Thermally sprayed zinc coatings for the corrosion protection of concrete structures

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Abstract

Structural damage in concrete structures caused by corrosion is widespread and demand comprehensive repair work. The installation of corrosion protective systems for structures being located in unfavourable conditions is imperative.

Cathodic protection is well known. 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 costs and are about to enter the competitive market for anode systems.

Thermally sprayed zinc coatings are applied to concrete surfaces of steel-reinforced concrete components which are affected by corrosion. The concrete cover of corrosion-damaged components is removed. After sandblasting and patching the structures zinc is sprayed on top of concrete, creating a galvanic anode up to 500 µm. The coating then is electrically connected with the steel to create a corrosion protective system.

In this contribution, the capability of the system to deliver protective current is examined by field tests in a marine structure in the Arabian gulf treated in 1997.

1 Introduction

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.

2 Corrosion of steel reinforced concrete

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, retreatment, additives) have a decisive bearing [1] on the durability of the steel passivation. Corrosion mechanisms in concrete corrosion are carbonation and chloride contamination (exceeding of the critical chloride content).

In the case of carbonation of the concrete the alkaline components of the hardened cement paste react with the carbon dioxide contained in the air. Thereby the normally high pH value drops to values below 9 or 10. The result is that the passivation is neutralised and this can lead to a gradual dissolution of the iron [2,3].

The corrosion protection can also be reduced on account of exceeding the critical chloride content (this amounts to approx. 0.4 to 0.5%) at the surface of the steel. A local neutralisation of the passivation results which as a rule entails local corrosion in the shape of pittings [4] (figure 1)

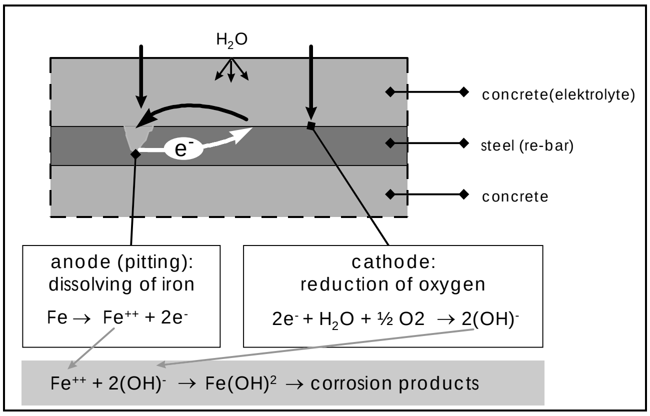

Figure 1: Steel corrosion through neutralisation of the passivation caused by exceeding of the critical chloride content (schematic)

Corrosion through chloride contamination requires humidity and oxygen available in the vicinity. This is the case for structures in marine atmosphere or inland structures effected by seasonal chloride loading (e.g. during winter).

3 Active corrosion protection

In the case of active corrosion protection, like cathodic corrosion protection, the surface to be protected remains completely or partially exposed to the aggressive medium; there is, however, active intervention into the corrosion process. Electrons originating from a base metal, the galvanic sacrificial anode, are offered to the steel to be protected.

This is realised by connecting the sacrificial anode and the reinforcement bars through an electron conductible material. The electric circuit is then closed through the electrolyte within the concrete. Thus a current flow is realised: the negative ions, e.g. chloride and hydroxide, travel to the anode - consequently away from the reinforcement. The application of galvanic anode systems requires a minimum current flow between reinforcement steel and anode.

When the level of moisture content is too low the protection of the re-bars cannot be guaranteed. In this situation the availability of electrons is not sufficient for the cathodic protection of the steel and these electrons are taken from the negative pole of a direct-current supply and the anode is connected to a direct-current supply (positive terminal). The steel reinforcement is connected to the same power supply (negative terminal) so that the usually interconnected electrically conductive reinforcement steels constitute the cathode (impressed current system).

Cathodic corrosion protection systems for concrete structures working with impressed current mostly employ titanium mesh as the anode which has to be embedded in a fresh layer of sprayed concrete. High cost of material (titanium) and the need for embedding the titanium mesh led to the development of zinc anodes sprayed on top of the concrete surface. The zinc anode is not only able to serve as an anode in impressed current systems but also as an anode in galvanic systems. In the US these systems have been in operation since 1983 [5].

4 Thermally sprayed zinc coatings as anodes

In principle, sprayed zinc coating can be applied in three different cathodic corrosion protection systems:

- As galvanic corrosion protection by sprayed zinc coatings for repair work without reprofiling: concrete excavations in which the reinforcing steel is partially uncovered are not filled with repair mortar, the initial concrete surface is not restored. The zinc layer is directly sprayed on exposed steel and concrete surfaces with this method.
- As galvanic corrosion protection by sprayed zinc coatings with reprofiling: The application of the zinc coating is possible when either no spalling of the concrete has occurred or spallings have been repaired. This variant allows the flow of current between the electrodes to be determined. A conditional current regulation is also possible through the arrangement of resistances. A reduced protection of the reinforcement, however, is possible in case of too low concrete conductivity. That is the reason why systems of this type only work in atmospheres offering sufficient humidity and a high temperature. This variant, however, offers the option of a retrofit with an artificial current supply so that installations of this type can also be operated as impressed current systems.
- As impressed current system with sprayed zinc coatings: such a systems requires the concrete reprofiling as first step. The cathodic corrosion protection effect does not arise from the potential difference between the zinc anode and the protected reinforcing steel but from the feeding of an electric potential by means of an appropriately arranged power supply.

