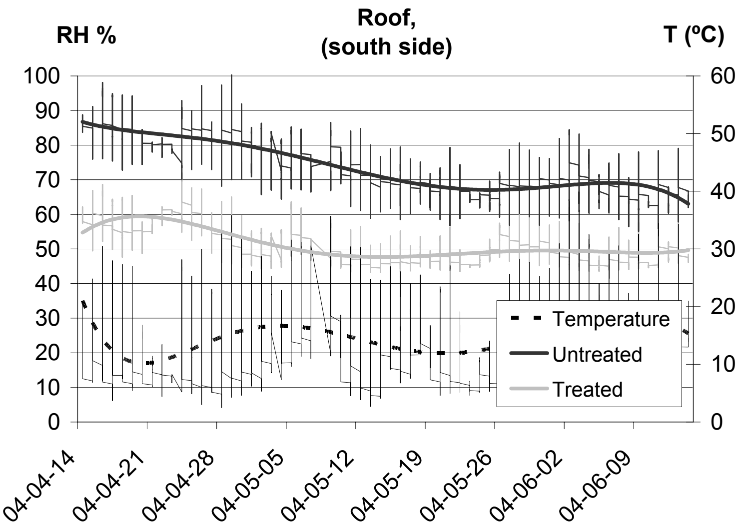

Figure 5: Results from the test period in 2004 on the south side of the roof.

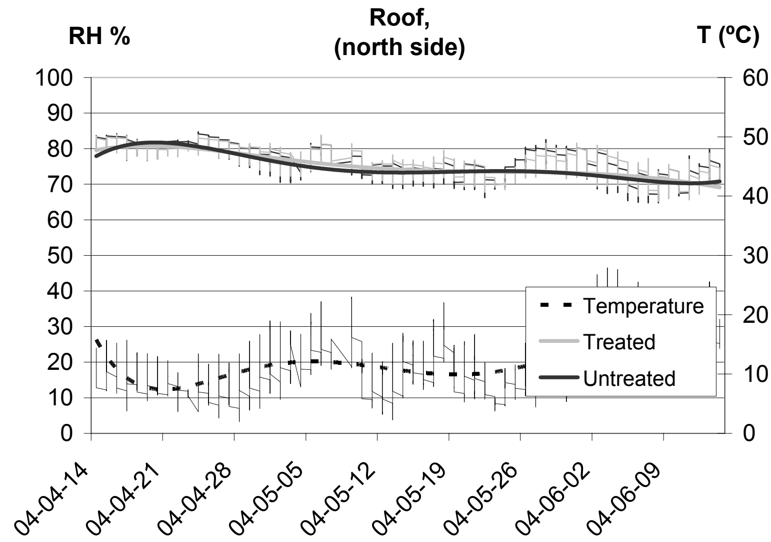

Figure 6: Results from the test period in 2004 on the north side of the roof. The treatment has not decreased the RH according to these measurements.

Except for the 2004 measurements on the north side of the roof, the two sets for 2003 (west ground floor and north roof) and for 2004 (west ground floor and south roof) showed a significant decrease in RH by the applied water repellent treatment. Based on these results, detailed in the report [5], the recommendation to treat all of the facade elements with a silane based water repellent product**.**

The lowered RH would stop the clay minerals in the aggregate from expanding more and according to calculations based on Faraday's law and a decreased humidity, the remaining service life of the corroded reinforcement bars would be extended with 20-30 % [5]. The anchorage bolts had to be replaced and to prevent the new ones from corrosion, stainless steel was recommended.

5 Conclusions

The results of humidity measurements in concrete elements after two evaluation campaigns carried out in 2003 and 2004, indicated that the RH could be lowered with 20 % by a water repellent treatment, given the right circumstances. The Scraper is high, placed on a hill, almost 50 m higher then the buildings surrounding it and often exposed to heavy wind and rain. The exceptionally good outcome of the water repellent treatment could probably be explained by the combination of the high porosity of the concrete with heavy rain exposure. An study based on humidity measurements conducted on concrete for housing and civil engineering structures exposed in the field showed that the water repellent treatment had no significant effect on the moisture content in civil engineering structures (dense concrete) while it was significantly reduced in housing structures (high porosity concrete) [6]. A 20 % decrease in RH, as the test periods on the Scraper indicate, should therefore not be expected for all water repellent treatments. Both concrete quality and the environment to which the structure is exposed will influence the performance of the water repellent.

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