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Repair of Concrete Members of Seaside Apartment Buildings Deteriorated by Steel Corrosion

CAS

COMPOSITE - ANODE - SYSTEMS GMB

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ABSTRACT: Apartment blocks erected on or near the seaside, especially on the Atlantic coast, are exposed to high sea salt loads. The sea salt is transported inland as a marine aerosol over long distances. Deposition on concrete structures, in combination with high humidity (> 80% near sea side), may induce severe damages due to the corrosion of steel in concrete. Conventional repair would require replacement of the with chlorides contaminated concrete, cleaning and subsequent re-encapsulation of the steel rebars and reprofiling. In many cases, e.g. balconies, these conventional repair techniques are not applicable. In the Netherlands, since about 8 years, an innovative technology, based on cathodic protection (CP) has been successfully employed using the composite anode system, for the repair and protection of balconies and concrete members of facades of apartment buildings near the marine coast line. The composite anode is easy to apply – like a conventional paint system – and has particular the advantage that only concrete that is mechanically damaged or is disbonded from the reinforcement has to be replaced. Structurally sound concrete may be left in place. The technology was successfully employed for the sustainable repair, protection and maintenance of apartment buildings in Scheveningen, Zandhorst, Bussum, Katwijk und Delft in the Netherlands.

1 INTRODUCTION

Apartment blocks erected on or near the seaside, especially on the Atlantic coast, are exposed to high sea salt loads. The sea salt is transported inland as a marine aerosol over long distances (Maira et al. 2008). Marine aerosol is composed of coarse salt particles generated from bursting sea foam in windy conditions (O'Dowd et al. 2001). Deposition on concrete structures, in combination with high humidity (> 80% near sea side), may induce severe damages due to the corrosion of steel in concrete. The sea salt load on the Atlantic coast is especially high due to frequent winds with high wind speeds, especially during the storm season during autumn in the Netherlands. Damages to concrete members (balconies, façade elements, beams) due to steel rebar corrosion are observed at apartment buildings up to 500 m from the coast line, even if the buildings are located behind high sand dunes or hills.

Conventional repair would require replacement of the with chlorides contaminated concrete, cleaning and subsequent re-encapsulation of the steel rebars and reprofiling. In many cases, e.g. balconies, these conventional repair techniques are not applicable.

In the Netherlands, since about 8 years ago, an innovative technology, based on cathodic protection (CP) has been successfully employed using the composite anode system, for the repair and protection of balconies and concrete members of facades of apartment buildings near the marine coast line. The advantage of the technology is that the concrete contaminated with chlorides has not to be removed and replaced with repair mortar. In medium term, chlorides will be extracted from the concrete cover. The composite anode is easy to apply – like a conventional paint system. In concrete members in whom the steel reinforcement is difficult to access from the surface, like beams supporting balconies, discrete galvanic anodes are installed.

In the following, representative examples of the restoration of apartment buildings in Scheveningen, Delft and Zandvoort in the Netherlands are presented.

2 EFFECTS OF STEEL CORROSION ON CONCRETE MEMBERS

In the concrete members of facades and in balconies of apartment buildings near the sea side, chloride concentrations of up to 7 wt.% / wt. cement were measured. Sea salt is especially corrosive due to the combination of chlorides, bromides, sulphates and magnesium salts.

Figure 1: Spalling and disbondement of the concrete cover due to steel rebar corrosion.

Examples for typical damages, induced by the corrosion of the steel reinforcement, are shown in figures 1 & 2. Typical types of damages are spalling and disbondement of the concrete cover (figure 1), degradation of edge beams and spalling and degradation of supporting beams (figure 2). Depending on the time of exposure and degree of contamination, significant loss of cross section of the steel reinforcement is observed that may lead to structural failure of the concrete members.

Figure 2: Spalling and local destruction of the concrete cover of supporting beams, severe loss of cross section of steel rebars due to steel rebar corrosion.

3 COMPOSITE ANODE SYSTEM – TECHNIQUE & APPLICATION

CAST^{x+} is a two component aqueous alkaline (pH 12,7) alumo-silicate/polymer composite paint for the active cathodic corrosion protection of reinforcing steel in concrete. The alumo-silicate component forms the proprietary micro capillary matrix that assures high adhesion to the concrete at current loads up to 30 mA/m^2 and up to 70 mA/m^2 for short periods.

