Short Partial Report

Characterization of protection vs. durability for different galvanized steels used for reinforced concrete (RC)

Background

The anticipated technical outcome of this work is to provide the characterization of the galvanized steel rebar (Figure 1b) materials used in reinforce concrete structures (figure 1a), and the mechanistic assessment for sacrificial effect vs. long-lasting durability of the reinforcing galvanized steel in corrosive environments. The sacrificial effect is based on thermodynamic concept, Figure 1a shows bare steel protected by a passive layer that will be breakdown when certain conditions are met (chloride threshold content). Figure 1b shows the galvanized layer that protects the bare steel. The Zn layer exerts the sacrificial protection by modifying the surface conditions of the substrate producing material that is more active and likelihood to react/dissolve. This latter can be validated by the half-potential magnitude that follows a thermodynamic concept. Different concept applies to this system, such as durability; this latter considers how long the protective (passive or sacrificial) layer will perform at the exposed conditions. The galvanized rebar is expected to be more durable than the classical passive iron layer. The results for different galvanized samples are displayed in this partial report.

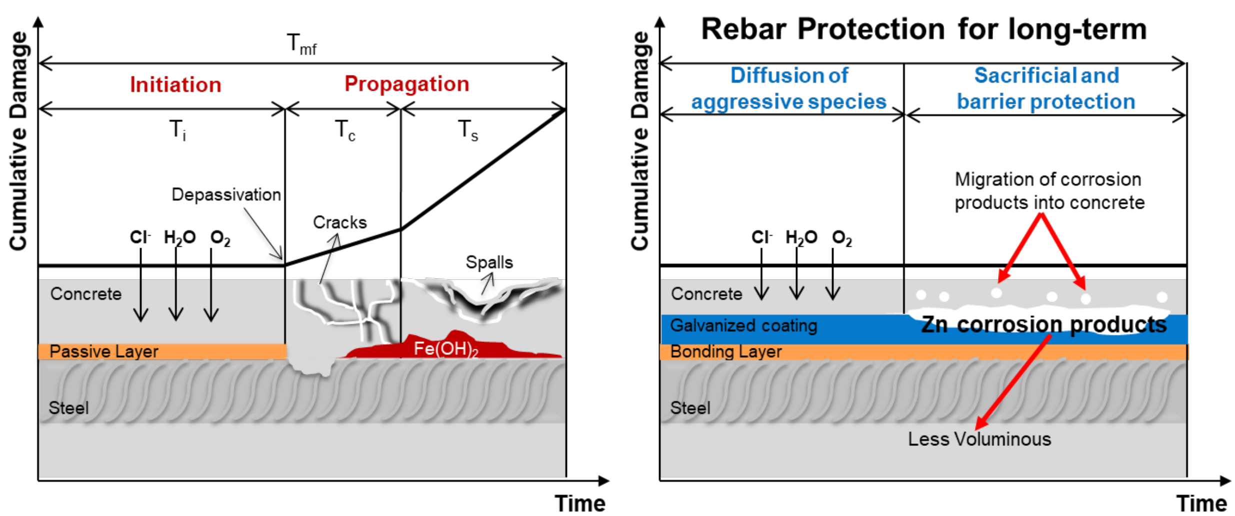

Figure 1. Proposal performance evolution for traditional rebar (a) and galvanized rebar (b) used in RC elements.

Results for Protection criterion (Thermodynamics)

Figure 1b illustrates the OCP values of the majority of galvanized rebar were below the cathodic protection limit suggesting that during 30 days of immersion, they were effective in providing sacrificial protection to the reinforcing steel when exposed to aqueous (pore concrete solution).

Figure 1a shows the protection criterion for the bare steel sample that is in the active state and no protection is present for the steel.

