JTTEE5 5:49-52

Long-Term Factors Influencing the Adhesion of Metallized Zinc to Concrete

R. Brousseau, M. Arnott, and B. Baldock

Metallized zinc cathodic protection often is used to mitigate steel reinforcement corrosion in concrete. The zinc is flame or arc sprayed to the surface of the concrete structure to be protected. The metallized coating should be applied such that its adhesion to concrete is maximized. Factors believed to affect adhesion were investigated for pure zinc and a 85Zn-15Al alloy. On reinforced concrete samples polarized for more than 800 days at three different current densities, adhesion decreased. The reduction increased as a function of time and of the current density applied. When no current was applied, there was a small initial increase of adhesion with time. For the metallized samples that were freeze-thaw cycled, no loss of adhesion was found after 70 cycles.

1. Introduction

CORROSION of reinforcing steel in concrete due to chloride attack is a serious problem in northern climate regions and on coastal structures. Cathodic protection often is used to mitigate steel reinforcement corrosion. It involves negatively polarizing the steel reinforcement in order to promote chloride ion migration away from the reinforcement and to reduce the rate of anodic oxidation of iron. This technique is usually applied to older and chloride-contaminated structures experiencing corrosion-related damage. It requires the application of an anode, such as metallized zinc, on the surface of the concrete structure to deliver the protective current to the rebars.

Zinc coatings have been successfully implemented as impressed-current anodes in California (Ref 1, 2), Oregon (Ref 3), and Ontario (Ref 4, 5). The Florida Department of Transportation (Ref 6) has also begun to use metallized zinc as a sacrificial anode on marine structures. It is, however, still unknown how this type of anode will perform in the long term.

In order for the metallized zinc to perform adequately as an anode, it must have good adhesion to the surface concrete of the cathodically protected structure. Steps should be taken to optimize the adhesion of the zinc coating when it is thermally sprayed on the concrete surface. Earlier work (Ref 7-10) has shown that a number of parameters can influence the adhesion of arc-sprayed zinc to concrete.

This paper discusses phenomena that may affect adhesion after zinc has been metallized onto concrete. The effects of anodic polarization, time from application, and freeze-thaw cycling are reported. A 85Zn-15Al alloy was also thermally sprayed in these experiments. However, it should be noted that zinc-aluminum coatings are not recommended for impressed-current cathodic protection (Ref 11, 12).

Keywords adhesion strength, cathodic protection, current density, freeze-thaw cycling, zinc on concrete

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2. Experimental Method

2.1 *Thermal Spraying*

Zinc and 85Zn-15Al were arc sprayed onto concrete blocks using a Thermion 500 electrical arc gun. All thermal spray applications were performed with 3 mm wires, using 620 kPa air pressure, 26 V, 300 A, and a spray distance of 15.2 cm. An automated application system was used to travel the electrical arc gun in the *x-y* plane during metallizing to produce a uniform 0.4 mm thick coating.

2.2 *Manufacture of Concrete Samples*

The concrete samples were manufactured in three different configurations and sizes to meet test requirements. The concrete mix design was the same for each of the three tests. The concrete formulation used a cement/sand/aggregate ratio of 1:2:3, type 10 Portland cement, and a water to cement ratio of 0.43. Chlorides were also introduced into the concrete mix to better simulate aggressive environments. The samples were cured in a humid room at 23°C and 100% relative humidity for 28 days. Unless otherwise indicated, the concrete surfaces were blasted with silica sand at 758 kPa air pressure prior to metallization with zinc.

2.3 *Adhesion Measurements*

Bond strength measurements were obtained using a pneumatic adhesion tester referred to as a "Patti." This equipment uses 50 mm dollies. The pulling force is perpendicular to the surface of the samples and is applied at a constant rate that is not operator dependent. A thick, high-strength, slow-setting, two-part epoxy was used to glue the dollies.

2.4 *Samples under Impressed Current*

The effect of impressed currents on metallized zinc adhesion was investigated using 60 concrete samples reinforced with a mild steel mesh (Fig. 1). The metallized concrete samples were placed in individual plastic containers partially filled with a saturated salt solution. The lower 1.0 cm of each sample was always immersed in the salt solution. The samples were subsequently wired in series and polarized at three different current densities—0, 2, and 10 mA/m^2—per anode surface. Ten replicates of each anode material were tested for each of the three current densities.

