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Anticorrosive Efficiency of Primer Applied in Carbon Steel AISI 1018 as Reinforcement in a Soil Type MH

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This work analyzes the corrosion behavior of three types of coatings, applied in steel bars AISI 1018, corrugated, of 3/8" in diameter, and commonly used for reinforcement in soils (reinforced soil). The three coatings were: the realkalinizing type (cement based), the cathodic type (Zinc Cromate) and inhibitor type (minimum, Lead oxide); all of them buried in a MH soil, simulating conditions when the steel is used in reinforced soil structures and the environment where it will be during the util life period. The evaluation of the corrosion of the bars was carried out by the monitoring of the corrosion potential (ASTM C-876-09), and in the corrosion kinetics was used the LPR technique. In this work show the results for 214 days of exposure in a MH soil, with 30% humidity. According to the analysis of the results, we concluded that the steel bars with primer inhibitor type (red lead), and cathodic type (zinc cromate) coats, presented a corrosion resistance of up to 100 times greater than the bars with realkalinizing type primer (cement based), and the bars without any primer.

Keywords: Primer, AISI 1018 Steel, Corrosion, Fine Soil, Corrosion Potential

1. INTRODUCTION

According to many investigations carried out around the world, has been shown that the most important factor in the deterioration of the civilian infrastructure (bridges, piers, processing plants, refineries, highways, buildings, etc.), built with reinforced concrete is the corrosion of reinforcing steel [1-3]. In first world countries where it has been a systematic process of evaluation of the structures, have been reported a cost of billions of dollars to fix damage caused by this phenomenon. There are innumerable national and international investigations that addressed this problem, and have studied the problem, and a number of proposals that are considered as preventive and correctives [4.5]. All of the above in the context of the infrastructure of concrete. But, the civilian infrastructure, such as bridges, shopping centers, etc, are not only built of reinforced concrete, also use other systems such as reinforced soil, better known in the area of the construction as reinforced earth. The information about the corrosion mechanism that occurs in this system is very limited and insufficient, hence the importance and innovation of this work.

This research addresses the problem of corrosion in the system: steel reinforcement - Soil (reinforced earth), with the idea to simulate in the laboratory the actual conditions faced by builders in the field, when using AISI 1018 steel for reinforce the soil. The problem of corrosion of the reinforcement in Soil, can cause a sudden and catastrophic failure of structures, generating higher material costs, and possibly loss of life. For all the above, the corrosion in the reinforced soil, due to the conditions of service, is considered the biggest problem in the short and medium term, and deserves as much attention as the problem of corrosion of steel embedded in concrete.

The simple fact that in developed countries have thousands of reinforced soil structures that present problems in a short period of their service life [6], allows to raise the need for research on this topic in Mexico. Information on this topic is almost nil, this work being the first to deals with the problem of corrosion in steel-Soil system, used in civil infrastructure.

The aim of this study is to evaluate the reinforcing steel in soil type MH (high plasticity silt) from the region of Xalapa, Veracruz. México. Their electrochemical behavior and the efficiency of the primer applied were evaluated, using the corrosion potential and linear polarization resistance techniques.

2. EXPERIMENTAL

2.1 Sampling and preparation of the soil sample.

The sample was obtained from the City of Xalapa, Ver. México, specifically in the area where was built the Concert Hall of the Universidad Veracruzana. The sample was obtained according to NMX-C-416-2003 ONNCCE [7].

The sample was identified by means of a card on the outside of the package containing the following information:

