Lifetime Extension of Thermally Sprayed Zinc Anodes for Corrosion Protection of Reinforced Concrete Structures by Using Organic Topcoatings

Jochen Spriestersbach, Armin Melzer, Jürgen Wisniewski, Andrea Winkels
Grillo-Werke AG, Duisburg /D

Michael Knepper
OSU Maschinenbau GmbH, Duisburg/D

Summary

Structural damage in concrete structures caused by corrosion is widespread and demand comprehensive repair work. The additional installation of an active corrosion protective systems for structures being located in unfavourable conditions is imperative. Thermally sprayed coatings serving as anode have been adapted from the cathodic protection of steel. These systems have gained attention as they offer advantages in efficiency and lower cost. Thermally sprayed zinc coatings are applied to new steel reinforced concrete structures or those which are subject to re-structuring. In this contribution, the capability of various systems is examined by field tests in a marine structure and in different laboratory tests under natural and under accelerated conditions.

Introduction

Significant advances have been made in the development of sacrificial anode cathodic protection systems to migrate steel reinforcement corrosion in the past two decades. The corrosion protection of the reinforcing steel in reinforced concrete structures is usually guaranteed by the alkalinity of the electrolyte accommodated in the pores of the concrete (pH > 12.5). This pH level leads to a passivation of the steel surface which suppresses the corrosion of the steel. Unfavourable environmental conditions or deficiencies in the building construction are often the reason for corrosion damages which in most cases has necessitate extensive reconstruction and repair work world-wide.

Spalling of the concrete coverage in steel reinforced concrete structures results from the fact that the corrosion products of steel take up five times the volume of the steel. Various environmental parameters (temperature, humidity), but also building parameters (type of cement, water-cement ratio, re-treatment, additives) have a decisive bearing on the durability of the steel passivation [1-3]. Corrosion mechanisms in concrete corrosion are carbonation and chloride contamination (exceeding of the critical chloride content). Corrosion of steel reinforcement in concrete due to the intrusion of chloride ions from seawater affects many structures located in marine environment. This is also the case for inland structures effected by seasonal chloride loading (e.g. during winter).

Thermally sprayed zinc coatings as anodes

Galvanic cathodic protection (CP) systems, which use sacrificial anodes, have recognised advantages of simplicity and reliability, and have recently become available as a viable alternative to impressed current CP systems (ICCP) [4]. Unlike ICCP, galvanic CP systems require no extensive wiring or conduit, and no power supplies. Their inherent simplicity greatly reduces the need for ongoing monitoring and maintenance.

Thermal sprayed zinc anodes were first investigated for use on concrete in the US in 1983 [5]. In principle, sprayed zinc coating can be applied in three different cathodic corrosion protection systems:

1. As galvanic cathodic protection (CP) system by sprayed zinc coatings for repair work without reprofiling,
2. As galvanic cathodic protection (CP) system by sprayed zinc coatings with reprofiling,
3. As impressed current CP-system (ICCP) with sprayed zinc coatings.

The substantial differences of the three above-mentioned systems are compared in table 1.

	Galvanic without reprofiling	Galvanic with reprofiling	Impressed current system
Reprofiling required	-		yes
Current measurable	-	yes	yes
Protective capacity detectable	conditional	yes	yes
Current adjustable	-	conditional	yes
External current retrofittable	-	yes	conditional
Installaion in dry environment	-	-	yes
Installation in humide environment	yes	yes	possible, not required

Table 1: Characteristics of different cathodic corrosion protection concepts [6]

In principle, an investigation has to be made for every application whether an external power supply is required. Optimal conditions for the operation without impressed current are in regions without long dry periods, such as coastal areas or tropical regions.

Thermal spraying of zinc on concrete as anode

Thermally sprayed coatings of zinc or zinc alloys can alternatively be produced by techniques widely known as flame (acetylene-oxygen or propane-oxygen) spraying and electrical arc spraying. In the wire arc spraying process (Figure 1) two wires which serve as electrodes are fed together in a gun. An arc forms between the two wires which causes the wire ends to melt. The smelted droplets are subsequently accelerated with an atomising gas flow in the direction of the substrate. On impact at the substrate surface the droplets solidify and adhere both to the substrate and to each other forming a coating [7].