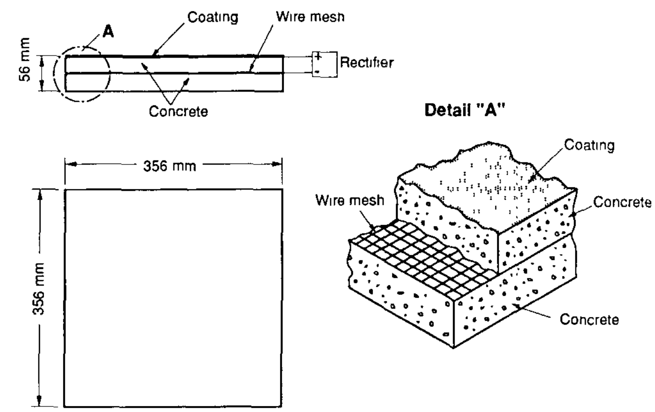

Fig. 1 Schematic diagram of polarized samples

2.5 *Freeze-Thaw Procedure*

The adhesion of zinc coatings exposed to freeze-thaw cycling and deicing salts was investigated via a modified version of ASTM C 672-84 ("Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals"). No current was applied to the samples. The procedure consisted of placing the samples in a freezer (–18 ± 2 °C) for 16 to 18 h. The concrete samples were subsequently removed from the freezer and thawed in the laboratory for 6 to 8 h at 23 °C and 50% relative humidity. The samples were finally sprayed with a salt solution (4% by mass of anhydrous calcium chloride) before being returned to the freezer for a subsequent cycle.

3. Results and Discussion

3.1 *Effect of the Impressed Current*

After 845 days of testing, the bond strengths on all the unpowered samples were similar to or higher than the initial bond strength values. Values presented in Fig. 2 and 3 are averages of 3 to 15 pullout measurements. The higher bond strength for the 85Zn-15Al alloy may be due to chemical reactions between this

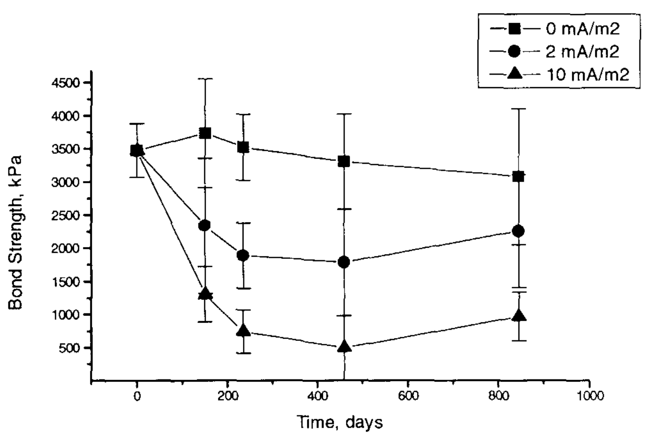

Fig. 2 Bond strength of arc-sprayed zinc as a function of time under an anodic impressed current density of 0, 2, and 10 mA/m^2

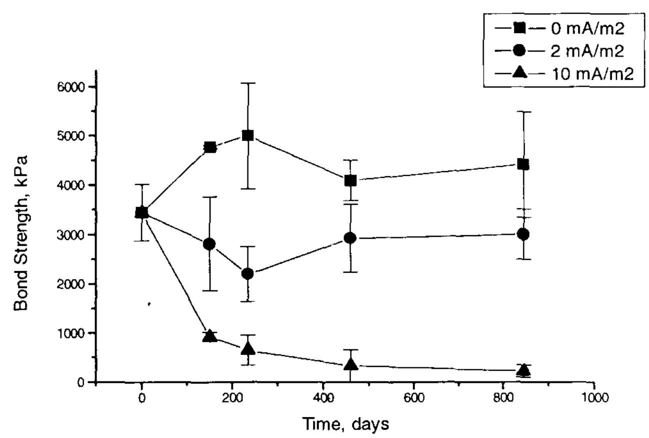

Fig. 3 Bond strength of arc-sprayed 85Zn-15Al as a function of time under an anodic impressed current density of 0, 2, and 10 mA/m^2