1. Name of the project
2. Localization
3. Date of sampling
4. Sample Number

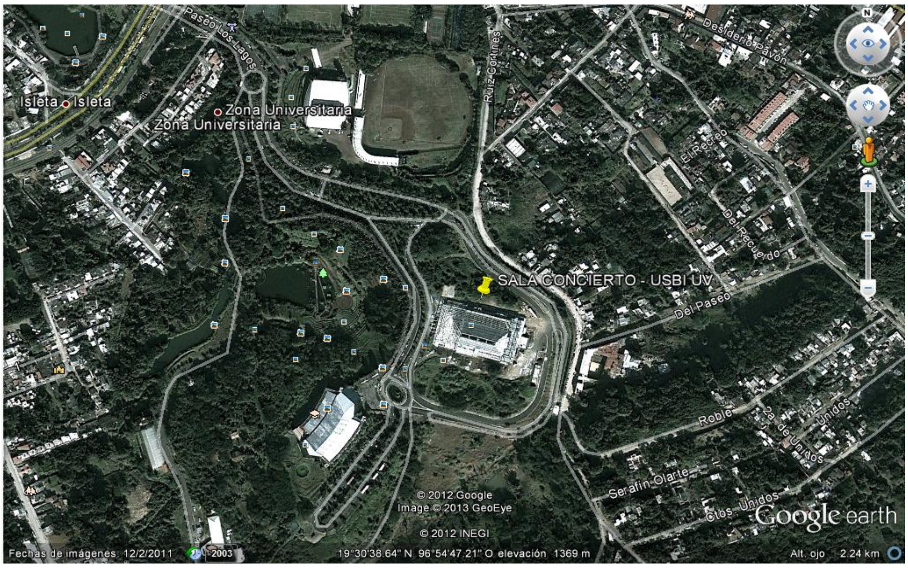

Figure 1. Zone Location of MH soil sampling

Was carried out a process of sample preparation in order to obtain representative portions for determination of moisture content, and consistency limits, which allow fine soil classification according to the Unified System of Soil Classification (USCS) [8]. Soil preparation was performed as follows:

1. Dry the material. Was spread on a clean smooth surface to expose to the sun in order to remove the water present and to facilitate the disaggregated.

2. Triturate soil sample in order to remove any lumps present. with a wooden mallet of 1 Kg is hit from a height below 20 cm, for separate the particles without breaking the rock aggregates.

3. The material was triturated to obtain fractions reduced, and the sample was homogenized. A cone was formed and placed material in its vertex using the shovel, allowing itself rearrange. then cut the cone, and inserts the shovel in radial form to make the material flows towards the periphery, verifying that the diameter was from 4 to 8 times its thickness. Subsequently was divided into quadrants with a wooden ruler. Of the quadrants obtained, were taken two opposites, and the operation was repeated to obtain the required portion.

2.2 Natural water content.

The water content in the soil was determined according to standard M-MMP-1-04/03 [9]. First the wet soil is weighed and then dried in oven at a temperature of 110 °C for 24 hours. Then to determine the difference between wet weight and dry weight, which is the amount of water evaporated, and then report this value as a percentage.

2.3 Limits of consistency and classification of the soil according to SUCS

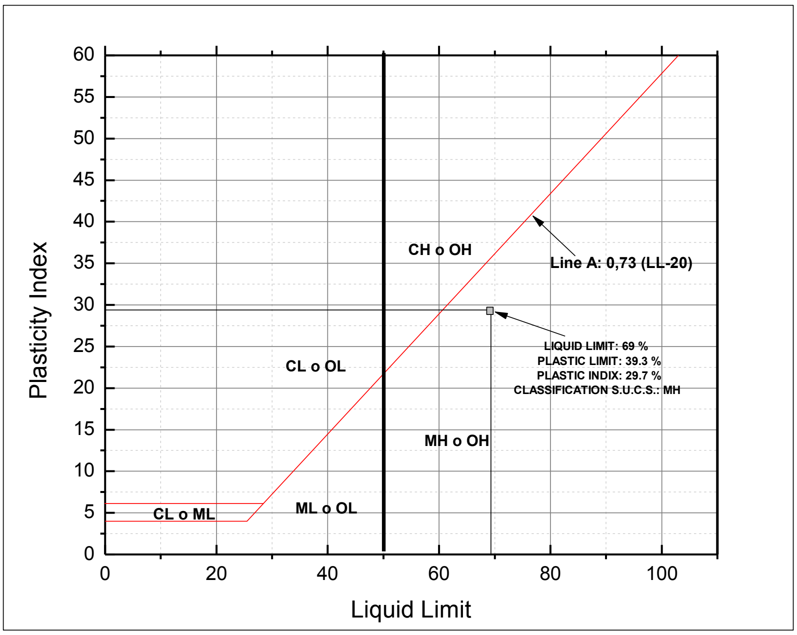

Figure 2. Soil classification in the letter plasticity of USCS.

