SURFACE CONDITIONS EFFECT ON THE CORROSION BEHAVIOUR OF STEEL REBAR IN SIMULATED CONCRETE PORE SOLUTION

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Abstract- In order to study a surface conditions effect on the corrosion behaviour of steel rebar, electrochemical tests were carried out in simulated concrete pore solution using samples with two different surfaces: polished and corroded (as received). The obtained results show that the oxide layer has a negative effect on the corrosion behaviour of reinforcement steel. This effect can be explained by the fact that the oxides provoke a decrease of the electrolyte resistance at the metal/concrete interface and reduce the re-passivating ability. In addition, the oxide layer acts as a physical barrier against the diffusion of hydroxyl ions, which prevents the re-alkalinization phenomenon.

Keywords: Corrosion, concrete, steel, chloride, rust.

I. INTRODUCTION

Durability of the concrete structures is strongly related to their steel bars resistance for the corrosion damage. In fact, in sound concrete, reinforcement steel are normally protected from corrosion by passive film due to the high alkalinity of concrete pore solution (pH > 12) [1]. However, due to the penetration of chloride ions, coming from the marine environment, this film can be locally destroyed and corrosion occurs. The corrosion products cause structural damages such as cracks and/or accelerating the corrosion process [2-4]. Therefore, studies on the corrosion mechanism and protection of steel are urgent tasks in modern society.

Chloride-induced corrosion was recognized as one of the major cause of the degradation of reinforced concrete structures [5-8]. The corrosion mechanism induced by the chloride ions diffusion has been, and continues to be, extensively investigated. There is a general agreement in the existence of a certain value representing the chloride threshold concentration (\(\text{Cl}_{\text{TH}}\)) that must be reached at the rebar surface in order to initiate the corrosion process [9]. It is usually presented as a ratio of chloride to hydroxyl ions, free chloride content or a percentage of the total chloride content relative to the weight of cement. The chloride threshold value is of great importance when evaluating the life service of reinforced concrete structures, as it determines how long it takes to initiate the corrosion process. Many investigations have been focused on determining the \(\text{Cl}_{\text{TH}}\) value [10-14], although the reported results show great variability. In fact, the chloride threshold value depends on various factors such as pH of the concrete pore solution and surface condition of reinforcement steel.

Most of the studies on corrosion of steel reinforcement in concrete are often conducted on the steel samples with polished surface (free of all oxides) in order to reproduce the same experimental conditions. However, before embedding in concrete, the steel bars are often covered with the natural oxides (rust) which are formed during exposure to the atmosphere. The reinforcing corrosion process in atmosphere is affected by both steel chemistry and environmental conditions, namely duration of exposure, temperature, wet-dry cycles and the composition of an electrolyte that wets the metal surface [15-16].

According to the literature, the presence of an oxide layer on the surface of steel rebar may affect its electrochemical behavior in concrete. Some authors [17-18] state that the presence of the oxide layers has no significant effect on corrosion resistance of reinforcement in concrete. Others [19] consider that the presence of oxides on the surface rebar is beneficial because they act as a physical barrier to the aggressive ions. However, most of the authors [20-25] affirm that the oxidized steel
reinforcements exhibit a high corrosion rate comparatively to the non-oxidized.

In order to contribute to the studies of surface conditions effect on a corrosion behaviour of reinforcement steel, several electrochemical tests were carried out in a simulated concrete pore solution using steel samples with two different surface conditions: polished and naturally pre-rusted samples.

II. MATERIALS AND METHODS

A. Steel samples

The tested material was a carbon steel with a chemical composition of (wt.%): C 0.12, Si 0.1, Mn 0.2, Cu 0.02, S 0.02, P 0.02, Mo 0.06 and balanced Fe. In order to bring out the oxides effect on the corrosion behaviour of steel, we used samples with two different surface conditions: polished samples (denoted PS) and naturally pre-rusted samples (denoted RS).

Polished samples (reference samples) were cut from deformed steel bar, 10 mm in diameter, following the cross section. Electrical contact was achieved through a copper wire soldered to the end of the steel sample. The electrode was covered with epoxy resin, leaving an area of 0.78 cm² exposed to the test solution. Before all tests the surface was metallographically polished using a series of silicon carbides emery paper of grade 220 to 1200. Rusted samples (as received samples) were cut from naturally rusted bar. Their top and bottom ends were masked with epoxy resin to give working surface of 6.28 cm².