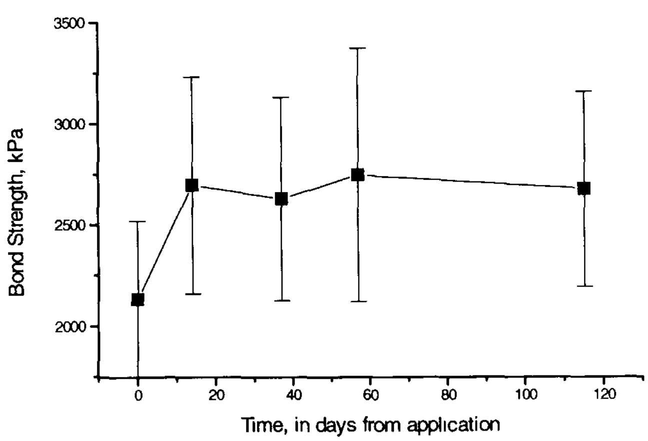

Fig. 4 Time variation of the adhesion of zinc after it has been metallized onto concrete.

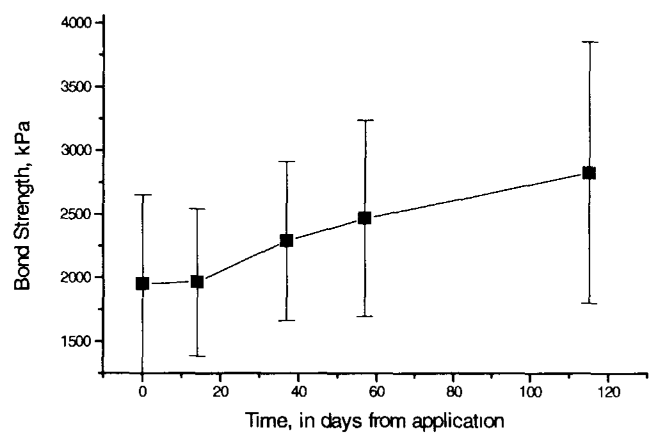

Fig. 5 Time variation of the adhesion of 85Zn-15Al after it has been metallized onto conrete

metallized alloy and the concrete. Aluminum is known to chemically react in higher pH environments as a result of its amphoteric oxides. The limiting factor for many of the bond strength tests on the unpowered samples was the tensile strength of the concrete. Failure often occurred in the concrete (cohesive failure).

The bond strength values for all the powered samples decreased over the course of the experiment. Samples powered at the higher current density experienced larger decreases in bond strength. The loss of adhesion of the metallized coating under anodic polarization is believed to be related to oxidation of the "anchors" that usually provide the mechanical bonding. Molten metal that penetrated into the pores of the concrete during metallizing is most susceptible to oxidation during the flow of anodic current because these "anchors" have a more intimate contact with the concrete pore solution through which electrolytic current flow is forced. This also suggests that excessively large current densities at the anode will be detrimental to the adhesion of the zinc coating. The 85Zn-15Al alloy should not be used as an impressed-current anode for reinforced concrete due to its severe loss of adhesion at 10 mA/m^2. An unusual formation of air pockets also occurs underneath the disbonding zinc-aluminum coatings, with unusual darkening. Such severe physical changes are not observed for pure zinc. Photographs illustrating this point are presented in Ref 11.

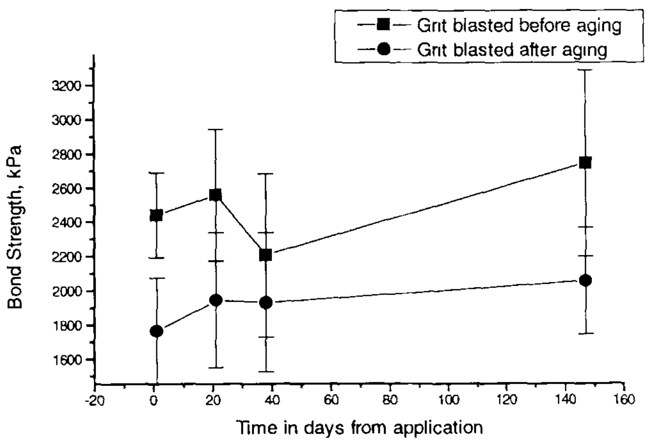

Fig. 6 The effect of time on the adhesion of arc sprayed zinc concrete. Before it was arc sprayed, the concrete was subjected to accelerated aging The concrete was grit blasted before or after it