The determination of consistency limit, liquid limit and plastic limit, of the soil under study, were performed as indicated NMX-C-416-ONNCCE-2003 [10]. These limits are essential to make the fine soil classification, by plasticity letter according to USCS [11], Figure 2.

2.3 Characteristics of the AISI 1018 steel rebars

To have control of the variables involved were given a nomenclature to the bars, according to the type of primary. The evaluation was in triplicate. The following table summarizes the characteristics of the bars and nomenclature. Figure 3 shows the bars embedded in the floor of the studio.

Table 1. Characteristics of rebars

Nomenclature assigned to the rebars, according to the type of primer			
Zinc Chromate	Red Lead	Cement based	Without coat
Z1	M1	L1	N1
Z2	M2	L2	N2
Z3	M3	L3	N3

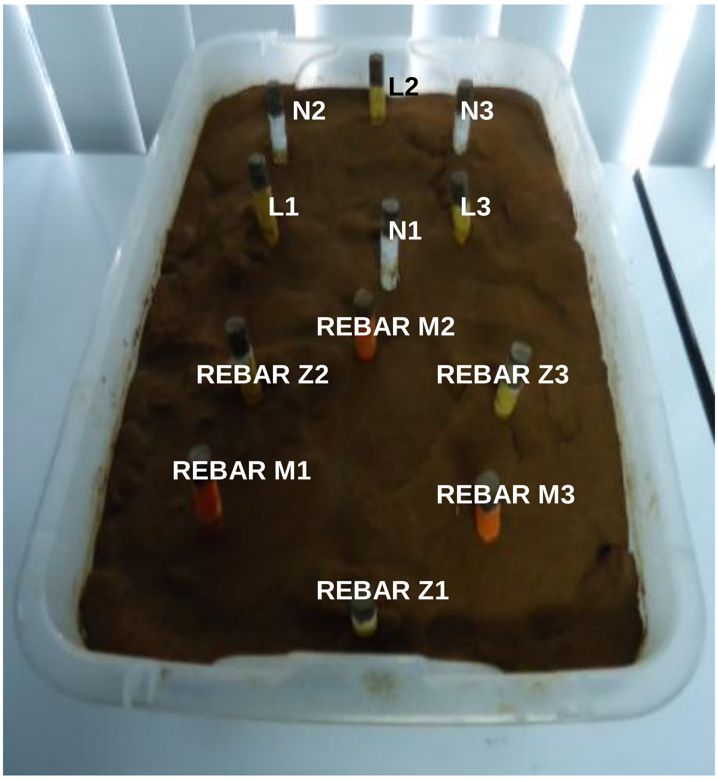

Figura 3. Distribution of rebars in the soil, for their monitoring.

2.4 Preparation of the rebars

All bars with and without primer were of AISI 1018 steel, corrugated of 3/8 "diameter, cut into pieces of 15 cm long, covered by Teflon tape on the bottom and top, Figure 4. Was buried in the ground without applying any protective coating, leaving the middle of the bar, to establish an area of corrosion attack, as reported for different authors [12-14]. As indicated above, three rods were placed for each type of primary evaluated.

Figure 4. Distribution of rebars in the soil, for their monitoring.

2.5 Electrochemical Evaluation

For electrochemical evaluation of steel bars, with and without coating, was carried out the monitoring of corrosion potential (E_{corr}), according to ASTM C-876-09. We also evaluated the rate of corrosion, with the technique of linear polarization resistance (LPR). The data were obtained with a scanning Ecorr ± 20 mV, and a scan rate of 10 mV/min. The measurements were carried out using an was an AC Gill potentiostat/galvanostat/ZRA, ACM Instruments. A conventional three electrode cell was used (Figure 5), where the working electrode was the steel rebar, a stainless steel plate as counter electrode and reference electrode copper-copper sulfate, $Cu/CuSO_4$.

