Effect of the Type of Curing on the Corrosion Behavior of Concrete Exposed to Urban and Marine Environment

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Abstract—This study analyzes the electrochemical behavior of AISI 1018 steel as reinforcement in concrete exposed to the Xalapa city (urban environment) and seawater (marine environment). Two concrete mixtures were made, with ratio w/c of 0.45 and 0.65, according to the method of ACI 211.1. The specimens underwent three types of curing, the first was submerged in water for 27 days as indicated by the ONNCE regulations, the second was cured as it is done on oeuvre (moisturizing the elements in the morning and in the afternoon) and the third one exposing to the environment (without applying water), before placing them in the exposition environment. The results of more than 340 days of monitoring of \( E_{corr} \) and \( I_{corr} \) demonstrate that the marine environment is the most aggressive in the corrosion of reinforced concrete, with a better performance of the concrete of ratio w/c=0.45 and with a curing according to normative.

Index Terms—Curing Type, Concrete, Corrosion, Urban Environment, Marine Environment.

I. INTRODUCTION

According to the literature it is known that one of the main economic problems of countries and in the process of development is the deterioration of reinforced concrete structures such as bridges, docks, buildings among others, considered to the corrosion that appears in the steel of reinforcement like the main cause of said deteriorations [1-3]. In first world countries where a systematic process of evaluation of the structures is carried out, figures of billions of dollars of cost have been reported to solve damages caused by this phenomenon [4-6].

Exist innumerable national and international works that board this problematic where this phenomenon is studied, and there are proposals considered as preventive as well as corrective and sustainable, using agroindustrial wastes such as sugar cane bagasse ash as a partial substitute for Portland cement, to improve the corrosion resistance of concrete [7-8], due to its pozzolanic properties [9].

The present work addresses the problem with the idea of simulating in the laboratory the real conditions that builders face in the field, in this sense, it was considered to study concrete specimens with different types of curing, a curing according how is established in the normative of the ONNCE, the second one a curing as it is commonly carried in the works where there is no quality control, which is humidify in the mornings and afternoons and the third one the most critical that would be without any cure, these specimens were made with two mixtures of different quality, ratio w/c of 0.45 and 0.65, subjecting them to two means, urban (environment of the City of Xalapa) and to a marine environment (seawater).

While there exist regulations, and extensive literature indicating the importance of curing in the process of setting of concrete, unfortunately, the variables contemplated for this work are very common in real life, it is also true that that there are few jobs that try to study the effect on the corrosion behavior of the reinforcing steel caused by the type of curing or lack thereof are counted, and exposure environments of carbonation and aggressive ions such as chlorides. The objective of this writing is to analyze the results of corrosion potentials \( E_{corr} \) and corrosion kinetics or corrosion rate \( I_{corr} \) after more than 340 days of exposure to the media, urban and marine environment, determining the influence of the contact medium, the concrete quality and the type of curing in the corrosion process of the reinforcing steel, main variables that influence the durability of reinforced concrete structures according to the world community.

II. MATERIALS AND METHODS

A. Materials

1) Physical characteristics of aggregates.

The method used to calculate the proportion was that of ACI 211.1 [10], which is based on the physical characteristics of the materials, for the elaboration of the concrete mix preparation it was used natural aggregates which were determined their physical properties all according to ONNCE standards, see Table I.

| Physical properties of materials | Coarse aggregate | Fine aggregate |
|----------------------------------|-----------------|---------------|
| Specific Mass (MES) g/cm³        | 2.32            | 2.66          |
| Bulk Volumetric Mass (BVM) Kg/cm³| 1380            | -             |
| Absorption (%)                   | 4               | 3.80          |
| Module of Fineness               | -               | 2.70          |
| Maximum Size Nominal (TMN)       | ¾ "            | -             |

TABLE I. SUMMARY OF RESULTS OF THE CHARACTERIZATION OF THE AGGREGATES

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2) **Proportion of concrete mixes**

For the present work was used a portland cement type CPC 30R, and water, were made two concrete mixtures, w/c=0.45 and w/c=0.65 ratio. The dosage for each mixture is shown in Table II.

| Materials       | w/c=0.45 (kg/m³) ratio | w/c=0.65 (kg/m³) ratio |
|-----------------|------------------------|------------------------|
| Water           | 178                    | 178                    |
| Cement          | 456                    | 316                    |
| Coarse aggregate| 913                    | 913                    |
| Fine aggregate  | 863                    | 1012                   |
| Additive (accelerant) | 2% wt. CPC   | 2% wt. CPC  |
|                 | 30R                    | 30R                    |