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]

Figure 2 compares the application of the sprayed zinc anode operating in an galvanic system and in an impressed current system.

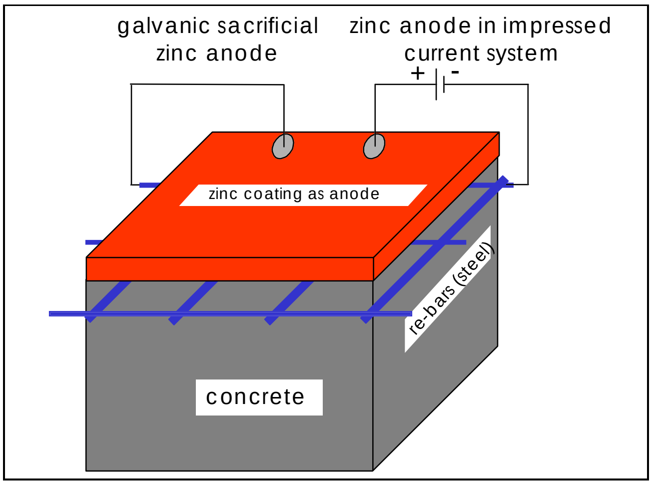

Figure 2: Corrosion protective system: Galvanic / with impressed current

The three variants are suitable for use under humid conditions, e.g. in changing water and spray water zones. 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.

The decision whether or not a galvanic system with/without electrical insulation between both electrodes has to be designed depends on the area of spalling on the concrete structure

5 Coating Application

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.

The thermal spray processes are characterised by liquid droplets depositing onto a surface. The coating material is injected into the heat source in which it melts. An atomiser gas accelerates the molten particles towards the substrate material. On impact at the substrate surface the droplets solidify and adhere both to the substrate and to each other forming a coating [7].

An acetylene-oxygen flame is mostly used for wire flame spraying (figure 3) in order to melt off the end of a wire which is introduced into this flame. The individual smelted droplets are subsequently accelerated with an atomising gas in the direction of the substrate surface. The density of a flame sprayed coating generally ranges between 85 and 90% of the density of the base material.

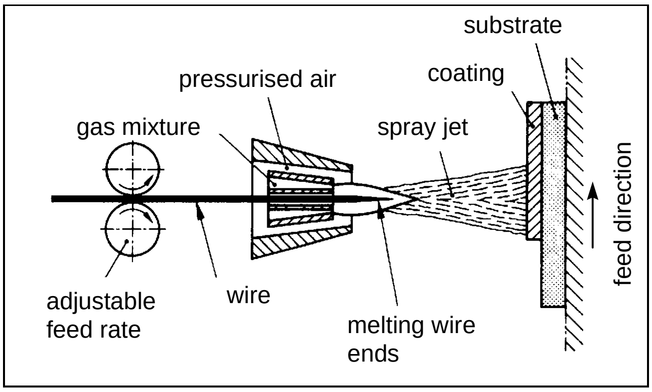

Figure 3: Wire flame spraying according to EN 657

In the wire arc spraying process (figure 4) 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 also subsequently accelerated with an atomising gas flow in the direction of the substrate.

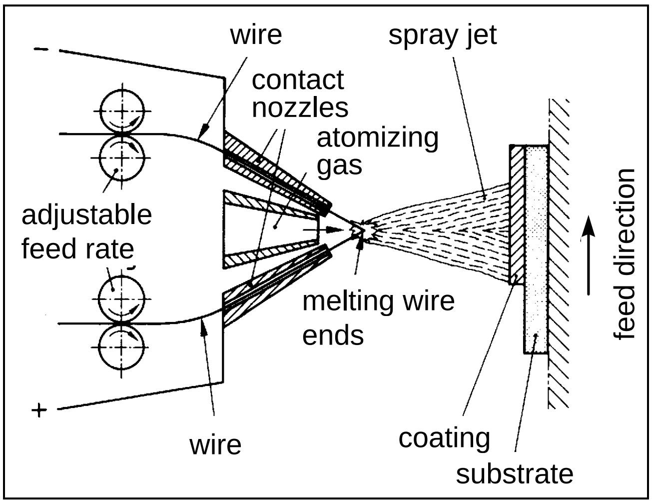

Figure 4: Wire arc spraying according to EN 657

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 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 (figure 5) 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 thickness is regularly controlled with test strips. The adhesion of the zinc coating normally ranges above 1.5 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.

