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RESEARCH ARTICLE

Behavior of Potential of Half-Cell AISI 1018 and GS in Concrete Buried in Sand in the Presence of $MgSO_4$

Brenda Paola Baltazar-García[1], Daniel Francisco Baltazar-Zamora[1], Griselda Santiago-Hurtado[2], Victor Moreno-Landeros[2], David Lozano[1], Laura Landa-Ruiz[1], Shivani Shukla[3], and Miguel Angel Baltazar-Zamora[1,*]

ABSTRACT

This project, in the area of reinforced concrete corrosion, evaluated the potential of half-cell AISI 1018 CS (Carbon Steel) and GS Steel (Steel with galvanized coating); 15 cm long bars were used as reinforcement in specimens of concrete buried in a Type SP Sand (contaminated with 0% and 3% $MgSO_4$). The experimental arrangement of this research represents the case of the elements of the foundations of concrete structures that are planted near marine areas where this type of soil exists with the presence of high contents of depassivating ions such as sulfates. The study specimens were made with two concrete mixtures with a water/cement ratio 0.45 but with different types of cement (Portland Cement and Sulfate Resistant Cement). For monitoring the half-cell potential according to ASTM C 876-15, the specimens were buried in the clean SP soil and in the same soil but contaminated with $MgSO_4$. After more than 270 days of exposure to uncontaminated SP sand contaminated with $MgSO_4$, the behavior of the half-cell potentials or corrosion potentials show that the specimen made with the sulfate-resistant cement and reinforced with GS Steel (Steel with galvanized coating) presents the highest resistance to corrosion by $MgSO_4$ at a concentration of 3%.

Keywords: Concrete, GS steel, potential of half-cell, sand with $MgSO_4$.

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[1] *Universidad Veracruzana, Mexico.*
[2] *Universidad Autónoma de Coahuila, México.*
[3] *Indian Institute of Technology, India.*

******Corresponding Author:*
e-mail: mbaltazar@uv.mx

1. Introduction

As indicated by various investigations worldwide, chloride ions are the main aggressive agents causing severe damage due to corrosion of reinforcing steel in infrastructure built with reinforced concrete, damage that can be estimated at billions of dollars only in the USA [1], [2]. In Mexico, there is no information on the real cost of the problem of corrosion of reinforcing steel present in Civil Infrastructure Works. However, the Gulf of Mexico is considered the most corrosive environment. Therefore, the studies that try to contribute to reducing this problem are currently numerous [3]–[5].

The corrosion of reinforcing steel is an electrochemical process, and according to the literature, it is mainly due to the interaction of concrete structures with the environment where they were built, which may contain aggressive agents that may be present in the atmosphere. such as CO_2 or aggressive ions (Sulphates and Chlorides), but there is also the possibility that the concrete mixture contains these agents since its preparation or manufacturing [6]–[9]. The elements of reinforced concrete structures that are most susceptible to interacting with sulfates are the foundations, such as foundation slabs, continuous or isolated footings, bridge piers, etc. The above is due to the fact that the presence of sulfates is more frequent in the subsoil and in areas near the coasts. When the concrete element comes into contact with the sulfates, the attack on the concrete matrix begins, causing its degradation. which will lead to the entry of catalyst agents that will depassivate the reinforcing steel [10]–[14]. Sulphate ions as aggressive agents that promote corrosion of reinforcing steel have been a reason to evaluate alternative steels to AISI 1018 steel, so according to results obtained in sulfate corrosion studies, Galvanized Steel has proven to be a viable option when it presents greater resistance than conventional steel [15]–[17].

The use of pozzolanic materials, whether natural or from industrial or agro-industrial waste, for the manufacture of sustainable concrete that improves or provides more protection against corrosion of reinforcing steel caused by aggressive ions such as sulfates has resulted in multiple restoration works. Research has shown promising results when using rice husk ash, sugar cane bagasse ash, metakaolin, and fly ash, among others [18]–[23].