### B. Method

1) **Concrete characterization in a fresh and hardened state**

To determine the characteristics of fresh concrete and its mechanical strength, studies were conducted according to the ONNCCE and ASTM standards, see Table III.

| Parameter          | w/c=0.45 ratio | w/c=0.65 ratio |
|--------------------|----------------|----------------|
| Shump [11]         | 7.0 cm         | 6.0 cm         |
| Temperature [12]   | 24.0 °C         | 23.5 °C        |
| Density [13]       | 2346 kg/m³     | 2307 kg/m³     |
| Compressive strength [14] | 395 kg/cm²   | 245 kg/cm²     |

2) **Characteristic and nomenclature of test specimens.**

In each specimen two steel bars of AISI 1018 were embedded, 3/8” diameter corrugated, reinforcing steel commonly used in reinforced concrete structures worldwide, one of the two rods were used as a working electrode (WE) and the other of auxiliary electrode (AE), and a standard copper-copper sulfate (Cu/CuSO₄) as reference electrode (RE), for to use the technique of linear polarization resistance (LPR) as indicated by the ASTM C876-15 standard [15], each of the bars were placed 5 cm paint at the top and 5 cm at the bottom, in order to delimit the area of exposure to corrosion of steel in concrete with a length of 5 cm (Fig. 1), experimental arrangement, which has been used in various investigations [16-19].

![Fig. 1. Dimensions of study specimens (cm)](image)

For the study specimens and according to the parameters to be evaluated, described and treated in the previous section, we proposed the nomenclature that shown in the following Table IV.

### III. RESULTS AND DISCUSSION

#### A. Corrosion potential (E<sub>corr</sub>)

The specimens were monitored in accordance with ASTM C876-15 [20] as well as the interpretation of the results obtained by adding a further range as indicated in the literature [21], the above are summarized in Table V.

| Corrosion potentials mV vs Cu/CuSO₄ | 10% Probability of Corrosion | 90% Probability of Corrosion |
|-------------------------------------|-------------------------------|-------------------------------|
| < 500                               | Severe corrosion              |                               |
| < -350                              | 90% Probability of Corrosion  |                               |
| -350 to -200                        | Uncertainty                   | 10% Probability of Corrosion  |
| > -200                              |                               |                               |

1) **Behavior of E<sub>corr</sub> of specimens exposed to urban and marine environment**

In Fig. 2, we can see the graph, that after curing the specimens of w/c= 0.45 and 0.65 ratio, exposed to the environment of the city of Xalapa, Ver. (Urban environment).

![Fig. 2. E<sub>corr</sub> specimens exposed to urban environment](image)

The specimens present after day 60 values of E<sub>corr</sub> more positive to -200mV, what it indicates according to the standard ASTM C-876-15, 10% of probability of corrosion according to the norm, this trend was maintained until the end of the exposure time that was more than 340 days. It is not observed or cannot be distinguished in the behavior of the corrosion potential of E<sub>corr</sub>, an influence of the type of curing and the relation with water/cement, having the six specimens a homogeneous behavior of passive or non-corrosive state.

In Fig. 3 it can be seen how the exposure in the marine environment evidence the temporal efficiency that concrete present of a lower relation with w/c, being more resistant to the aggressive environment as is sea water, presenting all specimens of relation w/c=0.45, values of E<sub>corr</sub> with a
tendency to more positive values, going from -300 mV to -215 mV from day 30 to 150, what according to the norm ASTM C-876-15 indicates uncertainty of the presence of corrosion, but after day 160 the specimen 4SM presents an activation, with a tendency until the end of the monitoring of $E_{corr}$ more negative until reach to $-490$ mV, the specimen with curing work 4OM presents on day 265 the trend towards more negative values reaching the end of values of $-480$ mV, the behavior is in the specimen with curing according to the norm, 4NM which until day 300 presents $E_{corr}$ more negative than $-350$ mV.

For specimens made with a lower quality concrete o relation w/c = 0.65, and with a poor cure, specimen 6SM, they present a 90% of probability of corrosion form the first week of exposure to the marine environment, the benefit of curing is observed from the norm in this relation w/c, 6NM presents until the day 150 values of $E_{corr}$ that indicate uncertainty of corrosion, with the passage of time this benefit by proper curing is lost, the same as the relation specimens w/c=0.45, presenting potential values after day 220 that indicate 90% probability of corrosion, to behave unfavorably as well as specimens cured on work and without curing (6OM y 6SM), presenting values that indicate the presence of severe corrosion, from day 260 to the end of monitoring, day 342.