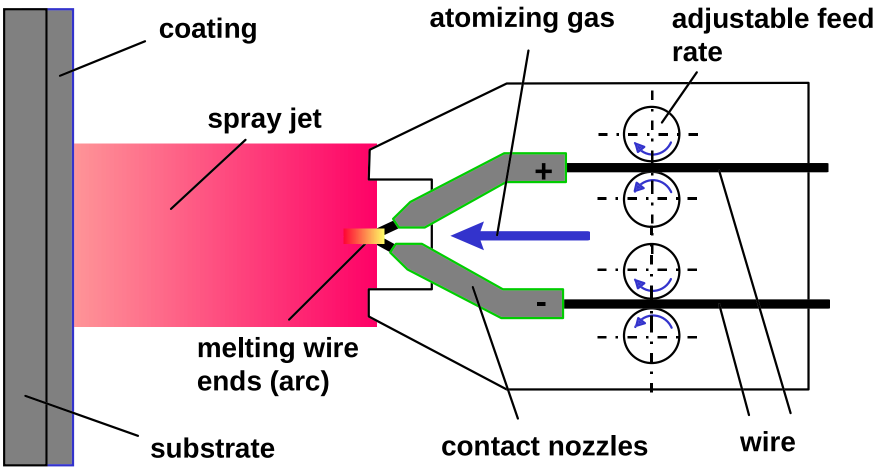

Figure 1: Wire arc spraying according to EN 657

Today arc spraying has gained greater attention for processing zinc as it offers advantages in efficiency and lower costs. In general equipment for arc spraying is more expensive than it is for flame spraying. However, higher investment costs can rapidly be absorbed by the higher efficiency and lower operating cost of the arc spray system [8].

The concrete surface must be pre-treated before a zinc anode can be applied. The surface has also to be cleaned and roughened in order to support a mechanical adhesion of the layers. Additionally the surface is heated immediately prior to zinc spraying in order to remove any existing residual humidity from the surface rim zone which would weaken the adhesion. The application of the zinc sprayed coating is accomplished in several layers. A mechanically and electrically connected coating is generated with sufficient adhesion to the concrete surface. The coating thickness of the zinc anode is variable and usually ranges between 300 and 500 μm. The adhesion of the zinc coating normally ranges between 1.5 and 3.5 MPa. Special appliances and methods of measurement also permit the inspection of the mechanical stability of the zinc coating on concrete. If a contact of the zinc coating with the reinforcement is intended, either as galvanic sacrificial anode or for the application with external current, metallic elements are installed during the concrete repair work which can be electrically connected with the sprayed zinc coating.

Studies carried out in the US have shown that the service life of a thermally sprayed zinc anode can lasts up to 20 years if the parameters are correctly chosen and after a correct analysis of structure and environmental conditions [9].

Lifetime Extension by using organic top-coatings

The lifetime of the zinc coating can be enhanced if an organic top-coating is applied to the arc sprayed zinc coating (Figure 2). This system is applicable for concrete structures and was developed and modified by GRILLO in 1997 for strong environmental conditions.

