Electrochemical Evaluation of Galvanized Steel and AISI 1018 as Reinforcement in a Soil Type MH

Miguel Angel Baltazar-Zamora, Laura Landa-Ruiz, Yazmin Rivera, and René Croche

Abstract—This work presents the electrochemical evaluation of bars of Galvanized Steel and AISI 1018 with 3/8” and 1/2” of diameter, these bars are commonly used for the construction of elements based on Soils Mechanically Reinforced (SMR), the bars were buried in a fine soil predominant in the region of Xalapa City, Ver., México, soil classified in the USCS (Unified Soil Classification System) as a high plasticity silt (MH). Corrosion evaluation was conducted by monitoring the corrosion potential Ecorr and corrosion rate, Icorr, using techniques half-cell potential according to the standard ASTM C-876-15 and Linear Polarization Resistance (LPR), respectively. The experimental setup simulates the real conditions when the steel is used as reinforcement in structures of SMR, where they remain buried throughout the useful life of the structure. The results of the first 110 days of exposure show that the Galvanized Steel bars have a better corrosion performance compared to the AISI 1018 steel regardless of their diameter.

Index Terms—Corrosion, AISI 1018, Galvanized Steel, Corrosion, Soil Type MH.

I. INTRODUCTION

The problem of the reinforcement corrosion in mechanically reinforced soil (SMR) could cause a sudden failure, causing damage that can be catastrophic if casualties were submitted. Such failures are generally along a vertical plane of maximum tensions in the reinforcement. Therefore, it is of great importance the study of accelerated corrosion of reinforcements due to conditions of service, regarded as the greatest long-term problem and that deserves immediate attention. The SMR structure design requires that the combination of a land section, and the reinforcement is such that the interaction between the two materials produces a better structural composite that combine both mechanical and physical characteristics [1]. In addition, the improvement of a soil is strongly related to the compaction process and the addition of stabilizing agents and directly improves the quality control of the shaped layers, seeking to obtain resistant, economic and sustainable soil structures [2]. The most commonly used to reinforce the structures of SMR is AISI 1018 steel and geosynthetics [3]. Aluminum alloys and stainless steel have been used to reinforce SMR structures, mainly in France. Corrosion of the metal reinforcement of the structures of SMR, has been little studied [4] compared to the phenomenon of corrosion in reinforced concrete structures is widely studied [5-11], but the problem of corrosion reinforcing steel in SMR is of great importance, because it significantly affects the functional characteristics of retaining walls, bridge abutments access or viaduct distributors, viaducts, tunnels, stations, etc.; examples of civil infrastructure wherein said reinforced floors are used. The different research reports on the subject [12-13] in first world countries, where it has been shown that reinforced soil structures present problems in a short period of its service life due to corrosion of reinforcing steel. It allows us to consider the need for research on this topic in the state of Veracruz, as being a state full modernization of the highway sector have carried out this type of work, without information on the corrosive aggressiveness that may be required soils used in different works carried out over the last 10 years and they may have problems of a process of accelerated corrosion in a not too distant future, and could be due to a failure of major consequences for society. Therefore, we have that the objective of this study is to evaluate the corrosion behavior of AISI 1018 steel and galvanized steel as reinforcement in soil type MH (high plasticity silt) in the region of Xalapa, Veracruz, to let us know the degree of corrosive aggressiveness of soil under study.

II. MATERIALS AND METHODS

A. Materials

1) Sampling and preparation of the soil sample.

The soil sample was collected in the City of Xalapa, Veracruz; on the ground of the USBI’s facilities, belonging to the USBI-Concert Hall of the Universidad Veracruzana (see Fig. 1), was used an unaltered sample and altered, according to the standard NMX-C-416 ONNCCE-2003 [14]. It was labeled with all required data for a study of soil mechanics as: soil origin, location and depth.

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M. A. Baltazar-Zamora is Research Professor of Universidad Veracruzana, Facultad de Ingeniería Civil – Xalapa, Xalapa, Veracruz, México (email: mbaltazar@uv.mx)
L. Landa-Ruiz is Academic Technician of Universidad Veracruzana, Facultad de Ingeniería Civil – Xalapa, Xalapa, Veracruz, México (email: lalanda@uv.mx)
Y. Rivera is Academic Technician of Universidad Veracruzana, Facultad de Ingeniería Mecánica y Eléctrica – Xalapa, Xalapa, Veracruz, México (email: yrivera@uv.mx)
R. Croche is Research Professor of Universidad Veracruzana, Facultad de Ingeniería Mecánica y Eléctrica – Xalapa, Xalapa, Veracruz, México (email: recroche@uv.mx)