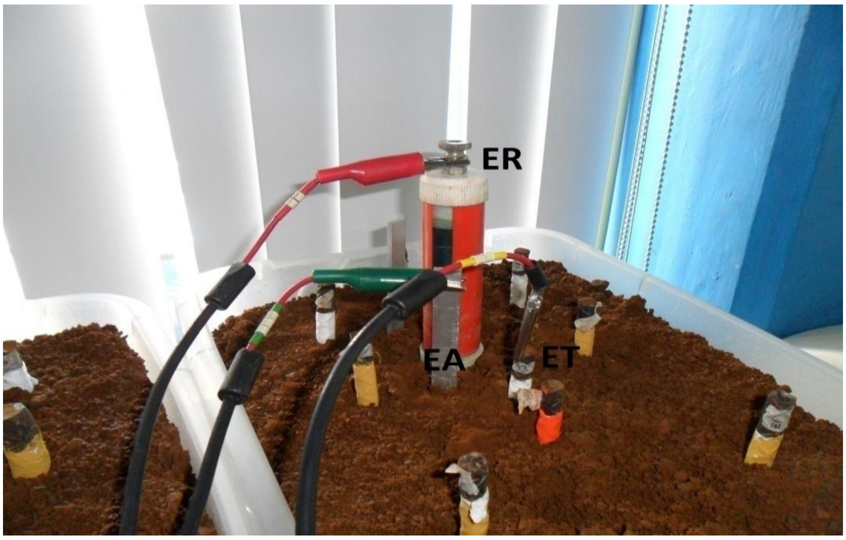

Figure 5. Electrochemical cell for experimentation.

3. RESULTS AND DISCUSSION

3.1 Corrosion Potential

The monitoring and interpretation of the corrosion potentials of the test specimens was performed according to ASTM C876-09 [15]. Was added an interval, according to the literature [16], see Table 2.

Table 2. Corrosion potentials in reinforced concrete.

Corrosion Potential, mV vs $Cu/CuSO_4$	
< - 500	Severe Corrosion
< -350	90% Probability of Corrosion
-350 a -200	Uncertainty
> -200	10% Probability of Corrosion

3.1.1 Corrosion Potential, unprimed steel bar, and with primer re-alkalinizing type.

After the first 25 days (to have constant soil moisture), the corrosion potential values indicate uncertainty (-200 and -300 mV), in unprimed bars. And a 90% probability of corrosion, for specimens with re-alkalizing primer (Figure 6.).

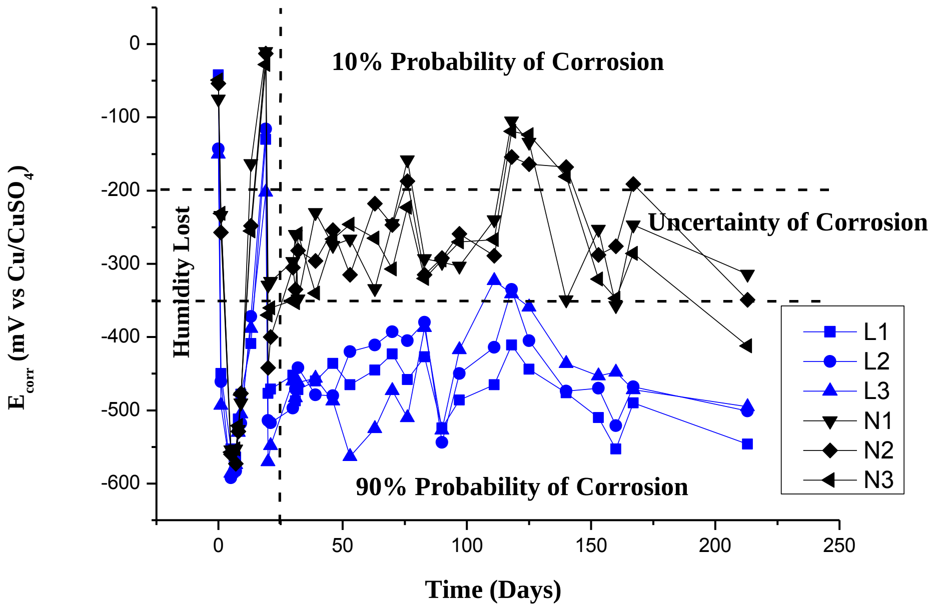

Figure 6. Corrosion Potential of steel rebars.