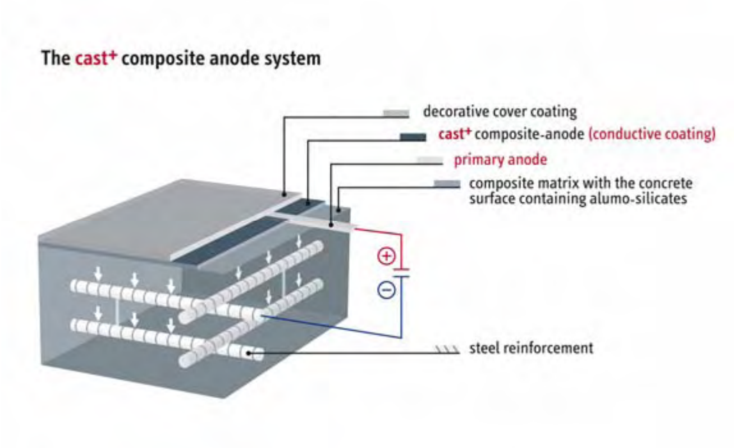

Figure 4: Schematic presentation of the CAST$^+$ composite anode system, based on the CAST$^+$ composite anode paint.

The composite anode is installed by applying the CAST$^+$ composite paint on the thoroughly cleaned concrete surface. Clean concrete surfaces are obtained e.g. by water-jetting, sand-blasting, etc. Before applying the composite paint, binding wires have to be removed ore insulated by applying epoxy coating locally – detailed installation instruction is available online.

The composite paint is applied like any other concrete paint either by rolling or by air-less spray. Current distributors – termed as primary anodes – are embedded into the composite paint (figure 4). Finally, a decorative cover paint is applied. Most of the available acrylic paints but also epoxy or polyurethane paints or coatings are suitable as decorative top coats. If high current densities are required, cover coats with high water vapour permeability are recommended.

Corrosion protection of the steel reinforcement is achieved by applying a voltage in the range of 2 – 5 Volts between the composite paint and the steel reinforcement, inducing a DC current of 1 – 5 mA/m^2. Start-up and operation of the composite anode system follows the rules and recommendations of EN-ISO 12696 (2012).

Operation of the CAST$^+$ systems may be fully automated by applying the proprietary CAS technology of macro cell controlled CP (Schwarz et. al. 2009).

4 CASE STUDIES

From 2004 until 2011, several apartment buildings in Delft, Groningen, Den Haag, Scheveningen, Katwijk, Assen, Bussum and Zandvoort were repaired with the composite anode system technology. In some cases, supporting beams were repaired and protected with discrete galvanic anodes. The technologies proved to be highly sustainable: The installation of the composite anode system produced nearly 0-waste – it required only washing of the concrete with water jetting at 400 bars. The discrete galvanic anodes produced limited waste - borehole cuts. Only these parts of the concrete overlay that were loose had to be replaced with repair mortar. Contaminated concrete could be left in place. Therefore traffic impairement due to transport of The CAST^{+} technology proved to be cost efficient also in comparison with the conventional repair techniques. In the following, selected examples of repair and protection of apartment buildings are presented.

4.1 *Apartment buildings on Scheveningen Strand*

Scheveningen, a district of Den Hague – the capital of the Netherlands - is a modern and a prominent beach resort in the Netherlands. Overlooking the beach, close to the famous pier and the Kurhaus concrete elements of the façade of an apartment complex were repaired and protected with the composite anode system covering a total area of 1600 m^2 (figure 5).

Figure 5: Installation of the CAST^{+} composite anode system on apartment buildings in Scheveningen 2008.

Before concrete repair and installation works start, windows are covered and protected with plastic sheets (figure 6). The concrete surface was cleaned and prepared for the CAST^{+} composite anode system with high pressure (500 atm) water jetting (figure 7).

Figure 6: Covering the windows with plastic sheets before repair and installation works start.

Figure 7: Cleaning of the concrete surface by high pressure water jetting.

