Effect of Balcony Glazing on the Durability of Concrete Structures in Nordic Climate

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ABSTRACT: Degradation of concrete structures cause globally a huge repair need. Reduction of the moisture exposure of concrete structures is one potential way to prolong the service-life of them because the progress of all the major degradation mechanisms, such as reinforcement corrosion and disintegration, require high moisture content in concrete. This paper describes a research project where the efficiency of a balcony glazing to decrease the moisture exposure of balconies was studied experimentally in three apartment blocks in Finland. The efficiency of the moisture protection by the glazing was measured by monitoring the corrosion rate of reinforcement in carbonated concrete sensors which were installed both in glazed and open balconies. The results showed that glazing changes the micro-climate in the balcony so that the hygrothermal conditions turned unfavourable to degradation resulting in remarkable increase in service-life of concrete structures.

1 INTRODUCTION

Deterioration of concrete structures may lead to extensive repairs causing large direct and indirect costs, use of both energy and non-renewable natural resources. There are many factors leading to repairs, but by far the most part of repair needs is known to result from reinforcement corrosion and disintegration of concrete.

To avoid massive repairs it is sensible to try to protect structures from deterioration. This means application of measures that change the conditions inside the structure unfavourable for one or more deterioration mechanisms. It is important that the measures that protect a structure from one deterioration mechanism do not change conditions so that some other mechanism will be accelerated harmfully.

There are several potential ways to protect concrete structures. However, the proven protective treatments, such as cathodic protection and over-cladding with additional thermal insulation, are very expensive to apply. This concerns especially those structures which are most potential for preventative measures, i.e. structures which are still without major visual signs of damage despite that there are serious deterioration processes proceeding inside the structure.

From the protection point of view it is important to notice that all the major deterioration mechanisms are strictly controlled by the presence of moisture. For example, carbonation induced corrosion is known to proceed only above 80 % relative humidity (Alonso et al. 1988, Tuutti 1982). The disintegration of concrete due to freeze thaw exposure or ASR requires moisture content of concrete close to the saturation state [Pigeon & Pleau 1995, Hobbs 1988).

The fact that deterioration needs a lot of moisture offers a simple way to protect structures by lowering their moisture content. However, the utilisation of this principle in practice is problematic because the efficiency and performance of these types of measures has usually not been proven.

A balcony glazing is one potential way to control the moisture exposure of balconies both in new construction production as well as in renovation (see Figure 1). Balcony glazing has been in use in Finland since the middle of 1980's. At that time the reason for installation of glazing was purely to increase the usability of the balcony space. As the balcony glazing become more common in 1990's it was noticed that the surfaces inside the glazed balconies were kept in better shape than in traditional open balconies. This connected with the knowledge about the positive effect of decreased moisture exposure on the deterioration of concrete structures gave an impulse to study the effect of balcony glazing on the durability and service-life of balconies constructed of reinforced concrete.

Figure 1. Balconies made of reinforced concrete and outfitted with glazing.

2 PROTECTION FROM MOISTURE BY BALCONY GLAZING

As stated already earlier in this paper, deterioration of concrete structures requires a lot of moisture. The corrosion of steel reinforcement in carbonated or chloride contaminated concrete is fastest when concrete is partially saturated with water (Alonso et al. 1988). On the other hand, the disintegration of concrete by freeze-thaw exposure requires that there is so much moisture in the concrete that there is not enough air-filled pore space in concrete for the volume expansion of the freezing water to discharge without causing physical damage. (Pigeon & Pleau 1995).

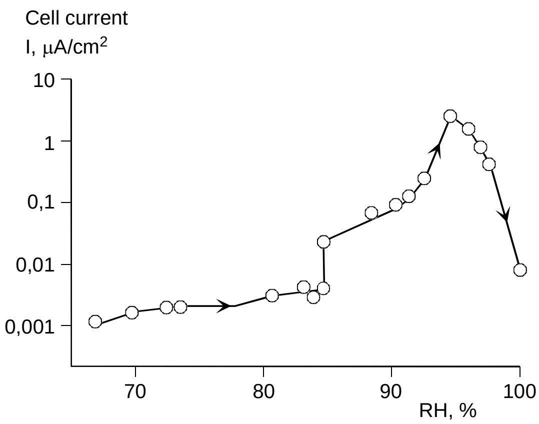

Figure 2. Relationship between cell current and relative humidity according to (Tuutti 1982).