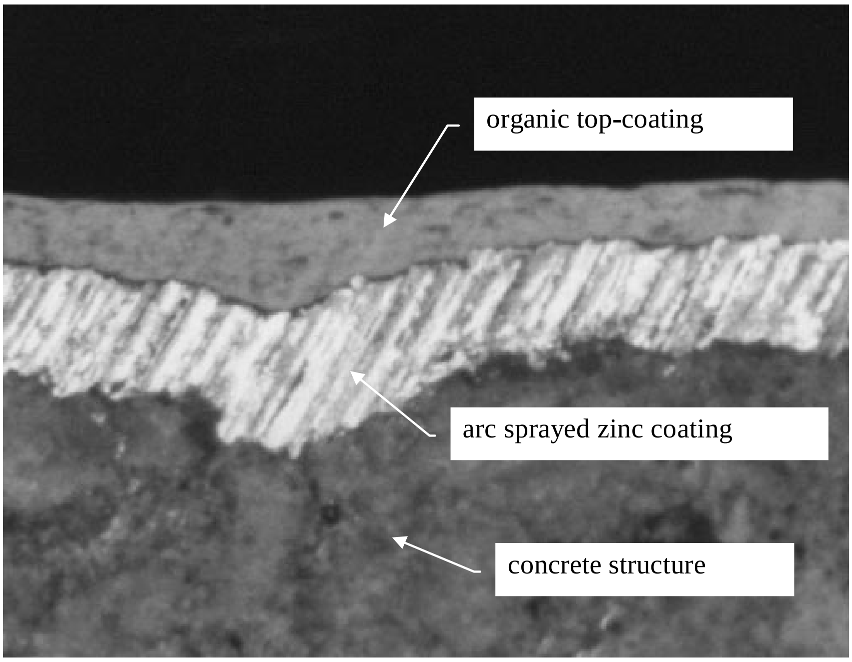

Figure 2: Arc sprayed zinc coating with organic top-coating

The advantages of the organic top-coating is that the zinc coating is not in direct contact with the atmosphere and thus subject to self corrosion. Therefore, only a inner consumption takes place in the interface of zinc coating and concrete. It is calculated that the zinc consumption can be reduced half (Figure 3).

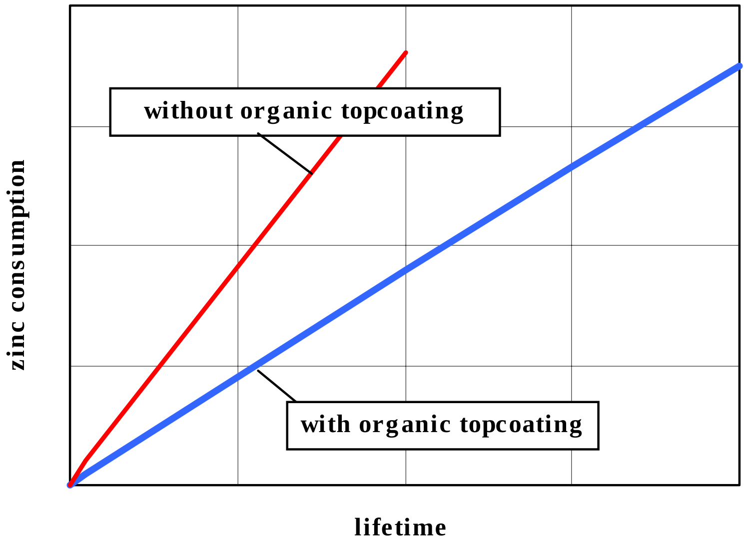

Figure 3: Scheme of lifetime extension by organic topcoating

In laboratory test several combinations of sprayed zinc coatings and organic topcoatings were evaluated to determine the best system configuration of anode material. Much of this work was focused on the adhesion of the system on concrete, and the behaviour as anodes. All systems were tested under accelerated conditions e.g. in the salt spray test. It was observed that the right choice of organic topcoating is of high importance for the adhesion strength of the system and the behaviour as anode material. Following this work, concrete specimens were coated and exposed to the atmosphere (Figure 4). To simulate maritime conditions these concrete blocks were contaminated with NaCl. Since the installation permanent current and static potential measurements were carried out, and the depolarisation potentials were measured.