However, all the information cited from multiple investigations previously in this paper has only provided and the variables minimal information related to the mechanism that occurs in the corrosion of the foundation element when in contact with a sulfated environment. Thus, the importance of studying this process using GS Steel (Steel with galvanized coating and and manufactured concrete mixtures with sulfate-resistant cement as a way to mitigate the potential deterioration of reinforced concrete structures reinforced that are in contact with this environment has considerable merit, considering that, more than 95% of the reinforced concrete structures have foundational that will always be in contact with soils that can potentially undermine the integrity of the structure itself.

2. Materials and Methods

2.1. *Materials*

2.1.1. *Design and Proportioning of Concrete Mixture*

It was considered for this research project a concrete of f´c = 350 kg/cm^2, Normal Cement and Sulfate Resistant Cement, bars of AISI 1018 CS (Carbon Steel) and GS Steel (Steel with galvanized coating), buried in sea sand with the presence of $MgSO_4$ at 0% and 3%. The monitoring the half-cell potential or evaluation of the corrosion potentials (E_{corr}) based on ASTM C-876-15 [24].

The ACI 211.1 method was used to carry out the proportioning for the study mixtures for compressive strength at 28 days of 350 kg/cm^2 [25]. The quantities of each material are summarized in Table I.

2.2. *Methods*

2.2.1. *Characteristics and Specifications of Specimens*

The characteristics of the specimens and the reinforcing steels used to monitor the half-cell potential are seen in Fig. 1.

The AISI 1018 CS (Carbon Steel) and GS Steel (Steel with galvanized coating) steel bars were previously cleaned as indicated by the scientific community, in addition to leaving an area susceptible to corrosion, as seen in Fig. 2 [26].

The preparation of the study specimens was carried out based on the standard NMX-C-159-2004 [27]. For the correct analysis of the results of the half-cell potential monitoring and according to the variables, the nomenclature presented in Table II was used.

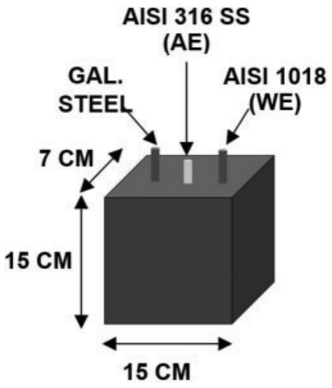

Fig. 1. Specimens for half-cell potential evaluation (characteristics).

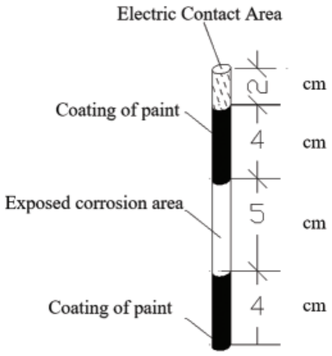

Fig. 2. Bars of AISI 1018 CS and GS steel.

TABLE I: Dosage of the Concrete Mixture for m^3

Materials	kg
Cement	456
Water	205
Coarse aggregate	995
Fine aggregate	562

The meaning of the abbreviations used in Table II is as follows:

- CM: Control Medium,
- AM: Agressive Medium,
- GS: Steel with galvanized coating,
- CS: AISI 1018 Carbon Steel,
- PC: Porland Cement,
- SRC: Sulfate Resistant Cement.

The soil used in the present study was obtained from the beach located in the Gulf Mexican, and according to the geotechnical laboratory tests, the soil is classified as poorly graded sand with the symbol SP according to the USCS [28]. Subsequently, containers of considerable size were chosen where the specimens buried in the SP sand with 0% and 3% of $MgSO_4$ as an aggressive agent were placed, see Fig. 3.

TABLE II: Nomenclature (Half-Cell Potential Monitoring)

Soil with 0% $MgSO_4$		Soil with 3% of $MgSO_4$	
Control medium		Agressive medium	
CM-GS-PC	CM-CS-PC	AM-GS-PC	AM-CS-PC
CM-GS-SRC	CM-CS-SRC	AM-GS-SRC	AM-CS-SRC

Fig. 3. Specimens in their environment of exposure.

3. RESULTS AND DISCUSSION

3.1. Corrosion Potential (E_{corr})

The analysis of the behavior of the half-cell potentials of the study specimens in the two exposure media was carried out based on what was established by ASTM C-876-15 more the severe corrosion range [29], see Table III.