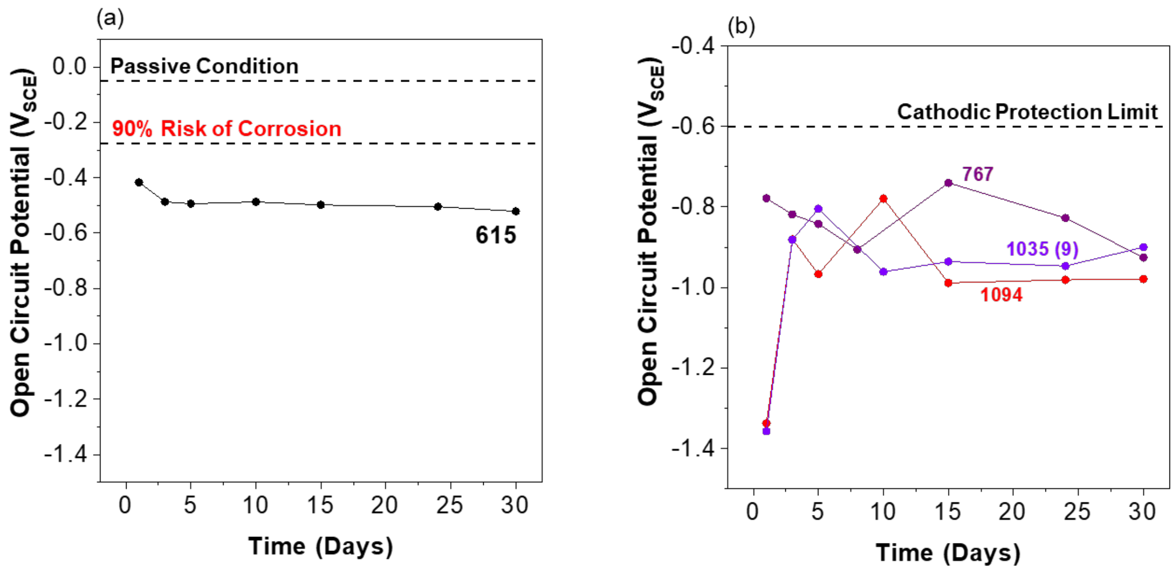

Figure 1. OCP results of (a) bare rebar and (b) galvanized coatings immersed for 30 days in a simulated concrete pore solution.

The NACE standard 0290 "Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures" proposes two criteria for cathodic protection in reinforced concrete structure: 1) a 100-mV polarization development/decay and 2) the E-log I test [1]. According to the first criterion, a minimum of 100 mV of polarization must be achieved to guarantee effective sacrificial cathodic protection of reinforcing steel embedded in concrete. This means that the electrode potential under cathodic protection must be at least 100 mV more negative than the electrode potential of bare reinforcing steel under the same exposure conditions.

From Figure 1(a), it is seen that the bare steel is actively corroding after three days of immersion due to the presence of chloride ions in the solution that induces the breakdown of the passive film and the initiation of corrosion. These results suggest that corrosion of the steel substrate underneath the coating might also occurred. However, it is also possible that these values are associated with an IR drop developed through the coating that induces a more negative OCP value than the actual value. For the case of the galvanized rebar, we assessed the performance of these specimens according to the cathodic protection criterion mentioned above. In this study, the OCP of the bare rebar in the simulated concrete pore solution is about -500 mV vs. SCE (see Figure 1(a)). Therefore, we defined the cathodic protection limit as -600 mV vs. SCE following the 100-mV polarization development/decay. The OCP values of the galvanized rebar were below the cathodic protection limit suggesting that during 30 days of immersion, they were effective in providing sacrificial protection to the reinforcing steel.

Results for the Durability

Figure 2 presents the impedance at lower frequencies ($Z_{0.01\ Hz}$) for each sample. This parameter is proportional to the kinetics or the dissolution rate of the samples during the exposed environment. Zinc layer is presented in the active state and exerting the sacrificial effect at certain corrosion rate. Sample 767 shows the lowest impedance (or the highest activation rate) than the rest of the galvanized samples.

Following this short-term results (30 days), the 1094 and 1035 (9) samples covers the required protection based on thermodynamic and OCP magnitudes and also the lowest dissolution rate.