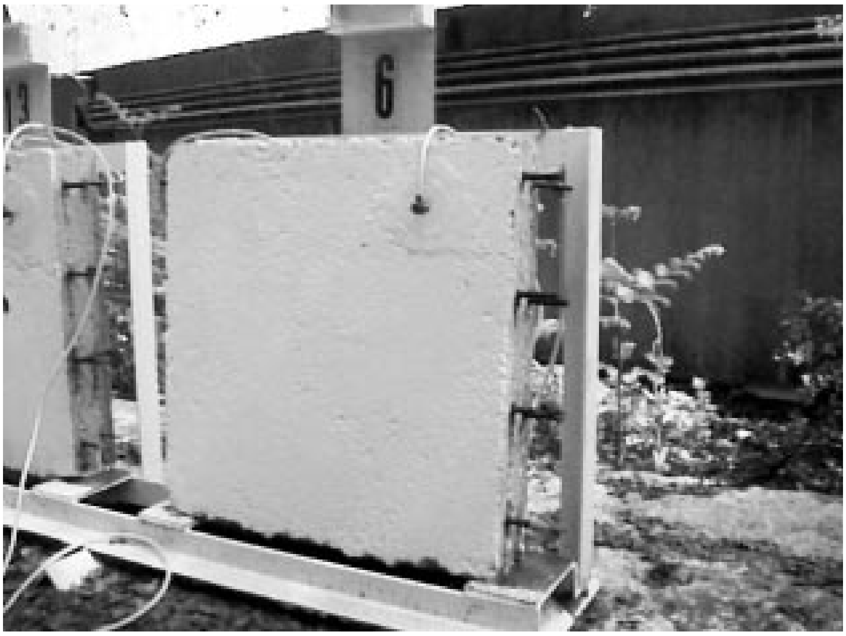

Figure 4: Sprayed zinc coated concrete specimen with organic topcoating

Thermally sprayed zinc CP-system in the Arabian Gulf

A galvanic cathodic protection system using arc-sprayed zinc anodes was installed by GRILLO to steel reinforced concrete structures in marine atmosphere located in a harbour of the Arabian gulf. The structures showed signs of severe corrosion. The structure was repaired at the end of 1997 and corrosion protected by the installation of an arc sprayed galvanic zinc anode system. Additionally, an organic topcoating was applied to the arc sprayed zinc coating. The following repair work was carried out on each structure:

1. removal of chloride contaminated concrete
2. cleaning of the corroded steel reinforcement
3. installation of reference cells and electrical contacts
4. patching of the structure
5. fitting of electrical contacts for the zinc coating
6. arc spraying of the zinc anode
7. applying of the organic top-coating

In order to guarantee the monitoring functions of the system for future maintenance and control a monitoring system was installed. Manganese dioxide reference electrodes were installed for potential measurements. Static potentials were determined by operating the monitoring system. Figure 5 shows one of the galvanic protected structures one and a half year after installation of the CP-system.

Figure 5: Concrete structure one and a half year after repair (1999)

After installation of the corrosion protection system no sign of rebar-corrosion could be observed. The collected monitoring data since the installation suggest that the steel rebars are adequately protected from corrosion by the installed corrosion protection system. The obtained values of the static potential measurements indicate that there is no sign of corrosion. All measured potentials in April 99 are below 520 mV (Figure 6). A possible corrosion attack can be expected at the earliest for potentials higher than 800 mV measured with respect to a manganese dioxide reference electrode. Insignificant deviations of the static potentials with the time are influenced by the climate and should not be considered as critical. By considering the curves of the static potentials measured at six different locations of the structure a stabilisation of the potential values can be observed since November 98.