The experimental arrangement to evaluate the effect of the presence of aggressive agents such as sulfates in soils and its relationship with the corrosion of reinforcing steel proposed in this research agrees with what has been carried out by the scientific community worldwide [30]–[32].

The Fig. 4 shows the analysis of the behaviour the half-cell or corrosion potentials, E_{corr}, of all specimens buried in SP sand with 0% $MgSO_4$, CM-CS-PC, CM-CS-SRC, CM-GS-PC, CM-GS-SRC. The specimens CM-CS-PC, and CM-CS-SRC, reinforced with AISI 1018 steel, present E_{corr} values of −205 to 196 mV in the first monitoring to continue at more positive values reaching more positive values than −100 mV for day 28, behavior due to densification of the concrete matrix in its curing stage, no influence of the type of cement used on the half-cell potential values is identified. However, when the specimens are buried in SP type sand, the CM-CS-SRC specimen has values half-cell potential of between −320 mV to −114 mV after the curing stage until day 84, to remain in a stable range of between −105 to −60 mV until day 160, around −200 mV until on day 238, which would indicate, according to the ASTM C 876-15 standard, a probability of 10% of corrosion, presenting for the last 30 days values more negative than −200 mV associated with corrosion uncertainty.

For the CM-CS-PC specimen, E_{corr} values are reported in a range of −295 to −215 mV from the end of the curing stage until day 161 of monitoring, which, according to the standard, would be associated with a corrosion uncertainty, however for The period from day 168 to the end of monitoring reports instability in the half-cell or corrosion potentials Ecorr with values of −540 mV on day 189, to maintain values between −350 to −500 mV until the end of the monitoring. Monitoring, which would indicate a 90% probability of corrosion according to ASTM C-876-15. Better behavior against corrosion of the specimen CM-CS-SRC is observed, this effect is due to the type of sulfate-resistant cement.

TABLE III: CORROSION POTENTIAL IN REINFORCED CONCRETE (E_{CORR})

Corrosion potentials mV vs. Cu/$CuSO_4$	
<−500	Severe corrosion
<−350	90% probability of corrosion
−350 to −200	Uncertainty of corrosion
>−200	10% probability of corrosion

In reference to the specimens CM-GS-PC, CM-GS-SRC present half-cell potentials or corrosion potentials, Ecorr, of −740 and −650 mV for the specimens with Portland cement and sulfate-resistant cement, respectively, at the beginning of the monitoring, to reach values more positive than −500 mV at the end of the monitoring curing stage.

Upon coming into contact with SP type sand, the two specimens present more negative values at −500 mV from day 42 to day 70, which is associated, according to the ASTM C-876-15 standard, with severe corrosion, but with the passage of exposure time, both specimens stabilize at values between −350 to −400 mV from day 168, to culminate with half-cell potential values more positive than −350 mV for the CM-GS-SRC specimen, which indicates a 90% probability of corrosion, and for specimen R values of −430 to −520 mV, which would be interpreted as severe corrosion.

For specimens buried in SP sand type with 3% $MgSO_4$, AM-CS-PC, AM-CS-SRC, AM-GS-PC, AM-GS-SRC, In Fig. 5, it is observed that from the beginning of contact with contaminated sand, the effect or influence of sulfate-resistant cement, presenting these specimens the better performance against corrosion throughout the experimental period, presenting values E_{corr} in a range of −100 to −150 mV throughout the monitoring period the specimen AM-CS-SRC indicating a probability of 10%. Instead, the AM-CS-PC specimen presents Ecorr values from the day 50 to 200 observation that indicate uncertainty, to be located in an area of 10% corrosion in the last 70 days. In the case of specimens with GS Steel (Steel with galvanized coating), AM-GS-PC and AM-GS-SRC, also from the 35th day up to the 200th demonstrated the best performance of GS Steel in the concrete made with sulphate-resistant cement with E_{corr} values indicating uncertainty in contrast to the elaborate with normal cement presenting values of half-cell potentials or E_{corr} more negative than −350 mV, which according to the ASTM C-876-15 standard is associated with a 90% probability that steel corrosion is occurring, results that agree with those reported in the literature [33], [34].