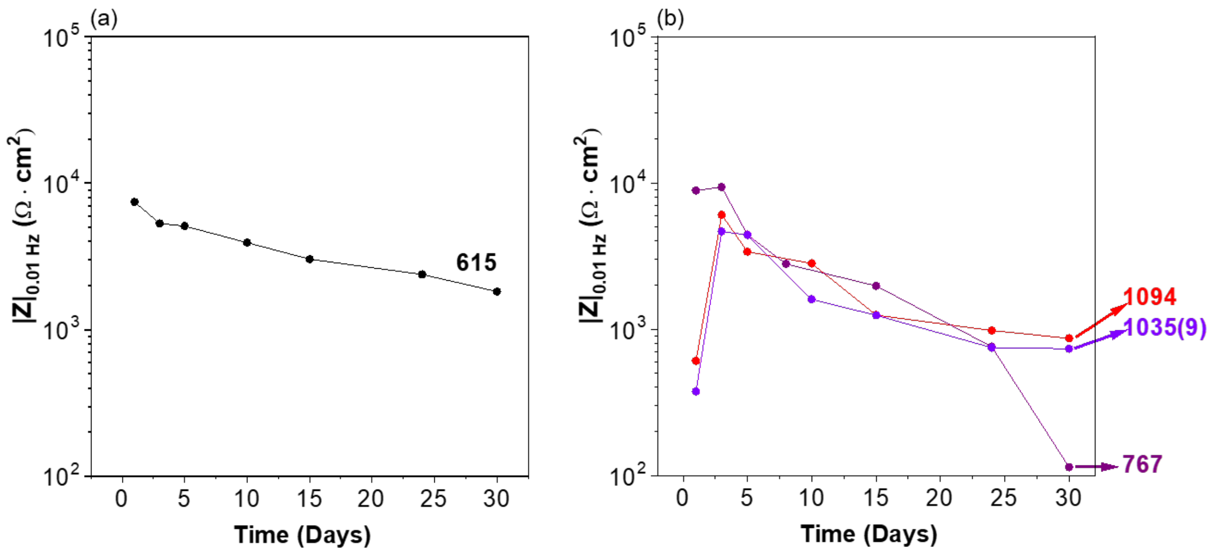

Figure 2. Evolution of $|Z|_{0.01\ Hz}$ values for (a) bare rebar and (b) the galvanized rebar immersed for 30 days in a simulated concrete pore solution.

The impedance magnitude at 0.01 Hz ($|Z|_{0.01\ Hz}$) was used in order to compare the corrosion protection performance of the different coating systems. This parameter has been reported for several research papers to describe the overall corrosion resistance of a coating system including electrolyte resistance, coating resistance, and charge transfer resistance of the metallic substrate. From Figure 2(a), it is seen that the bare rebar shows a low corrosion resistance (~10^4 Ω-cm^2) that gradually decreases with time, demonstrating its continuous degradation by the corrosive environment. From Figure 2(b), the 1094 coating and 1035(9) specimen exhibited very similar trend and $|Z|_{0.01\ Hz}$ values. It is worth to clarify that the 1035 specimens consist of martensitic micro composite formable steel as the substrate coated with 1094 CGR. Therefore, the similarity in the trend and $|Z|_{0.01\ Hz}$ values between the 1094 and 1035(9) systems suggests that the EIS response of these specimens describe the dissolution of the galvanized coating providing effective sacrificial protection to the steel substrate, with no evidence of corrosion processes occurring in the substrate. It is expected that when corrosion of the substrate initiates, the EIS signal of the 1094 and the 1035(9) will be significantly different owing to the different substrate, which will induce a different electrochemical response. This hypothesis will be further explored by measuring the EIS response of these coatings at longer immersion time. Finally, it is seen that the 767 specimens exhibited the lowest impedance values among all different galvanized materials. These results indicate that although this coating provide sacrificial cathodic protection, it is likely that the zinc corrosion products formed as a result of the anodic dissolution of zinc, are less protective that the corrosion products formed on the 1094 galvanized specimens. The higher corrosion or dissolution rate on the Zn layer will have less durability in terms of sacrificial protection effect. (i.e. 767 specimen will have higher corrosion or dissolution rate and the galvanized layer have less life expectancy based on the current results).