3.1.2 Corrosion Potential, unprimed steel bar, and with primer cathodic type.

Analyzing Figure 7, is observed (after the first 25 days of moisture control), that the rods with and without cathodic primer, generally have a homogeneous behavior to 120 days, with potentials indicating passivation of the steel. The value of potentials moves from -350 to -200 mV. After day 120, there is evidence of protection provided by the cathodic primer, since the values are more noble than those in unprotected rods, indicating 10% probability of corrosion. The unprotected steel bars have values indicating a 50% probability of corrosion and even one of them, a 90% probability of corrosion.

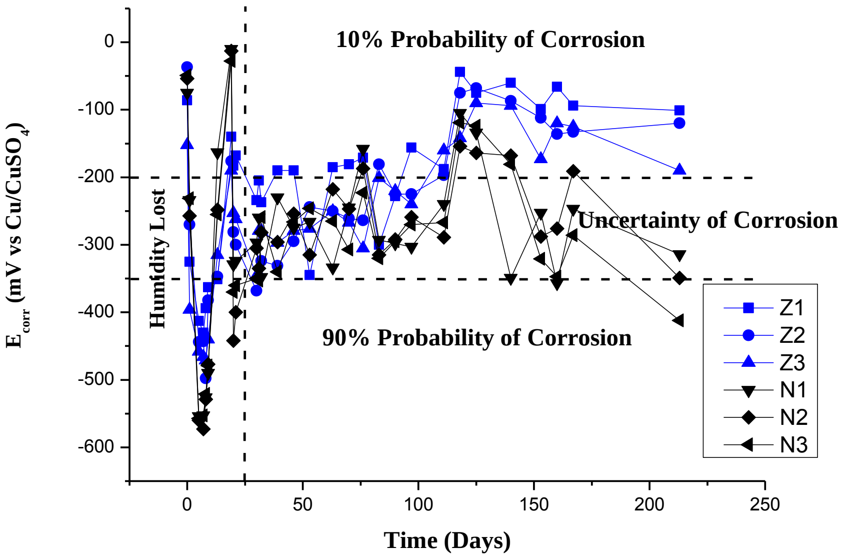

Figure 7. Corrosion Potential for steel bars with and without primer (cathodic type).

3.1.3 Corrosion Potential, Steel bar without primer and inhibitor type primer.

Figure 8 shows that in the entire monitoring period (1 to 214 days), the steel bars with inhibitor type primer, has a better efficiency anticorrosive, presenting potentials more positive than -100 mV, and indicating a probability of 10% corrosion. Those potentials turns more noble with time. For unprotected steel rods, as seen in Figures 6 and 7, values of potential represents always uncertainty corrosion. At the end, is located in the 90% probability of corrosion.

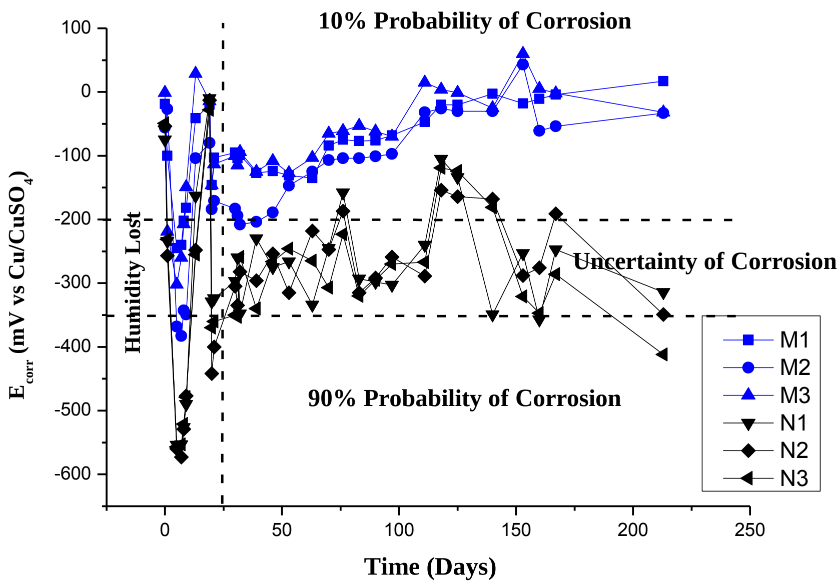

Figure 8. Corrosion Potential of steel bars (inhibitor type primer)