From Figure 2 it can be seen that if the relative humidity of reinforced concrete can be lowered down to 90 % of relative humidity or less, the corrosion rate may decrease up to 90 % (Tuutti 1982). What comes to the potential acceleration of carbonation due to drying of concrete (Parrott 1987), it is important to notice that increased moisture content may retard carbonation only by some tens of percents, but the same change may multiply the corrosion rate. Also from the experience it is known that corrosion damage due to carbonation has not usually occurred in those parts of structures where the moisture exposure has been lowest and carbonation quickest, but just the opposite.

The main function of a balcony glazing in Nordic climate is to keep rainwater, snow and dust away from a balcony and the warmth inside it so that it is more convenient to use. For this purpose glazing is always equipped with such flashings etc. that prevent rainwater from leaking in through the joints etc. It is also found that glazing should not be too air-tight to enable sufficient ventilation to demist the glazing in certain climatic conditions. Because of this, glazing is most usually composed of adjacent cageless glass panes with interstices of few millimetres between them. This has been found to ensure sufficient ventilation. The drainage of glazed balconies is usually arranged by internal piping.

It is obvious that balcony glazing will not affect the moisture exposure only by preventing the moisture get inside the balcony but also by creating such micro-climate that promotes drying. The solar radiation as well as the thermal flux through the external wall or a window behind the balcony most probably raises the temperature inside the balcony, which increases the saturation deficit and will probably further lower the moisture content of concrete.

3 EXPERIMENTAL

3.1 General aspects

The evaluation of the efficiency of balcony glazing to lower the moisture load and moisture content of concrete structures is a complicated problem. Apparently, the impact seems to be positive, but it is impossible to evaluate this quantitatively without measurement data from representative structures and conditions.

One potential way to evaluate the performance of balcony glazing to lower the moisture content of concrete is to monitor the moisture content of concrete by electronic devices. This is, however, scientifically unsound method because of two reasons. Firstly, the accuracy of the electronic moisture measurement is not very high. For example, the corrosion rate of reinforcement in carbonated concrete may vary even more than one decade within the incremental sensitivity of the best devices on market. The moisture meters also operate on the hygroscopic area only, whereas deterioration is known to be fastest in partially saturated concrete, i.e. at the super-hygroscopic moisture range (Alonso et al, 1988). This is why the performance of balcony glazing to reduce deterioration rate cannot be studied reliably by measuring moisture unless the decrease of the moisture content is systematic and very large.

A potential mean to pass the problems with the moisture measurement is to measure the rate of deterioration itself. The are not available feasible instruments for the NDT monitoring of disintegration processes so far, but the corrosion rate of embedded steel bars can be monitored relatively simply for example by polarization resistance method (Stern & Geary 1957). This is a sensible way to get a quantitative picture of the protective effect of balcony glazing because corrosion is controlled mainly by ambient moisture and temperature.

3.2 Monitoring method and apparatus

A tailor-made device for the monitoring of corrosion rate of steel in concrete was prepared for this purpose. The device uses polarisation resistance technique to measure the instantaneous corrosion rates (Stern & Geary 1957). The cumulative corrosion attack can be calculated easily from this data.

The device utilises modern computer technology so that steel potential is directly controlled by a computer without a potentiostat. The device is fully automatic to perform continuous monitoring of corrosion rates and equipped with mobile data connection to fetch the data from field sites to the university campus. The device can deal with a maximum of 120 measurement channels and it is described in more detail in (Mattila 2003).