Before each measurement, all of the samples were degreased in acetone, rinsed with distilled water and dried in air.

B. Electrolyte

Due to its complexity, the internal medium of concrete is often simulated by aqueous solutions of high alkalinity. The work in these solutions can significantly reduce the time of electrochemical tests. Therefore, simple alkaline solutions, usually composed of Ca(OH)₂, KOH and NaOH are used by different authors for reinforcing steel corrosion testing [26-28].

In this work, a saturated Ca(OH)₂ solution simulating concrete medium (pH = 12.5) has been used as electrolyte. To simulate the aqueous phase of a contaminated concrete, chloride ions were added to the solution at concentrations expressed by the ratio R = [Cl⁻] / [OH⁻] (For a pH value equal to 12.5 the corresponding hydroxyl ion concentration [OH⁻] is equal to 0.032 mol.L⁻¹). The maximum chlorides concentration used is equal to 0.5M (average chlorides rate of Mediterranean seawater) which corresponds to a [Cl⁻] / [OH⁻] ration equal to 15.5.

C. Electrochemical tests

Open circuit potential (OCP), polarization curves and electrochemical impedance spectroscopy (EIS) measurements were carried out to evaluate the surface condition on the corrosion behavior of reinforcement steel in concrete pore solutions.

To show the OCP evolution of polished and rusted samples in the simulated solution, periodic measurements were taken using high impedance multimeter and saturated calomel electrode (SCE).

Polarization curves (I = f(E)) were plotted with a scan rate of 0.25 mV.s⁻¹ from −800 to +800 mV vs SCE in the anodic direction. EIS measurements were carried out at corrosion potential with a frequency variation between 10² Hz and 0.01 Hz and a potential sine signal of 10 mV around the corrosion potential obtained after 1 and 24 hours of immersion in the solution. All the electrochemical tests were performed at room temperature in a polyethylene cell with a platinum electrode as counter electrode and a saturated calomel electrode (SCE) as reference electrode.

III. RESULTS

A. Steel rebar characterisation

1) Microstructure of polished steel

Metallographic micrographs of polished steel, Figure 2, show two dominant crystalline phases: ferrite and perlite. It can be seen that the perlite grains appear darker while the ferrite phase is brighter, which is typical microstructure for this alloy. However, we observed a remarkable heterogeneity in the distribution of these two phases; the core material is rich in ferrite, while on board, perlite is the predominant phase.

Fig. 1. Optical micrographs of steel rebar: rusted sample.

This structural heterogeneity has a direct effect on the physico-chemical and mechanical properties of steel; mechanically, perlite, which is consisting of alternating layers of ferrite and cementite (iron carbides), is harder than ferrite which gives the steel a compromise of superficial hardness and ductility in the core. In terms of electrochemical behavior, the ferrite is more resistant to corrosion than perlite due to the fact that
perlite is formed at the cooling speed of steel greater than the cooling speed at which the ferrite is formed. In consequence, perlite has a high level of stress and is less thermodynamically stable than ferrite. Fan Zhang [29], in his study focused on the localized corrosion behavior of reinforcement steel in simulated concrete pore solution, reported that the localized corrosion occurs on the ferrite grain boundaries and perlite grains.

1) Oxides composition

Rust is a substance of red-brown color formed naturally when iron compounds corrode in air (presence of oxygen and moisture). It is a slow oxidation reaction leading to the formation of oxides or hydroxides more or less hydrated and poorly crystalline, which is more stable hematite. Rust is a complex mixture consisting of oxides and hydroxides of iron. The process of rust formation can be decomposed into three basic steps:

- Formation of iron hydroxide (II), \([Fe(OH)_2]\), by acting on the iron hydroxide ions jointly formed by the reaction of oxygen in the air with water (oxidation-reduction);
- Oxidation of iron (II) ions in ferric hydroxide under the action of oxygen in the air;
- Spontaneous transformation of the solid ferric oxide hydrate.