After cleaning the concrete surface, installation of sensors for remote monitoring the efficiency of the corrosion protection of the steel reinforcement, removal of binding wires and covering of potential short circuits with epoxy coatings, the CAST^{+} composite paint is applied (figure 8).

After application of the CAST^{+} system, installation of the current distributers (termed as primary anodes) and after completion of electrical installation works (wiring, distributors, central control and data-logging unit), a cover coat is applied (figure 9).

Performance of the anode system is very good as 100 mV depolarization is obtained within 24 hours, and for most reference electrodes even within 4 hours. Anodic current density is about 3-5 mA/m^2. Life time expectancy is well above 10 years, as no signs of ageing in 4 years of usage are observed.

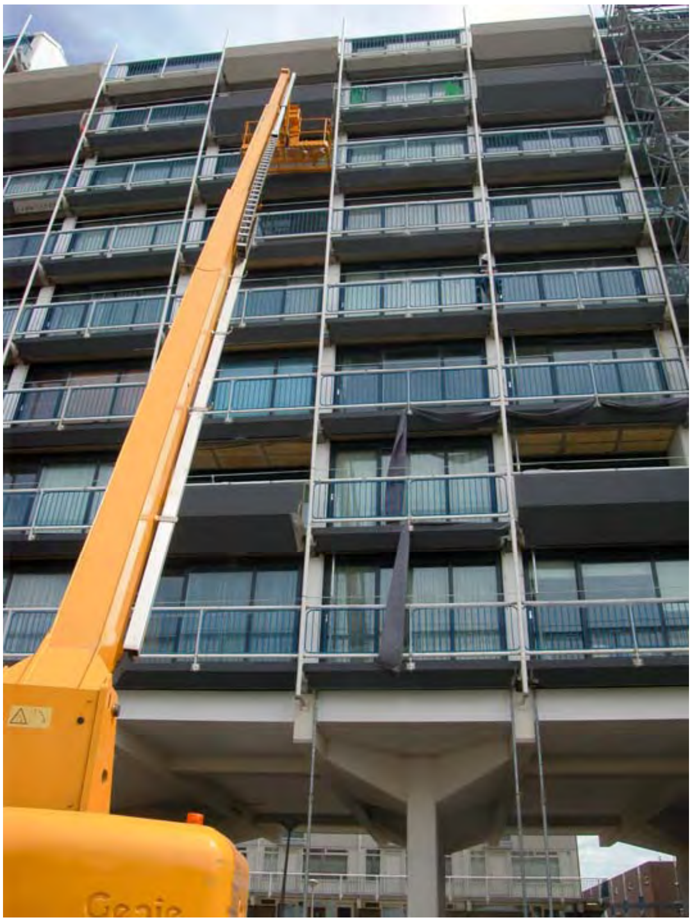

Figure 8: Application of the CAST+ composite paint on balconies, roof decks and balustrades (paint with anthracite colour).

Figure 9: Apartment building in Scheveningen Strand after completion of repair works.

4.2 *Apartment buildings on Weststraat in Scheveningen*

In 2005, apartment blocks near the center of Scheveningen were repaired and protected with the CAST$^+$ composite anode system. The CAST$^+$ system was applied on balconies, supporting beams, balustrades with a total surface of 450 m^2. Before applying the composite anode system, the concrete surface was cleaned by water jetting with 400 bars (figure 10).

Figure 10: Concrete surface preparation and cleaning by high pressure water jetting.

The concrete surface In figure 11, part of the apartment building is shown after completion of repair and installations works.

Figure 11: View on the apartment building after application of the CAST$^+$ system and after application of white acrylic cover coating.

Performance of the anode system suffices the 100 mV depolarization criterion within 24 hours. Anodic current density is about 3 mA/m^2. At an age of 7 years no visual or electrochemical signs of ageing and / or deterioration are present. Life time expectancy is about 15 years.

4.3 *Apartment buildings in Zandvoort*

In 2011, the new CAST^{3+} composite anode system was applied on two apartment buildings in Zandvoort. The CAST^{3+} paint is the 3d generation of the composite paint systems exhibiting high durability, high weathering resistance (UV-resistance, frost resistance, frost thaw salt resistance) and compatibility with most of acrylic, PU and epoxy based paint and coating systems.

