

Long-term Monitoring Provides Data Required to Predict Performance and Perform Intelligent Design of Galvanic Corrosion Control Systems for Reinforced Concrete Structures

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Abstract

Long-term monitoring of galvanic anodes installed in reinforced concrete structures has provided the data required to better understand long-term anode performance. Detailed analysis of field and laboratory performance data has identified an aging pattern which follows an exponential decrease in current output similar to a ‘half-life’ principle where current is halved at constant periods of time. A predictive model has been developed to describe anode current output over time. The predictive model which includes an “aging-factor” can be determined for any galvanic anode. The aging-factor is primarily dependent on the activating chemistry of the anode. The aging-factor also depends on the relative surface area of the anode compared to the surface area of steel wherein the harder an anode works early on in its life the worse its aging-factor becomes.

The predictive model which is based on long-term field data allows galvanic anode systems to be designed to meet any desired performance criteria at any point in time. The model may also be used to design galvanic cathodic protection systems to provide specifiable long-term current density and more controlled polarization to the steel.

Keywords

Galvanic anodes, Corrosion control, Steel reinforcement, Aging-factor

Background

Galvanic anodes for mitigation of corrosion of steel in concrete have now been monitored to various degrees for up to 20 years. A large volume of data exists, which has enabled this detailed analysis. This in turn has allowed a much better understanding of long-term anode behavior and the development of predictive models.

A major finding of this analysis is that the long-term current of a particular anode diminishes in an approximately exponential manner that can be modelled by a “half-life” principle.¹ This was shown by analysis of many sets of current output results which revealed repeated behavior of a slowly decreasing trend consistent with Equation 1.²

$$i_t = i_o e^{-\lambda t} \quad \text{Eq. (1)}$$

Where,

i_t = current density at time, t (mA/m²)

i_o = initial current density, (mA/m²)

λ = exponential decay constant,
 t = time (years)

The relationship usefully allows an estimation of an aging-factor, that can define the current output capability of the anode at any future time. The value of the aging-factor in years required for halving of the current can be easily determined by inserting the exponential decay constant, λ , as determined in Equation 1, into Equation 2.

$$t_{1/2} = \frac{\ln(2)}{\lambda} \quad \text{Eq. (2)}$$

Where,

$t_{1/2}$ = the time required for the current density to be halved, and

λ = exponential decay constant, as in eq. (1)

Knowledge of such parameters, describing the long-term behavior of the anodes, allows a better design of the galvanic corrosion control system if it can be shown that it is constant and quantifiable for a particular type of anode based on the zinc activation chemistry, encasement mortar or anode core design.

This paper extends the data analysis to several field studies and lab trials, most already reported in literature, and attempts to elucidate the aging-factor concept and explain the factors that contribute to the aging of galvanic anodes. It further discusses the substantial impact of the aging-factor on the design of long-term galvanic corrosion control and cathodic protection systems.

Field studies

Monitoring of anodes employed for enhancing three different patch repairs on a bridge in Leicester, UK, has been highly successful in revealing the performance of alkali-activated galvanic anodes. The anodes were utilized for preventing incipient anode formation or the ring corrosion effect which ordinary patch repairs have historically suffered from.^{3,4} Results from one set of galvanic anodes in a beam, have been reported extensively^{1,5} and variation of the current is reproduced in Figure 1.