B. Kinetics of Corrosion ($I_{corr}$)

The results of the corrosion kinetics $I_{corr}$ were interpreted according to the criterion of the DURAR Network Manual [22], see Table VI.

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

1) Behavior of $I_{corr}$ of specimens exposed to urban and marine environment

Figure 4 shows the behavior of the corrosion rate, $I_{corr}$ of the specimens of both relations w/c, exposed to the urban environment of the City of Xalapa, Ver., Mexico.

When $I_{corr}$ was evaluated by the technique of RPL, the behavior observed in the corrosion potentials of all specimens exposed to said medium is reaffirmed. It has to be all specimens that made with a concrete of better quality that which are of relation w/c=0.45, they have a good performance against corrosion during more than 342 days of exposure, highlighting the specimen that was cured according to the standar 4NU, 27 days submerged in water, as presented throughout the period values of $I_{corr}$ below 0.1 µA/cm² what is indicated a despicable level of corrosion according to the DURAR Network Manual, followed by a curing applied as it is done on work, 4OU, presenting values of $I_{corr}$ below of 0.1 µA/cm² until the day 330, to activate the system and present at the last monitoring an $I_{corr}$ greater than 0.1 µA/cm², which indicates a moderate level of corrosion, so also the specimen without curing 4SU, which presented a despicable level of corrosion until day 300, to present a moderate level of corrosion in the last 60 days of exposure. In the case of relation specimens w/c = 0.65, the specimen with standard cure 6NU, presented values of $I_{corr}$ slightly higher than the specimen 4NU, but all until the end of monitoring below to 0.1 µA/cm², indicating a despicable level of corrosion., however the specimen 6OU presented a despicable level of corrosion only until day 270, from there until the end of the monitoring show a moderate level of corrosion, with values of $I_{corr}$ higher than 0.1 µA/cm², observing the influence of the type of cure, so too the specimen 6SU, which was activated from day 180 presenting values greater than greater than 0.1 µA/cm², with a tendency over time to increase, reaching up 0.14 of $I_{corr}$, at the end of the exposure time. The analyzed results of $I_{corr}$ of concrete exposed to the environment of the City of Xalapla, Ver., coincided with what is reported in the literature [23], being this a little aggressive environment compared to a marine environment.
Fig. 5 presents the $I_{corr}$ results of the study specimens exposed in a marine environment (seawater). It can be seen unlike the urban environment, that the marine environment is very aggressive, which confirms what is mentioned in the literature [24]. But what needs to be analyzed is how the corrosion kinetics behavior of each specimen, highlighting the importance of concrete quality and type of curing, that as indicated by the concrete quality community or the relation w/c ratio used, the concrete will present important mechanical and durability characteristics such as resistivity and ultrasonic pulse, which correlates with corrosion resistance [25]. Although the aggressiveness of the medium is observed from the first 60 days of exposure presenting all specimens values greater than 0.2 $\mu$A/cm², it can be seen relatively better performance of low water cement specimens, those of 0.45, highlighting whether it can be considered that way, the specimen cured with norm 4NM which presented $I_{corr}$ below 0.5 $\mu$A/cm² until day 180, moderate corrosion level, followed by specimens with curing type in Work and Without Curing, which kept the level of corrosion moderate, until before the 150 days of exposure with lower values than 0.5 $\mu$A/cm². Analyzing the specimens of w/c = 0.65 relation, it is observed that since day 120 they have a high level of corrosion, finished at the end of monitoring the specimen without curing 6SM, with an $I_{corr}$ greater than 1 $\mu$A/cm², which indicates a very high level of corrosion, followed by the 6OM, 6NM y el 4SM specimen. Confirming the behavior of $E_{corr}$ corrosion potentials in Fig. 3.

IV. CONCLUSION

It was shown that the quality of the concrete and the type of curing are the most important factors in the behavior of the corrosion kinetics of reinforced concrete with AISI 1018 steel.

When said element is exposed to an environment as aggressive as it is marine environment, in this case seawater, it was observed that concrete low and medium ratio w/c (0.45 y 0.65) cured according to standard have relatively higher corrosion resistance in a marine environment, than concrete with poor curing or no curing.

It was also observed how the urban environment of the City of Xalapa is less aggressive than the marine environment, but that is an environment where corrosion occurs and that the quality of the concrete as well as the type of curing would have to be considered mainly in the works of self-construction type (Works without Quality Control of Hydraulic Concrete Processing).

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