When iron (or steel) is in contact with water, an electrochemical process starts progressing rather slow. On the surface of the metal, iron at 0 oxidation state is oxidized to the oxidation state +II by following the reaction [30]:

\[
Fe + 2OH^- \rightarrow Fe(OH)_2 + 2e^- \quad (1)
\]

While the oxygen in the air (oxidation state 0) is reduced to the hydroxide ion:

\[
2H_2O + O_2 + 4e^- \rightarrow 4OH^- \quad (2)
\]

At the second stage (almost instantaneous) iron (II) hydroxide is rapidly oxidized to ferric hydroxide by the reaction:

\[
4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3 \quad (3)
\]

Finally, the ferric hydroxide is transformed spontaneously into hydrated ferric oxide according to the chemical reaction:

\[
2Fe(OH)_3 \rightarrow Fe_2O_3.3H_2O \quad (4)
\]

Rust has the extreme disadvantage of weakening the structure. Indeed, iron is replaced by healthy iron (III) oxide, which is friable, porous and ill-driver.

Figure 2 shows the SEM micrograph of rusted sample. From this figure we clearly see that the thickness of oxide (rust) layer is not uniform.

2) Open circuit potential measurement

The corrosion potential \((E_{corr})\) is a qualitative indicator of the corrosion state of a metallic substrate in its environment. The evolution of corrosion potential of the sample over time can follow the development of the steady state. It can also reveal the possible transitions from active to a passive state of metal.

The effect of surface conditions of steel samples on the evolution of corrosion potential in SCP solution without and with chlorides content is reflected by the curves in Figure 3a and 3b. From these curves we can clearly see the effect of rust layer on the potentials evolution of reinforcement steel.

Fig. 3. Surface conditions effect on the OCP evolution of steel:
(a) chloride-free solution, (b) chlorinated solution.
At the moment of an immersion in SCP solution free of chlorides, the RS sample shows the highest potential value (-125 mV) and the lowest is given by the PS sample (-540mV). However, the potential of this last is increasingly positive with time; it stabilizes around a value of -330 mV, while the potential of rusted sample becomes more and more negative and stabilizes at the value of - 300 mV. In the presence of chlorides, the evolution of corrosion potential with time follows the same tendency for both samples (polished and rusted). The potential becomes increasingly less noble with immersion time and reach values more negative than that achieved in chloride-free solution, which reflects the aggressive effect of chloride ions.

As first conclusion, we can say that in absence of chlorides the oxide layer provides a relative electrochemical stability to the steel bar. Whereas, in the presence of chlorides, this later has a negative effect by the fact that chlorides prevent the formation of a protective film on the steel surface.

3) Polarization curves

Figure 4 shows examples of the anodic polarization curves obtained for polished steel in simulated solution and in the same solution with the addition of different concentrations of chloride ions.

In the chloride-free solution, upon increasing potential above the corrosion potential, a passive plateau was found where the current density was of the order of 10^-6 A.cm^-2. This plateau is mainly attributed to the formation of a passive film of iron hydroxide (Fe(OH)₂) on the metal surface. This result is in perfect agreement with the predictions of the equilibrium potential-pH described by the Pourbaix diagram for Fe-H₂O system. According to this diagram, a passive oxide film should be stable in solution. At potential values higher than 600 mV/SCE an increase in the current density was observed resulting from the onset of the oxygen evolution reaction.

The anodic polarization curve obtained for rusted steel samples in saturated Ca(OH)₂ solution was similar to those found for polished samples. A passive region, where the current density was lower than 10^-6 A.cm^-2, was observed before reaching the onset of the oxygen evolution reaction. Increasing the chloride ions concentration causes an increase in corrosion current density and a shift of corrosion and pitting potentials towards more negative values, Table 1. However, in the presence of oxide layer the negative effect of chloride ions is more accentuated.