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The sample was identified by means of a card on the outside of the package containing the following information:
- Name of the project
- Localization
- Date of sampling
- Sample Number

There was a process of preparation of the sample in order to obtain the necessary portions representative to carry out the determination of moisture content and the limits of consistency that allow the classification of the fine soil according to the USCS (Unified Soil Classification System) [15]. The preparation of the soil was realized as follows:

Drying the material extending it in a clean surface and smooth to expose to the sun, to eliminate the water present and facilitate the disintegrated. Disintegrated from the soil sample with the purpose of eliminating the lumps present; with a wooden mallet of 1 kg of weight blows are given from a drop height not greater than 20 cm by separating the particles without breaking the stony aggregates.

Became strained the material to obtain reduced fractions shoveling about four times to homogenize the sample, a cone is formed by placing the material in the vertex of the same with the help of the loader allowing alone locate your accommodation, it was truncated cone by clipping the shovel in radial form and making the material toward the periphery by verifying that the diameter is 4 to 8 times the thickness, it is appropriate to divide the quadrants with a wooden rule recovering fine with a brush. Of the quadrants obtained as shown in Fig. 2, are taken two opposed by repeating the entire operation described until the required portion.

2) Natural water content.

The water content in the soil was determined according to the standard of the Ministry of Communications and Transport (SCT): M.MMP.1.04 / 03 [16], where the first step is to weigh the wet floor, then mop up in oven at a temperature of 110 ° C, ± 5 ° C, for 24 hours, to determine the difference between wet weight and dry weight, which is the amount of water evaporated, finally report that amount as a percentage.

3) Limits of consistency and classification of the soil according to USCS

The determination of the boundaries of consistency, for the soil in this research was according the NMX-C-416-ONNCE-2003, these limits are used for to classification of the fine soils through the plasticity charte of USCS, Fig. 4.

4) Characteristics of the steel bars AISI 1018 and Galvanized Steel

To keep the control of the variables involved in this investigation were assigned a nomenclature to the bars depending on the type of steel; the evaluation was performed in triplicate. The following Table I summarizes the characteristics of the bars and the nomenclature.
The monitoring corrosion potential of the test specimens was performed according to standard ASTM C876-15, and its interpretation, just adding one more interval according to the literature [23] see Table II.

### Table II: Corrosion potential in reinforced concrete (E_{corr})

| Corrosion potentials mV vs Cu/CuSO₄ |  
|-------------------------------------|
| -500                                |
| -750                                |
| -350                                |

1) \( E_{\text{corr}} \) AISI 1018 Steel and Galvanized Steel of 3/8”

Fig. 7 shows the results of corrosion potential (\( E_{\text{corr}} \)) of AISI 1018 Steel and Galvanized Steel, of 3/8” diameter. It can be seen that the corrosion potential behavior is homogeneous for the three AISI 1018 steel bars (N31, N32, N33), for all the exposure period, with \( E_{\text{corr}} \) value indicating 90% Probability of Corrosion, with some values more negative -500 mV period considered severe corrosion. In the case of the three Galvanized Steel bars (G31, G32, G33), also have a homogeneous behavior throughout the exposure period, with \( E_{\text{corr}} \) values more negative than -750 mV, which indicates according to ASTM C-876-15 the presence of severe corrosion. Corrosion potentials indicate a probability that the corrosion of steel is occurring, because of the values observed in both steels the soil under study has to be considered if it is a corrosive medium.

2) \( E_{\text{corr}} \) AISI 1018 Steel and Galvanized Steel of 1/2”

Fig. 8 shows the results of corrosion potential (\( E_{\text{corr}} \)) of AISI 1018 Steel and Galvanized Steel, of 1/2” diameter. In the case of AISI 1018 steel bars, an even more homogeneous behavior of the \( E_{\text{corr}} \) can be observed than that observed in the bars of 3/8 “diameter (Fig. 7), with values of \( E_{\text{corr}} \) that oscillate throughout the exposure period in a range of -350 mV to -500 mV, with points of monitoring exceeding -500 mV, but in general they are maintained in a range that indicates according to ASTM C-876-15 90% Probability of Corrosion. For the three bars of Galvanized Steel, a behavior similar to that observed in the bars of 3/8 “ is presented. With more negative \( E_{\text{corr}} \) values at -700 mV, in a range of -750 mV to -860 mV during the entire exposure period, indicating the presence of severe corrosion, according to what is established in Table II.