An important point to consider is that should the data be gathered from field or is it possible to get representative data from laboratory tests. In this study, laboratory tests were excluded because the moisture exposure in outdoor concrete structures cannot be simulated very accurately in laboratory. The reason for this is that all the parameters determining the microclimate inside a balcony, which determines the rate of degradation, cannot be predicted accurately enough.

Because the moisture conditions of real structures under climatic exposure are in a continuous state of change, data is gathered by the device frequently to catch also short-term phenomena.

3.3 Sensors

For the monitoring purposes, special sensors were prepared and mounted into balconies of existing buildings (see Figure 3). The sensors contain reinforcement bars and suitable electrodes for the monitoring of corrosion rate by polarisation resistance technique.

The reason to use the sensors was to get uniform concrete quality for all the monitoring points. In this case the variation of concrete quality in different field test buildings and measuring points can not cause bias in the results. Another point was to have to possibility to make sure that all the reinforcement bars are positively in active corrosion in carbonated zone by accelerated carbonation. In this case the corrosion rate in the sensors will reflect the change in hygrothermal conditions achieved by balcony glazing and gives a reliable picture of the possible retardation of deterioration. As a by product, information of the risk of progressing frost damage will be got as well, because the critical moisture content required for this can be recognised from high corrosion rates.

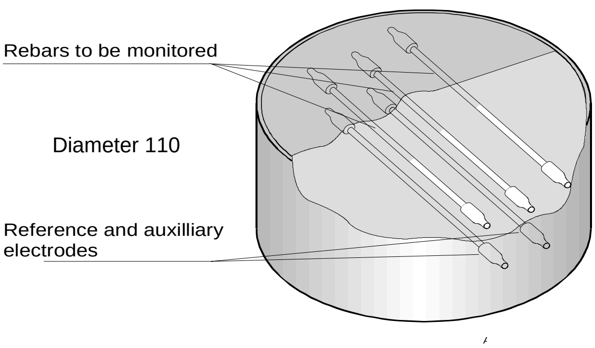

Figure 3. Schematic diagram of the sensor used.

The composition of the concrete used in the sensors was selected so that the concrete would be as similar as possible to the aged concretes used in concrete facades in Finland during 1960’s and 1970’s. The cubic strength of the concrete was 25 MPa.

The diameter of sensors was 110 mm and thickness 60 mm. The steel bars were ordinary cold drawn reinforcement with the diameter of 4 mm and nominal yield strength of 500 MPa.

After casting and 28 days of curing in 40 °C water (to achieve high degree of hydration as in old structures), the sensors were exposed to accelerated carbonation in 4 % carbon dioxide according to (Dunster 2000) until carbonation has reached all the studied bars.

The sensors were coated with permeable silicate paint for aesthetic reasons. The coating is totally open for both liquid water and water vapour so that sensors will represent also uncoated concrete.

Sensors were mounted in the balconies of three residential blocks, of which two were located in Tampere (exposed to Finnish midland climate) and one in Espoo near to the south coast of Finland (exposed to more severe coastal climate). All the instrumented balconies were facing south or west.

Altogether 14 sensors were installed in each building. One half of this was installed in glazed balconies and another half in open balconies for reference. In both group, six sensors were installed in the side walls and one on the ceiling.

The sensors in the walls were mounted into holes drilled through side walls of balconies (see Figure 4). The gap between the sensors and the hole was sealed with elastic polyurethane sealant to prevent the leakage of water into the structure. In addition, the envelope surfaces of the sensor cylinders were sealed with aluminium adhesive tape to prevent the moisture transfer between the sensor and the concrete of the outer panel so that the performance of the old coating on the concrete surface surrounding the sensor would not have an influence on the moisture stress of the sensors. The sensors on the ceiling were mounted below the ceiling.

A part of the sensors were equipped with temperature transducer so that the temperatures of the balcony structures could be monitored as well.