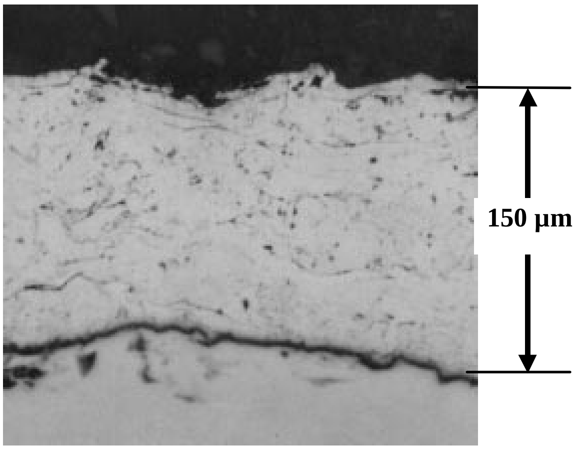

Figure 5: Arc sprayed zinc coating

6 Repair of damaged concrete and corrosion protection through zinc anodes

A thermally sprayed surface anode can also be employed as a sacrificial anode at structures located directly next to the sea, especially at structures located in the splash water or changing water zone, as the reinforced concrete features good conductivity values under those conditions on account of high chloride and humidity content.

These situations can be found in Florida, in the coastal regions of the Arabian gulf countries or even on the coast line of the North Sea or the Baltic Sea. There is often considerable damage to the reinforcement of concrete structures in these regions which is also connected with spalling. After the first occurrence of spalling at buildings of this type, further drastic damage can be expected very quickly.

Figure 6 illustrates a concrete structure in marine atmosphere located in a harbour of the Arabian gulf. The structure is appr. 20 years old and shows signs of severe corrosion.

The structure was repaired at the end of 1997 by including the installation of an arc sprayed galvanic zinc anode system. In order to carry out the repair work as required the whole procedure had to be followed:

- removal of chloride contaminated concrete
- cleaning of the corroded steel reinforcement
- installation of reference cells and electrical contacts
- patching of the structure
- fitting of electrical contacts for the zinc coating (figure 7)
- arc spraying of the zinc anode
- fitting of a monitoring system

Figure 6: Damaged concrete structure

Figure 7: Fitting of the zinc contacts

In order to guarantee the monitoring functions of the system for future maintenance and control the monitoring system had to be planned in detail including:

- number of protection and monitoring zones
- number and location of the connections to the steel reinforcement
- number and location of the zinc connections
- number and location of the reference cells
- location and accessibility of the monitoring system
- option for impressed current operation

After repairing the structure (figure 8) the performance of the system was tested. Current flows and potentials were determined by operating the monitoring system: the performance could be assessed (Table 2).

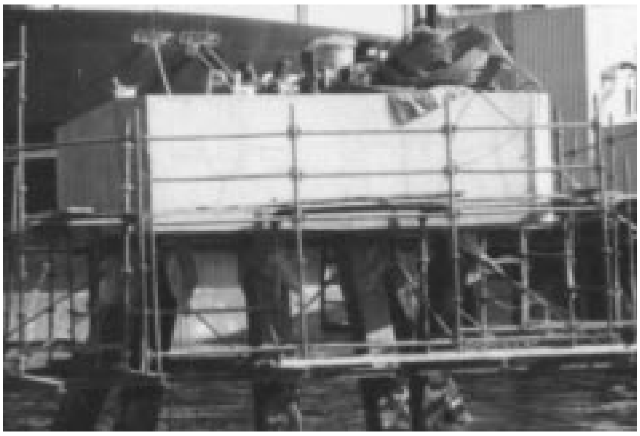

Figure 8: Concrete structure after repair

Terminal	Elevation	Natural potential [+mV]	Applied potential [+mV]	Current flow [mA]
1	Top	520	531	5
2	Bottom	405	501	6
3	North	400	487	6
4	South	523	537	6
5	East	418	673	5
6	West	421	583	4

Table 2: Applied potentials and current flows after installation of the galvanic system

The conditions do not allow automated continuous data collection. Therefore the data collection has to be carried out manually every three months. If the driving voltage reduces the system offers the option to integrate a direct current source even after years of operation.

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 [7, 8]. It is in any case possible to extend the lifetime of the whole corrosion protection system by renewing the zinc anode by re-spraying.

7 Summary and Conclusions

Cathodic corrosion protection with sprayed zinc coatings can be performed in different variants, as galvanic system with a sacrificial anode with and without the option of electrical separation between anode and reinforcement. Both types can be operated under very humid environmental conditions. The application as impressed current protection system for concrete is favoured under dry conditions.

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. Galvanic corrosion protection with sprayed zinc coatings therefore offers decisive advantages, i.e. under very humid conditions.

Thermally sprayed zinc anodes can be renewed very easily after being consumed. Even after the complete removal of the zinc coating, the anode can be easily replaced by spraying a new zinc coating on the concrete surface.

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.

8 References

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