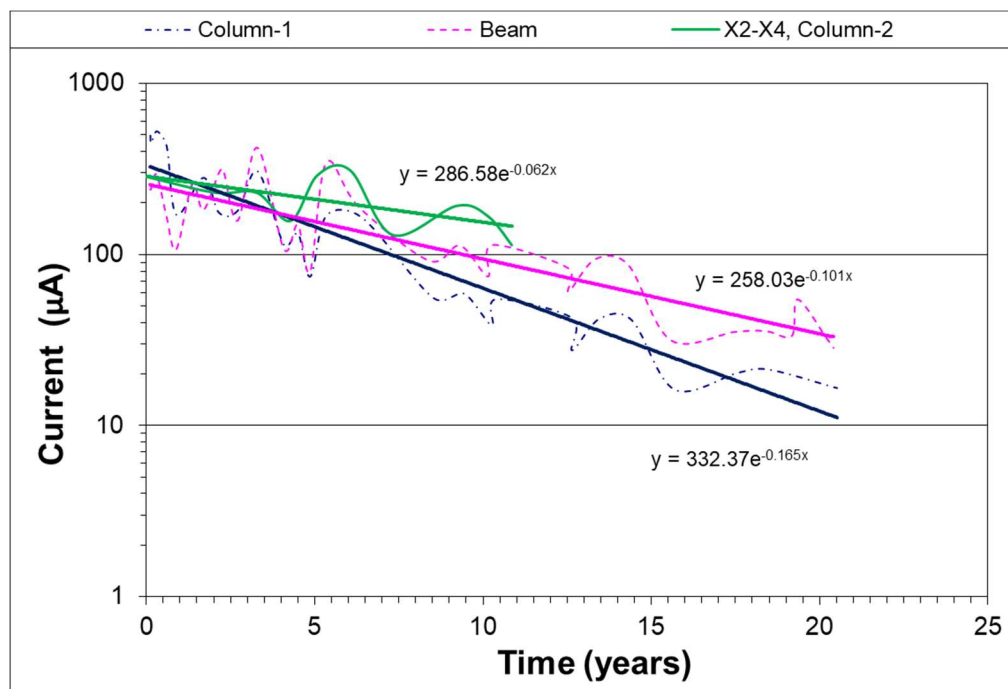


Figure 1 Current reduction with time of three sets of anodes at the same bridge but with differing spacing of anodes: Column-1, 750 mm on center, Beam, 600 mm on center and Column-2, 300 mm on center. Anodes embedded in Column-2 were of a later version and each had either double or four times the zinc surface area than the other two earlier sets.

The variation of the current, experiencing peaks and troughs, is partly caused by the effect of relative humidity, which influences the concrete resistance. It was shown, however, to be particularly sensitive to temperature of the concrete and in this case, as with the anode set in Column-1, which were installed at the same time (Fig. 1), peaks were recorded during summer months and troughs during the winter. The current output is expected to be governed by the Arrhenius equation (Eq. 3). This effect was demonstrated in field tests over a 35° C range² and in the laboratory of triplicate galvanic anodes embedded in reinforced concrete slabs and exposed over the range of 8° C and 30° C (Fig. 2). Figure 2 suggests that the current output of the galvanic anodes roughly doubled every 10° C increase in temperature while in the field trial this doubling appeared to occur nearer a 15° C temperature increase.

The apparent difference in current variation with temperature between laboratory-controlled specimens and field tests can be explained by the hysteresis response of temperature gain or loss of the concrete during the daily variations. It can be assumed, to a reasonable degree of accuracy, that the current range over a typical annual temperature range in the UK and across many states in America, if this range is assumed to be ±15° C, that the current output variation could be within a range of half to double the mean.

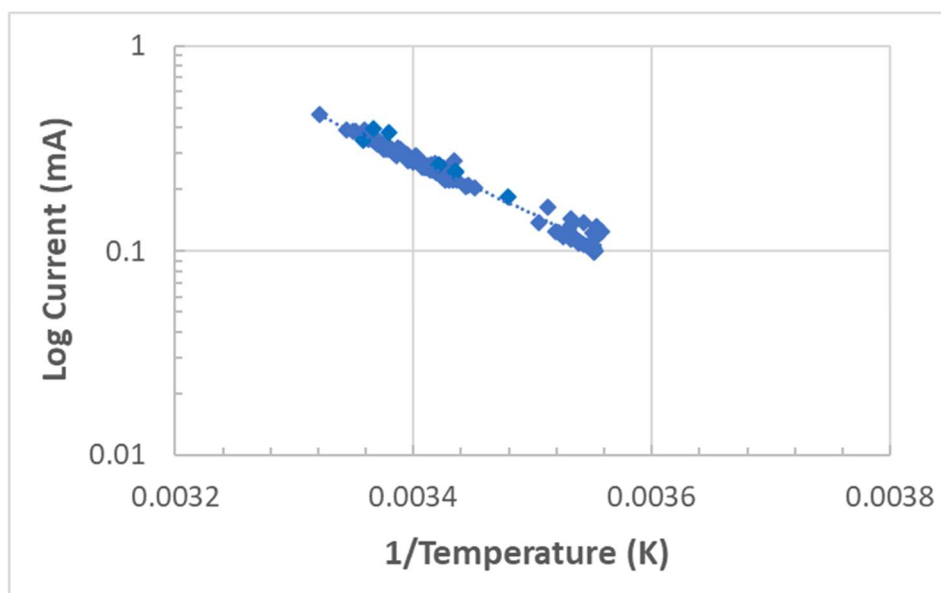


Figure 2 Relationship between the reciprocal of the concrete temperature in K and the logarithm of current output of the anode

$$k = Ae^{-\frac{Ea}{RT}} \quad \text{Eq. (3)}$$

Where,