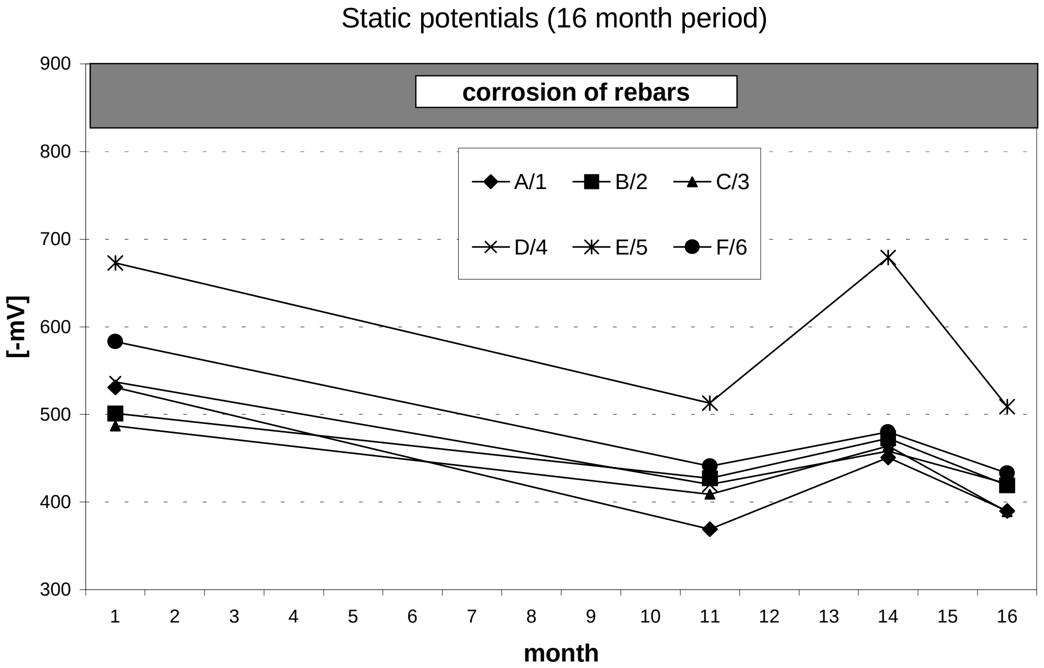

Figure 6: Static potentials measured on six different locations of the structure with respect to a manganese dioxide reference electrode

Conclusions

Sprayed zinc coatings do not present any significant limitations with regard to their applicability in comparison with the other cathodic corrosion protection variants for concrete, i.e. they are practically always suitable whenever structural elements are to be protected by cathodic protection. Galvanic corrosion protection with sprayed zinc coatings has the significant advantage in comparison with the other cathodic protection variants for concrete, that a reprofiling of the concrete surfaces is not absolutely necessary and that no electrical installations have to be carried out.

The service life of a thermally sprayed zinc anode can last up to 20 years or more if the parameters are correctly chosen and after a correct analysis of structure and environmental conditions. By applying organic top-coatings to the sprayed zinc coating the lifetime can be enhanced, considerably.

References

[1] Schießl, P., RILEM; Technical Committee 60-CSC: Corrosion of Steel in Concrete. New York: Chapman and Hall,1988 (RILEM Report)

[2] Nürnberger, U., Korrosion und Korrosionsschutz im Bauwesen. Bauverlag (1995), Wiesbanden; Berlin, ISBN: 3-7625-3199-4

[3] Raupach, M., Zur chloridinduzierten Makroelementkorrosion von Stahl in Beton, in: Schriftenreihe des Deutschen Ausschusses für Stahlbeton (1992), Nr. 433, Beuth-Verlag, Berlin

[4] Bennett, J, Galvanic Cathodic Protection of Reinforced Concrete Using Surface-Applied Zinc Anodes, in: Proceedings of ICCRRCS, Orlando, Florida, 1998, Publication No. FHWA-SA-99-014

[5] Tinnea, J.S., Field Performance of Sprayed Zinc Cathodic Protection Anodes, in: (ed: C. Coddet) Proceedings of the 15th International Thermal Spray Conference 1998

Proceedings Eurocorr'99, Aachen/Germany, 30 Aug-2 Sept 199

[6] Spriestersbach, J., Knepper, M., Gamroth, M., Zinkschichten zum Korrosionsschutz von Stahlbetonbauwerken, in: Erzmetall 51 (1998) Nr. 4, 291-298

[7] Knepper, M. Spriestersbach J., How to successfully battle corrosion: Thermally sprayed coatings of zinc and zinc alloys, in: Proceedings of the ITSC Shanghai 1997 (Nov 18-21, 1997): Surface Engineering Towards The 21st; Century Editor:X. Binishi et. Al, China Machine Press, Beijing 1997, pp. 384-391

[8] Porter F., Corrosion Resistance of Zinc and Zinc Alloys, Marcel Dekker inc., New York 1994

[9] Sagüés, A., Powers R.: SHRP-S-337: Sprayed Zinc Galvanic Anodes for Concrete Marine Bridge Substructures, 1993 (Strategic Highway Research Program, Washington)