<table>
<thead>
<tr>
<th>[Cl⁻] / [OH⁻]</th>
<th>I (mA)</th>
<th>E_cor (mV)</th>
<th>E_p (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polished sample</td>
<td>0</td>
<td>-406.5</td>
<td>630</td>
</tr>
<tr>
<td>0.4</td>
<td>-440</td>
<td>-85</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-452</td>
<td>-218</td>
<td></td>
</tr>
<tr>
<td>15.5</td>
<td>-530</td>
<td>-307</td>
<td></td>
</tr>
<tr>
<td>Rusted sample</td>
<td>0</td>
<td>-464.6</td>
<td>468</td>
</tr>
<tr>
<td>0.4</td>
<td>-511.3</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-553</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>15.5</td>
<td>-566</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

The anodic polarization curve obtained in Figure 6a and 6b permit to compare the electrochemical behaviour of polished and oxidized samples in simulated solution with and without chloride ions.
Fig. 6. Effect of surface conditions on the corrosion behavior of reinforcement steel: (a) chloride-free solution, (b) chlorinated solution.

From these curves we can clearly see the effect of the oxide layer presence on the corrosion behaviour of metal in both simulated solutions (without and with chlorides). In chlorides free solution, the rusted sample exhibits a less noble value of corrosion and pitting potential than those presented by polished sample. But, in chlorinated solution, the rusted sample shows the same corrosion potential than the polished one. The pitting potential is clear only in the polished sample, which is not the case for the rusted one which is subject to a generalized corrosion. In the other hand, the rusted sample presents the higher corrosion current density in both solutions, as shown in Table 2.

TABLE 2. Effect of surface condition on the electrochemical parameters evolution.

<table>
<thead>
<tr>
<th></th>
<th>[Cl]</th>
<th>$E_{\text{corr}}$ (mV)</th>
<th>$E_p$ (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Polished surface (PS)</strong></td>
<td>0%</td>
<td>-406.5</td>
<td>630</td>
</tr>
<tr>
<td></td>
<td>3%</td>
<td>-530</td>
<td>-307</td>
</tr>
<tr>
<td><strong>Rusted surface (RS)</strong></td>
<td>0%</td>
<td>-464.6</td>
<td>-468</td>
</tr>
<tr>
<td></td>
<td>3%</td>
<td>-566</td>
<td></td>
</tr>
</tbody>
</table>

4) Electrochemical impedance spectra

To complete the results of the OCP evolution and polarization curves, the corrosion behavior of the reinforcement steel specimens were also evaluated by EIS measurements. The impedance spectra obtained at the corrosion potential were recorded after 1 and 24 hours of immersion of the polished and rusted samples.

The impedance spectra reflect the effect of chlorides content and surface conditions of reinforcing steel on its corrosion behavior, in the simulated concrete solutions (Figures 7, 8 and 9).

All spectra present two semi-circular capacitive loops, high frequency and low frequency loops, with two time constants, in agreement with literature [31-33].

Fig. 7. Nyquist plot of reinforcement steel immersed in chloride-free solution: (a) polished surface, (b) rusted surface.

Nyquist plots in Figure 7a, depict an increase in capacitive part and polarization resistance (impedance in real part) with increase of immersion time for polished sample in the free-chloride solution. Nyquist plots of polished steel in chlorinated solution, Figure 8a, indicate a decrease in the two parameters mentioned above with increasing immersion time. We can observe the same trend on the Nyquist plots of steel with pre-rusted surface, Figure 7b and 8b.
When metal is immersed in the solution, the current (or current density) in the metal-electrolyte interface (electrical double layer) leads to charging-discharging of capacitance as $C = Q/V$, where $Q$ is the charge build up in double layer during metal dissolution and $V$ is free corrosion potential of the sample. Thus, if the passive film is growing and its nature improves by increasing coverage of film on the electrode surface, the size of the micropores present in passive film will decrease and metal dissolution in the initial exposed area will decrease. Hence, double layer capacitance will decrease [34]. With presence of the aggressive chloride ions, the increase in capacitance and decrease in impedance (in real part) with time indicated the breakdown of passive film.

The Nyquist plots presented in Fig. 9a and 9b depict the effect of surface condition on corrosion reinforcement in the simulated solution without and with chlorides. We can clearly see the negative effect of oxides layers on the corrosion behavior of steel. This effect is expressed by a significant decrease in the impedance value of pre-rusted steel, Table 3.