One of the apartment blocks repaired and protected with the CAST^{3+} composite anode system is shown in figure 12.

Figure 12: Apartment block (left side, with scaffolding) in Zandvoort, repaired and protected with the CAST^{3+} composite anode system.

Figure 13: Balustrades and underside of balcony, coated with the CAST^{3+} composite anode paint.

The underside of balconies, balustrades and beams were coated with the CAST^{3+} composite anode paint as shown in figure 13 & 14. After installation of the current distributors (termed as primary anodes), a white cover paint, top coat from Sikkens, was applied (figure 15).

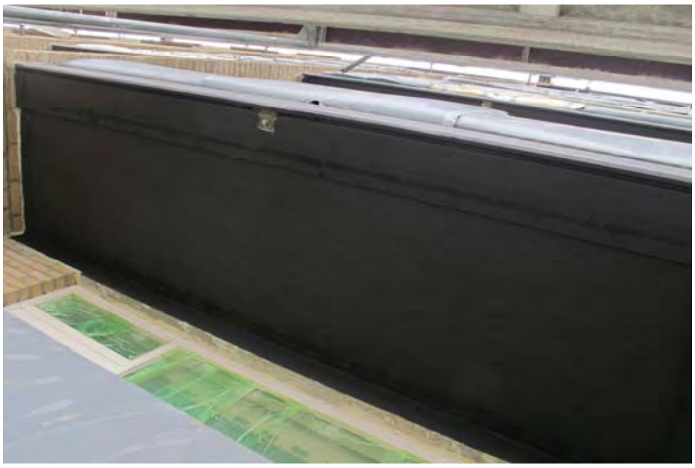

Figure 14: Underside of balcony coated with the CAST^{3+} composite anode paint.

Figure 15: Application of a white top coat after the installation of the CAST^{3+} system.

The works were completed in July 2011. Start up and operation follows the guide-lines of EN ISO 12696.

Depolarisatie metingen - KB-systeem CAS T+

Project "Duinroos"- Burgemeester van Alphenstraat 59 - Zandvoort

22.11.2011
helder
droog
4˚C

VOEDING NOORD

Voeding	Voor	Na	DATUM		
V	2,01 V	2,01 V	I/O	22 november 2011	14.05 uur
A	115 mA	164 mA	1 uur meting	22 november 2011	15.10 uur
W	231 mW	330 mW		ongewijzigd	

Re	Aan	I / O	+ 1 min	+ 2 min	+ 3 min	+ 5 min	+ 10 min	+ 15 min	+ 30 min	+ 45 min	+ 55 min	+ 60 min	Aan	Potentiaal val	Anode
1	0,704 V	0,494 V	0,452 V	0,447 V		0,440 V	0,406 V	0,397 V	0,382 V	0,368 V	0,360 V	0,356 V	0,700 V	138 mV	
2	0,619 V	0,533 V	0,422 V	0,410 V		0,394 V	0,348 V	0,335 V	0,311 V	0,295 V	0,285 V	0,282 V	0,607 V	251 mV	
K															1,156 V

VOEDING OOST

Voeding	Voor	Na	DATUM		
V	3,02 V	3,02 V	I/O	22 november 2011	14.05 uur
A	860 mA	1004 mA	1 uur meting	22 november 2011	15.10 uur
W	2597 mW	3032 mW		ongewijzigd	

Re	Aan	I / O	+ 1 min	+ 2 min	+ 3 min	+ 5 min	+ 10 min	+ 15 min	+ 30 min	+ 45 min	+ 55 min	+ 60 min	Aan	Potentiaal val	Anode
3	0,925 V	0,482 V	0,465 V	0,457 V		0,444 V	0,427 V	0,420 V	0,394 V	0,380 V	0,376 V	0,373 V	0,877 V	109 mV	
4	0,649 V	0,481 V	0,432 V	0,413 V		0,384 V	0,364 V	0,357 V	0,338 V	0,330 V	0,328 V	0,326 V	0,624 V	155 mV	
K															1,273 V