3.2 Corrosion Kinetics

To evaluate the results of the kinetics of corrosion, of steel bars with different coatings, the electrochemical technique of Linear Polarization Resistance (LPR) [17-18], was used. Based on the Stern and Geary equation [19], one can obtain the current density (i_{corr}). In interpreting the results of current density, to assess the level of corrosion present in the steel-soil system, we used the criteria of the Red Durar Manual, see Table 3.

Table 3. Corrosion level, in accordance to the current density [20].

Current density (i_{corr}) µA/cm^2	Corrosion Level
< 0.1	Negligible
0.1 – 0.5	Moderate
0.5 - 1	Elevated
> 1	Very high

3.2.1 Current Density, Steel bar without primer and with re-alkalinizing type primer.

In Figure 9, the behavior of current density (i_{corr}) results, in the first 40 days of monitoring, is very homogeneous between the two types of steel bars analyzed, with initial corrosion levels ranging from negligible to moderate, to reach high to very high level in the 20th day. After these 40 days, show a trend of increased corrosion rate, for both conditions of the steel rods (with and without realkalinizing primer), indicating that this primer has no corrosive effect on the bars steel.

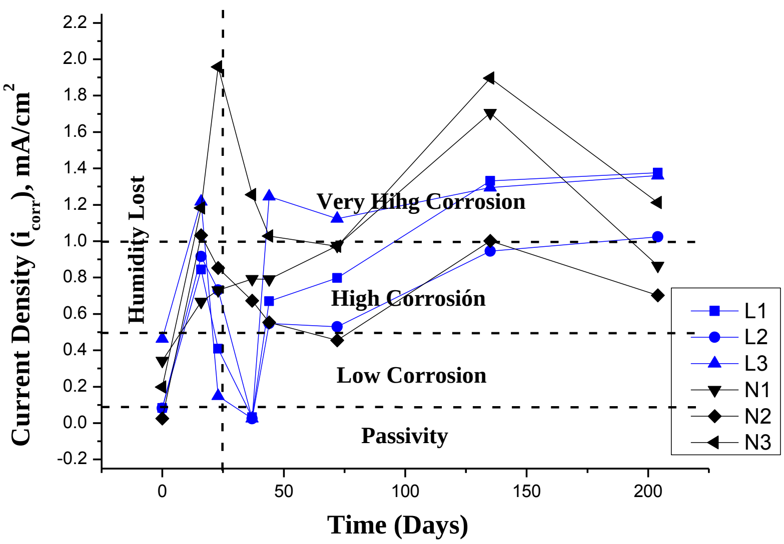

Figure 9. Current density, steel bars with and without realkalinizing primer.

3.2.2 Current density, steel bar without primer and with cathodic type primer.

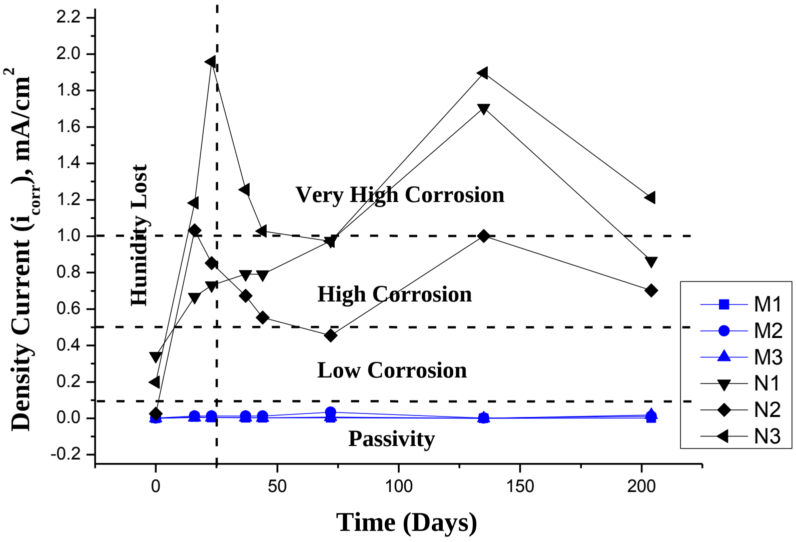

Figure 10. Current density, steel bars with and without cathodic primer.