### TABLE 3. Fitting results of EIS circuit for steel samples with polished and rusted surface.

<table>
<thead>
<tr>
<th>Condition</th>
<th>$R_1$ (ohm.cm²)</th>
<th>$Y_1$ (S.cm²)</th>
<th>$n_1$</th>
<th>$R_2$ (ohm.cm²)</th>
<th>$Y_2$ (S.cm²)</th>
<th>$n_2$</th>
<th>$R_3$ (ohm.cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polished surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>19.41</td>
<td>1.24E-5</td>
<td>0.80</td>
<td>2097</td>
<td>27.3E-5</td>
<td>0.54</td>
<td>3.96E4</td>
</tr>
<tr>
<td>3%</td>
<td>7.85</td>
<td>7.9E-5</td>
<td>0.6</td>
<td>1756</td>
<td>18.4E-5</td>
<td>0.52</td>
<td>1.38E4</td>
</tr>
<tr>
<td>Rusted surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>23.18</td>
<td>1.75E-5</td>
<td>0.44</td>
<td>32.1</td>
<td>6.1E-5</td>
<td>0.49</td>
<td>2.42E4</td>
</tr>
<tr>
<td>3%</td>
<td>340</td>
<td>25.1E-5</td>
<td>0.4</td>
<td>1156</td>
<td>88.4E-5</td>
<td>0.5</td>
<td>2.19E4</td>
</tr>
</tbody>
</table>

Fig. 9. Nyquist plot reflecting g surface conditions effect of steel in chloride-free solution (a) and chlorinated solution (b).
Figure 10 gives the equivalent electrical circuit reproducing the experimental impedance data. This is composed with two RC hierarchically distributed time constants according to the impedance function given in following equations:

\[ Z(\omega) = R_0 + R_d/[\omega R_1 C_1] + 1/(1 + (Z_0(\omega)/R_1)] \]  
Even \[ Z_0(\omega) = R_2 / (1 + (\omega R_2 C_2)^n_2) \]  

Being -
\[ \gamma_1, n_1 \]
\[ \gamma_2, n_2 \]
\[ \gamma, n \]
\[ \gamma_0 \]
\[ \gamma_1, n_1 \]
\[ \gamma_2, n_2 \]
\[ \gamma CPE \]
\[ \gamma W \]
\[ \gamma Y, n \]
\[ \gamma R_0 \]
\[ \gamma R_1 \]
\[ \gamma CPE \]
\[ \gamma R_0 \]
\[ \gamma R_2 \]
\[ \gamma CPE1 \]
\[ \gamma Y_1, n_1 \]
\[ \gamma Y_2, n_2 \]
\[ \gamma R_1 \]
\[ \gamma CPE2 \]
\[ \gamma R_1 \]
\[ \gamma CPE \]
\[ \gamma W \]
\[ \gamma Y, n \]
\[ \gamma R_0 \]
\[ \gamma R_2 \]
\[ \gamma CPE1 \]
\[ \gamma Y_1, n_1 \]
\[ \gamma Y_2, n_2 \]
\[ \gamma R_1 \]
\[ \gamma CPE2 \]

This circuit has been already reported to model the behaviour of steel in alkaline media [35, 36]. The high frequency constant time, \( R_1 C_1 \), is associated to the charge transfer with the solution through the double layer capacitance \( C_1 \). The low frequency constant time, \( R_2 C_2 \), is related to the redox process occurring in the passive film. A detailed description of these parameters can be found in literature [36, 30]. The non-ideality of the surface of the electrode has been considered by the inclusion of constant phase elements (CPE1 and CPE2) [28] instead of pure capacitors. Then, \( n_1 \) and \( n_2 \) account for the distribution of time constants similar to the constant phase element, and the meaning of the parameters of CPE depends on the value of \( n \) (0 \( \leq \) \( n \) \( \leq \) 1). An ideal capacitor corresponds to \( n = 1 \), while \( n = 0.5 \) becomes the CPE in a Warburg component [36]. Intermediate \( n \) value has been related to the non-homogeneities and the roughness of the surface of the electrode [31]. The constant phase elements impedance (\( Z_{CPE} \)) can be defined as follows:

\[ Z_{CPE} = 1/[(\omega)^n] \]  

IV. DISCUSSION

The corresponding anodic polarization curves have that passivity was maintained even when potentials values were several hundreds of millivolts higher than the corrosion potential. In highly alkaline solutions, such as saturated Ca(OH)\(_2\) solution, the passive state of steel is provided by the presence of a thin oxide film that protects the metal from active corrosion. Nagayama and Cohen [37] as well as Kruger and Calvert [38] suggested that the main component of the passive film formed in alkaline solutions were FeO\(_4\) or FeO\(_3\) oxides. Yonezawa and al. [39] found that in saturated Ca(OH)\(_2\) solution a discontinuous layer of Ca(OH)\(_2\) was present on the metal surface.