VOEDING ZUID

Voeding	Voor	Na	DATUM		
V	2,00 V	2,00 V	I/O	22 november 2011	14.05 uur
A	97 mA	157 mA	1 uur meting	22 november 2011	15.10 uur
W	194 mW	314 mW		ongewijzigd	

Re	Aan	I / O	+ 1 min	+ 2 min	+ 5 min	+ 10 min	+ 15 min	+ 20 min	+ 30 min	+ 40 min	+ 50 min	+ 60 min	Aan	Potentiaal val	Anode
5	0,695 V	0,592 V	0,541 V	0,524 V	0,503 V	0,492 V	0,479 V	0,475 V	0,468 V	0,460 V	0,458 V	0,453 V	0,555 V	139 mV	
6	0,601 V	0,453 V	0,408 V	0,397 V	0,378 V	0,364 V	0,348 V	0,343 V	0,334 V	0,325 V	0,323 V	0,319 V	0,561 V	134 mV	
K															1,221 V

Conclusies:
Alle zones functioneren naar behoren.

Figure 16: Results of depolarisation measurements according to EN 12696 summarized in a form presented to the owner.

The performance and efficiency of CP systems is measured according to EN ISO 12696 by interrupting the applied current for at least 24 hours. Steel potentials are measured and recorded during the current interruption. Steel potentials are measured against in the concrete cover embedded reference cells (usually Ag/AgCl or Mn/MnO_2 cells) or depolarisation probes (MMO-Ti ribbon mesh stripes). Immediately after current interruption (0,1 – 0,5 sec), steel potentials are recorded as "instant off potentials". The difference between "off potentials" and the "instant off potential" is termed as depolarisation value or potential shift.

Steel rebars are reliably protected against corrosion, if the potentials of the steel rebars shift by at least 100 mV towards the positive direction within not more than 24 hours.

Table 1: Depolarisation values according to EN ISO 12696, measured on 22 November 2011, Apartment building Zandvoort (applied voltage 2,00 Volt).

Zone	On	Inst. Off	60 min Off	1 hour Depol.
North				
Ref 1	0,704 V	0,494 V	0,356 V	**138 mV**
Ref 2	0,619 V	0,533 V	0,282 V	**251 mV**
East				
Ref 3	0,925 V	0,482 V	0,373 V	**109 mV**
Ref 4	0,649 V	0,481 V	0,326 V	**155 mV**
South				
Ref 5	0,695 V	0,592 V	0,453 V	**139 mV**
Ref 6	0,601 V	0,453 V	0,319 V	**134 mV**

Results show that the steel rebars in the concrete members protected by the $CAST^{3+}$ composite anode system are reliably protected from corrosion. Installation costs are competitive with conventional repair techniques.

5 CONCLUSIONS

Sea side apartment buildings are exposed to high loads of marine salt that cause severe damages to the concrete structures induced by the corrosion of the steel reinforcement. The $CAST^{3+}$ Composite Anode System offers a cost efficient and reliable technology for the repair and protection of concrete members exposed to marine salt. The technology is highly sustainable as it produces nearly 0-waste, requires minimum concrete preparation – in comparison with water jetting at 2000 bars for conventional repair techniques and involves minimum traffic impairment. In the Netherlands, this technology has now a successful record of over 8 years in the repair, protection and maintenance of sea side apartment buildings. There were no problems in meeting the 100 mV criterion from ISO-EN 12696. Furthermore no signs of ageing visually or electrochemically are observed.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

C. D. O'Dowd, Michael H. Smith, Ian E. Consterdine, and Jason A. Lowe. Marine aerosol, sea-salt, and the marine sulphur cycle: a short review. Atmospheric Environment, 10: 1352–2310, 2001.

Meira, G.R., Andrade, C., Alonso, C., Padaratz, I.J., Borba, J.C., Modelling sea-salt transport and deposition in marine atmosphere zone – A tool for corrosion studies, Corrosion Science (2008), 50, 2724–2731

Schwarz, W. & Tritthart, J. 2009. Effect of cathodic protection: a viable method to monitor and control the efficiency of CP?, *Materials and Corrosion* 60: 138 – 147