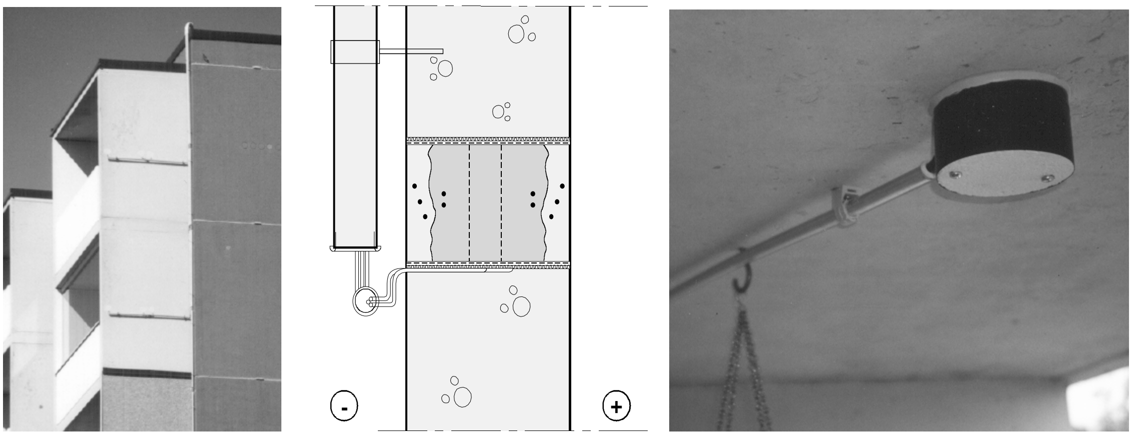

Figure 4. Pictures showing the principle of the installation of sensors into the structures. On the left: Glazed and open reference balcony. The sensors in the side walls are installed in the middle height of the wall panel. In the middle: Vertical cross-section of the sensors mounted into a hole drilled to a side wall. On the right: A sensor installed on the lower surface of the slab.

The installation of the sensors took place in the summer 2000 and the monitoring system was installed during the autumn 2000. The collection of the corrosion rate data was started from the beginning of December 2000 and it was stopped at the end of year 2002.

4 RESULTS AND DISCUSSION

The efficiency of the balcony glazing to retard deterioration was evaluated by monitoring the corrosion rate of reinforcing bars in carbonated concrete, both in glazed and open balconies. The quantity measured by the monitoring system is the instantaneous corrosion current [µA/cm2]. The data was converted to cumulative radius loss of steel section in µm (i.e. depth of corrosion attack) by integrating the corrosion currents over time and applying the Faraday’s law.

The cumulative radius losses calculated from the monitoring results from the 25 month monitoring period are presented in Figure 5. The results were very uniform in all the three buildings. This is the results are not presented separately, building by building.

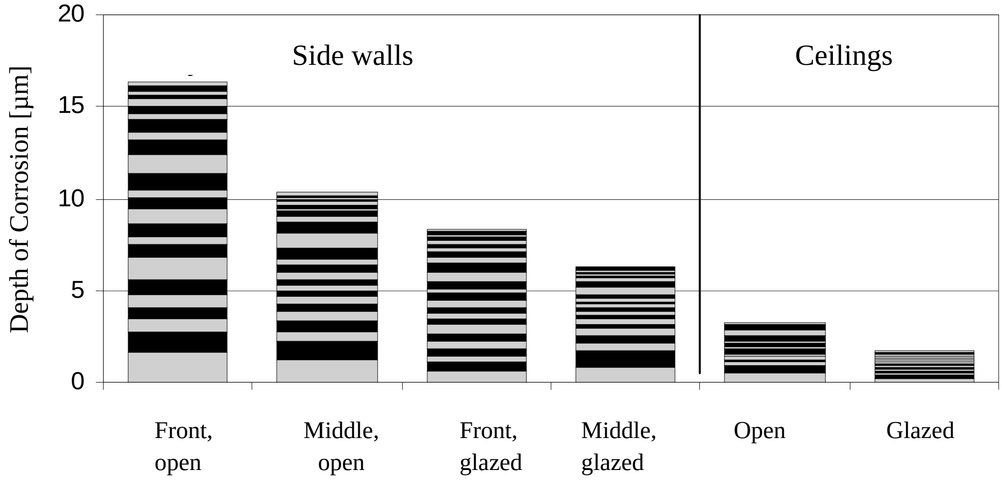

Figure 5. Average cumulative radius losses of steel sections in three buildings in the 25 month monitoring period.