The apparent benefit of sulfated media observed in Fig. 5, or apparent protection against corrosion of reinforcing steel in concrete buried in sulphated sand, only occurs in the first months of contact, according to the literature [35], and is associated with the action of by magnesium sulphate also results in a hard, dense film formed in the concrete due to the deposition of magnesium hydroxide in the pores, and this tends to impede penetration of the solution. This is because the concrete has a lower permeability, and it is very likely that potential and low corrosion rates will result, which could be interpreted as a beneficial effect against corrosion [36].

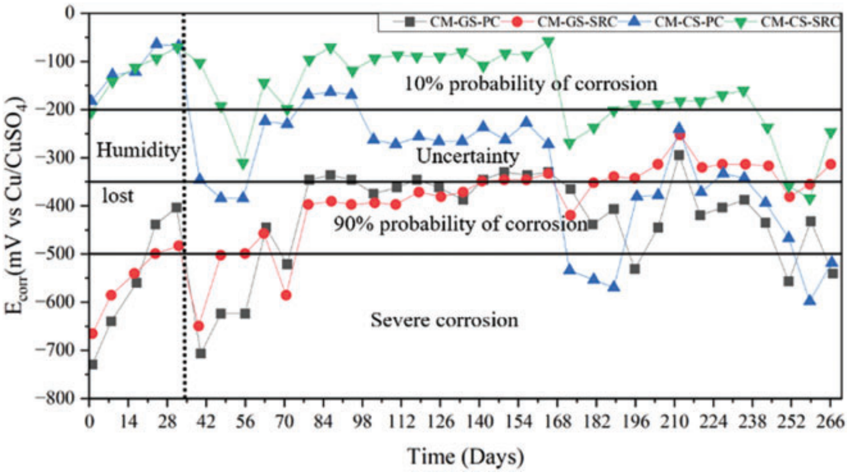

Fig. 4. E_{corr}, specimens in SP sand with 0% of MgSO4.

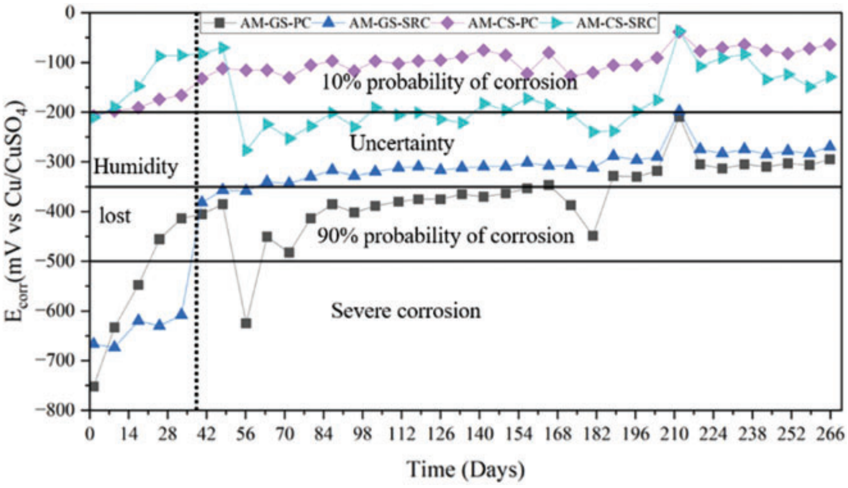

Fig. 5. E_{corr}, specimens in SP sand with 3% of MgSO4.

4. CONCLUSIONS

With this work and according to the results obtained, it has been demonstrated that the type of cement used for the elaboration of concrete exposed to soils in the presence of sulphates influences the electrochemical behaviour of reinforcing steel, galvanized, as well as non-galvanized steel.

Since the demonstration of the efficacy of reinforcing steel in concrete made with sulfate-resistant cement has a better performance compared to reinforcing steel in concrete made with common Portland Cement.

Also, it can be concluded that specimens with galvanized steel as a reinforcing agent present more homogeneous behaviour but, at the same time, a higher probability of corrosion than normal steel specimens.

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