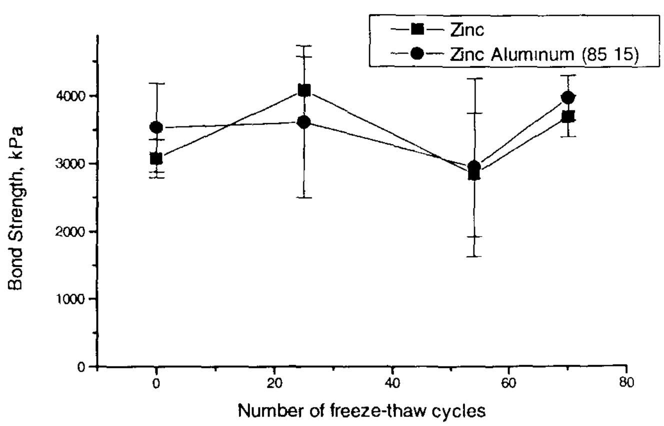

Fig. 7 Effect of freeze-thaw cycling on the adhesion to concrete of arc-sprayed zinc and 85Zn-15Al

3.2 *Effect of Rest Time after Metallization*

It has been speculated, based on field observations in Oregon and Florida, that a delay in testing the adhesion of metallized zinc after application frequently results in higher bond strength values. This was also noticed in the present results. More detailed experiments were undertaken to study this phenomenon. The changes in bond strength over time were monitored for both zinc and 85Zn-15Al. The surfaces of 30 concrete blocks were pretreated in three ways prior to metallizing. After metallizing, bond strengths were monitored on all the samples that were maintained in a 50% relative humidity atmosphere at 22 °C.

In the first test, concrete samples manufactured as described in the experimental procedure were metallized shortly after completion of their curing period. The same experiment was repeated twice to ensure reproducibility. Each time, no polarizing current was applied to the samples. The individual values in Fig. 4 and 5 represent averages of nine pullout tests. The results indicate an initial increase in bond strength for at least a few weeks after the metallizing. The magnitude of the increase in bond strengths varies, but in some cases can be as high as 25% of the original value.

Experiments were also conducted on aged samples to determine whether the apparent increase in bond strength was related to concrete strengthening. Concrete samples (half of which were already grit blasted) were stored for 5 months in tanks kept at 70% relative humidity and 22 °C. There was also a slight positive overpressure of CO_2 to promote carbonation of the concrete. Those samples that had previously been grit blasted were metallized without additional grit blasting. All other samples were grit blasted and metallized according to the usual procedure. Increases in zinc bond strength over time were once again observed (Fig. 6).

Chemical interaction between the zinc coating and the concrete substrate is the only explanation for such an increase in bond strength. Details of the process are not yet fully understood. It is evident that consistency in the delay period for measuring bond strength should be specified in quality-control procedures.

3.3 *Freeze-Thaw Cycling*

Many applications for metallized coatings on concrete involve exposure to freeze-thaw cycling, and thus its influence on the coating life cycle was determined. Bond strength measurements were made at regular intervals. No significant drop in the adhesion of the metallized coatings was observed after 70 freeze-thaw cycles (Fig. 7).

4. Conclusions

- Metallized zinc performs well as an impressed-current anode.
- There is a loss of adhesion for metallized coatings with higher current densities and longer polarization times. Therefore, the zinc should be applied to the concrete such

that its adhesion is maximized and should not be used where excessively high current densities are required.

- Metallized 85Zn-15Al should not be used as an impressed-current anode due to poor bonding performance and an unusual formation of large air gaps underneath the disbonded coating.
- Zinc bond strength on concrete increases slightly during the first few weeks after metallizing when no current is applied.
- The adhesion of metallized zinc on concrete does not appear to be influenced by severe freeze-thaw cycling.

Acknowledgments

The authors wish to thank the International Lead Zinc Research Organization and the National Research Council of Canada for funding this research project. Special thanks to Dr. Serge Dallaire and Mr. Jean-Guy Allard from IMI(NRC) for their assistance with the metallizing of the samples.

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