The sections of each bar in the figure represent the monthly values of radius loss so that the bottom section of each bar represents the radius loss measured in the first monitored month, i.e., Dec. 2000, and the uppermost section represents the last monitored month, i.e., Dec. 2002. All the sections are not distinguishable because of the exiguity of the monthly corrosion.

From Fig. 5 it can be observed that balcony glazing decreased the corrosion rate of steel in concrete clearly and systematically. The reduction over the monitoring period was roughly 30 to 50 % in the side walls and 50 % in slabs.

To evaluate the measured quantities (radius losses), results from (Alonso et al 1998, Andrade et al 1993) can be used as a guideline. According to these, an average radius loss of 50 µm is required to cause the first visible crack (0.05-0.1 mm) in the cover concrete when the cover depth is relatively small. On the basis of this it can be calculated coarsely, what will be the duration of the active corrosion phase before cracking in studied structures. The results from this calculation are presented in Table 1.

Table 1. Average yearly corrosion depths and calculated durations of the active corrosion in glazed and open balconies.

	Balcony side walls		Ceiling surfaces	
	Glazed	Open	Glazed	Open
Average yearly corrosion depth during the monitoring period [µm]	4	7	1	2
Calculated duration of the active corrosion [a]	12	7	50	25

From Table 1 it can be noticed that increase in the service-life of the structures can be significant. From the viewpoint of lifespan of a building, fro example one decade is not a significant period, but from financial point of view it is a remarkable prolongation in service-life.

It is worthwhile to notice especially the low corrosion rates in the ceiling surfaces. The calculatory duration of active corrosion will be about 25 years even in open balcony and this can be doubled by glazing. This is an important finding because there are often low cover depths and deeply penetrated carbonation on the ceiling surfaces. These results show that that kind of struc-

ture may have residual service-life of decades left without any major repair measures. This naturally requires that the waterproofing of the upper floor is kept in a good shape.
The temperature of concrete was also monitored once an hour at the same spots as corrosion was measured. The recorded temperatures were processed to monthly averages in glazed and open reference balconies. The monthly differences in temperatures between glazed and open balconies were calculated and presented in Figure 6. The positive difference means that temperature was higher in glazed balconies.

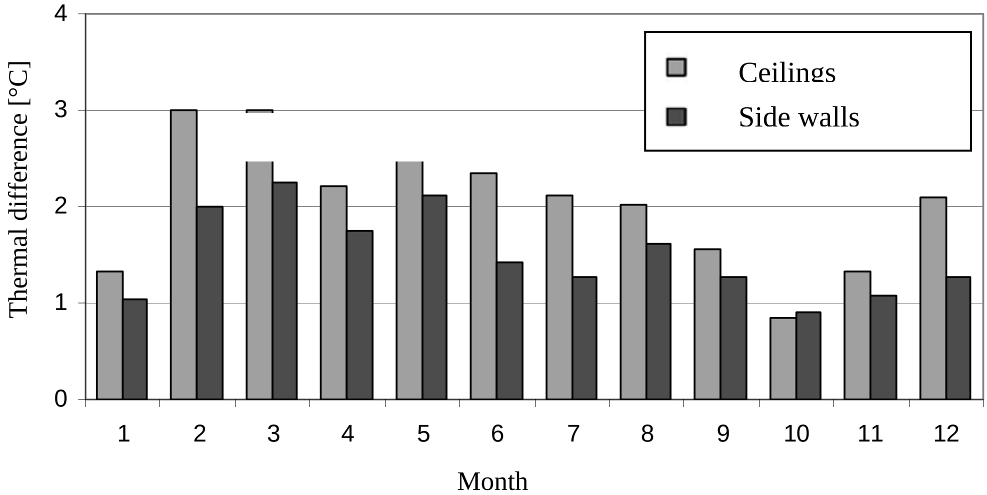

Figure 6. The difference of monthly average temperatures in glazed and open reference balconies. The positive difference represents the situation that that temperature has been higher in glazed balconies.