### III. Results and Discussion

#### A. Corrosion potential (\( E_{\text{corr}} \))

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Fig. 5. Characteristics of the study bars

Fig. 6. Electrochemical cell of experimentation

DISCUSSION

#### TABLE II: Corrosion potential in reinforced concrete (\( E_{\text{corr}} \))

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Fig. 7. \( E_{\text{corr}} \) AISI 1018 and Galvanized Steel of 3/8”

Fig. 8. \( E_{\text{corr}} \) AISI 1018 and Galvanized Steel of 1/2”

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After analyzing the behavior of the $E_{corr}$ presented in Fig. 7 and 8, there is little influence of the diameter of the steel bars under study, in the behavior of the corrosion potential, so it seems sufficient to use 3/8” diameter Galvanized Steel to reinforce an SMR with this type of soil (MH).

B. Corrosion Current Density ($I_{corr}$)

To evaluate the results of the Corrosion Current Density ($I_{corr}$) of AISI 1018 Steel and Galvanized Steel the electrochemical technique of Linear Polarization Resistance was used (ASTM G59) [24], and for the interpretation of the results obtained of $I_{corr}$, the criterion indicated in the DURAR Network Manual was used, the summarized in the Table III [25].

| Corrosion rate ($I_{corr}$) | Level of Corrosion |
|-----------------------------|--------------------|
| <0.1 µA/cm²                 | Despicable or Passivity |
| 0.1 - 0.5 µA/cm²            | Moderate           |
| 0.5 to 1 µA/cm²             | High               |
| > 1 µA/cm²                  | Very high          |

1) $I_{corr}$ AISI 1018 Steel and Galvanized Steel of 3/8”

Fig. 9 presents the results of the $I_{corr}$ for AISI 1018 Steel and Galvanized Steel, bars of 3/8” of diameter. In the case of AISI 1018 Steel, it is observed that from the first days of being in contact with the MH soil type, the three bars presented $I_{corr}$ values greater than 0.1 µA/cm² indicating a low level of corrosion, after 35 days present values of $I_{corr}$ greater than 0.5 µA/cm², presenting after day 70 until the last day of monitoring, values of $I_{corr}$ greater than 1.0 µA/cm² indicating a very high level of corrosion.

Unlike AISI 1018 Steel bars, Galvanized Steel bars showed a better performance against corrosion when they came into contact with the MH soil type. Galvanized steel presented $I_{corr}$ values below 0.1 µA/cm², indicating a despicable or passivity level of corrosion until day 35, after day 50 and until the end of monitoring, presenting $I_{corr}$ values in the range of 0.2 to 0.3 µA/cm², indicating a low level of corrosion. The good performance of galvanized steel is for a period of time when it is in contact with an aggressive medium, thus it has been shown to be evaluated as reinforcement in concrete exposed to a soil similar to that of this study but contaminated with different percentages of NaCl, where it was shown that by having the soil 2% NaCl the efficiency of Galvanized Steel is greatly diminished [26].

2) $I_{corr}$ AISI 1018 and Galvanized Steel of 1/2”

Fig. 10 shows the results of the $I_{corr}$ of AISI 1018 Steel and Galvanized Steel, bars of 1/2” diameter, the bars were exposed for more than 100 days to an MH type soil., the results are very similar to those reported for bars 3/8” in Fig. 9, with a better performance of Galvanized Steel bars, which have $I_{corr}$ values that indicate a passivity level of corrosion in the first days, and low level of corrosion after 40 days until the end of monitoring. It is also seen as the AISI 1018 steel bars, from the first days they present $I_{corr}$ values greater than 0.1 µA/cm² this indicate a low level of corrosion, to end the period of monitoring with $I_{corr}$ values greater than 1 µA/cm², indicating a very high level of corrosion. It is not observed that the diameter of the steel bars -AISI 1018 Steel and Galvanized Steel- influences the corrosion behavior in both steels.

IV. CONCLUSION

An anticorrosive efficiency of Galvanized Steel is 10 times greater than AISI 1018 steel. This significantly increases the structures durability of a mechanically reinforced soil.

It is not observed that the diameter of the steel bars -AISI 1018 Steel and Galvanized Steel- influences the corrosion behavior in both steels.

It was demonstrated that the MH type soil is highly corrosive according to the results of $E_{corr}$ and $I_{corr}$ obtained for both steels used in the present research.

It was demonstrated that the parameters of $E_{corr}$ and $I_{corr}$ used in the evaluation of corrosion in reinforced concrete structures can be used to research, evaluate and study the problem of corrosion in Soils Mechanically Reinforced (SMR).

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