Analyzing Figure 10, the results shows the efficiency of the cathodic primer, throughout the exposure period, showing corrosion rate values (I_{corr}) lower than 0.1 µA/cm^2, from day 1 to day 214. That indicates a negligible corrosion level, opposite to unprimed steel bars, which from the start of monitoring had a moderate level, ending with a very high level of corrosion.

3.2.3 Current density, steel bar without primer and with inhibitor type primer.

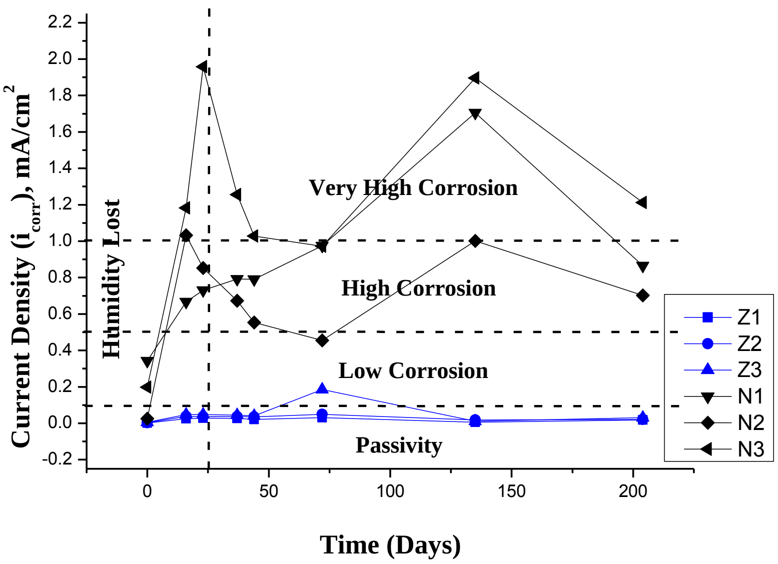

Figure 11. Current density, steel bars with and without primer inhibitor type

Figure 11 also shows the good performance against corrosion of steel bars with inhibitor type primer, presenting throughout the exposure period, Current density values lower than 0.1 μA/cm2, indicating a negligible level of corrosion.

In current density graphs, we observe the benefit of protective coat for increase the corrosion resistance due to MH soil. This work when uses steel AISI 1018 like soil reinforcement, and agree with investigations where are been used zinc cromate primer [21, 22]. Is essential consider the section loss by corrosion of reinforcement steels used in reinforced and mechanically stabilized soils [23]. AASHTO and FHWA establish minimum corrosion rates for the reinforcement design of this structures, with steel AISI 1018 and galvanized steel [24]. The results indicate that electrochemical techniques can be more adequate in corrosion rate measurement than other techniques [25].

5. CONCLUSIONS

It was shown in this research, for conditions indicated, that corrosion efficiency for the cathodic type primer (zinc chromate), and barrier type primer (red lead), when applied to corrugated steel AISI-1018, buried on soil type MH, is 10 times higher compared to AISI-1018 steel, with realkalinizing primer and without protection. Its application is recommended for protection of reinforcing steel in reinforced earth systems or mechanically stabilized soil, in order to increase the life of these structures.

We conclude with the results presented in this paper, that is feasible to use the electrochemical techniques: corrosion potentials monitoring, E_{corr} (ASTM C-876-09), and Linear Polarization Resistance, LPR (ASTM G -59 (2009)), to determine the corrosion level of reinforcing steel, caused by the soil in which it is, for structures made from steel-ground system known globally in the construction industry as soil mechanically stabilized or reinforced earth.

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