From the average temperatures in Figure 6 it can be seen that temperatures are systematically higher in glazed balconies. In the half height of side walls the temperatures were in average about 1.5 °C and in the ceilings in average about 2 °C higher in glazed balconies compared to open reference balconies practically throughout the year. This temperature difference prevailed even during the cold season when the solar radiation is very weak.

This apparently small difference in the temperatures can be regarded as important because it increases the saturation deficit and therefore promotes the drying of concrete.

To evaluate the risk of frost damage on the basis of corrosion rate data, the single corrosion rate measurements were plotted against the temperature of concrete at the moment of the corrosion rate measurement. This plot is presented in Figure 7.

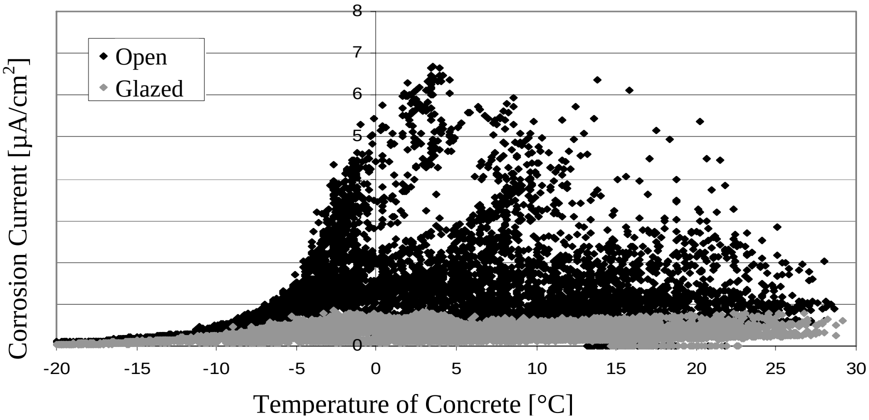

Figure 7. Instantaneous corrosion currents plotted against the temperature of the concrete at the moment of corrosion rate measurement.

From Figure 7 it can be observed that corrosion rates in glazed balconies remain permanently below 1 µA/cm^2. When the progress of frost damage process requires almost full saturation, which means corrosion currents of at least 4 to 5 µA/cm^2, the plot proves that damage by freeze-thaw exposure is prevented by glazing.

When considering the reliability of the results it is important to notice that the results depend strongly on the climatic conditions, especially on the amount of liquid rainfall during the monitoring period. Because the period is only a little longer than two years, the conditions might not necessarily fully represent the long-term average conditions. However, on the basis of examination of the meteorological data from the monitoring period, it can be stated that the results seem not to be significantly distorted due to abnormal weather conditions.

5 CONCLUSIONS

The objective of this study was to evaluate the effect of balcony glazing on deterioration and service-life of concrete structures. Carbonation induced reinforcement corrosion and disintegration by freeze-thaw exposure were considered as main deterioration mechanisms.

The rate of deterioration was measured by monitoring the corrosion rate of steel in carbonated concrete sensors. On the basis of the results, the following conclusions may be drawn:
1) Balcony glazing prolongs the service-life of balconies made of reinforced concrete by reducing their moisture load and by raising their temperature and consequently enhancing their ability to dry out.
2) Because of this enhanced hygrothermal performance the service-life of the structure is prolonged against visual cracking due to active corrosion for about 5 years in side walls and for about 25 years in the bottom surface of the slabs. Especially the latter finding makes it possible to avoid useless and difficult patch repairs in the lower surfaces of the balcony slabs.
3) Conditions enabling the progress of frost damage were removed totally by the glazing totally.

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