The addition of chloride ions has a noticeable effect on the corrosion behaviour of carbon steel in high alkaline solution. In fact, chlorides have two effects on the steel corrosion mechanism: (i) they increase the ionic conductibility of the electrolyte, which facilitates the transport of ions, and (ii) they provoke localized breakdown of passive layer. At sites where the passive layer has been destroyed the steel dissolution occurs (anodic sites) while the surfaces that remain passive corresponds to the cathodic sites. Thus, the high ratio cathode/anode promotes the localized and in-depth progress of the corrosion. The mechanism of this corrosion type is very complex, because the composition of the solution within the pit is changed compared to the interstitial solution that surrounds it. In the pitting, the chloride ions react with hydrogen ions from water to form hydrochloric acid. These reactions cause a significant drop in pH (in the range of 3 to 5). The dissolution of iron is accelerated. The regenerated chloride ions continue to be active during the corrosion process, which becomes an autocatalytic process. Hydroxyl ions in the interstitial solution are then combined with the Fe\(^{3+}\) ions that diffuse outside the pitting, while the cathodic reaction is as same as in the case of corrosion in absence of chlorides.

The beneficial effect of alkalinity on chloride induced localized corrosion of carbon steel is accounted for the pitting mechanism developed by Galvele [40-42], in which the maintenance of a local acidification on the metal-solution interface is required as well as the necessary condition for pitting, initiation and propagation. The micrographs presented in Figure 11 show the detrimental effect of Cl\(^-\) ions on the reinforcing steel surface. This effect is manifested by the appearance of more or less developed pitting.

![Micrographs showing the effect of chloride ions on the surface of steel samples](image)

Active corrosion of rusted steel can be explained as follow: the presence of the oxide film (rust) makes the less active surface towards the passivation by the height alkalinity of simulated concrete pore solution, otherwise cause a screen effect against the diffusion of hydroxyl ion (OH\(^-\)). Thus, the polished steel presents a corrosion product forming beneficial barrier called “passive layer”, while the pre-rusted steel is susceptible to localized corrosion upon immersion (presence of cathodic areas (oxydes) and anodic areas (bare metal where local destruction of the oxide layer occurs). These defects (local destruction of the oxide film) are privileged sites for the attacks in depth of the metallic matrix, the cathode surface is much larger than the anode surfaces (local film defects) cause faster development of pitting corrosion evolving to a crevice corrosion form. The reduction of steel section and
therefore, its load capacity can lead to catastrophic failure.

The four main phases constituting the rust layer are goethite (α-FeOOH), lepidocrocite (γ-FeOOH), magnetite (Fe₃O₄) and hematite (Fe₂O₃). Akaganeite (β-FeOOH) can be linked with the presence of chlorides in the environment [31 - 32]. The former is the predominant phase in the composition of unaged rust formed in relatively short exposure times, and is also usually the only reactive compound of the rust. The Akaganeite, once appeared, can play a fundamental role in the corrosion process. It is noted that the polarisation of rust to negative potentials causes the formation of Fe²⁺ states in the oxide lattice which confer the oxide electrical conductivity, which is necessary for the electrochemical process, between the local anodes in the metal and the local cathodes in the surrounding rust, to proceed. In general, the final composition of the reduced rust depends upon a great extent on the pH, polarisation potential and composition of the electrolyte.

The strong tendency of pre-rusted steel to develop active corrosion results in a direct relation between the corrosion rate and the amount of rust initially present on the steel surface. This rust favours corrosion both by providing a reducible material for the cathodic reaction and by acting as a porous electrode for the reduction of oxygen [20].

V. CONCLUSION

The obtained results showed that the presence of rust layer on the reinforcement surface has a negative effect on its corrosion behavior, with or without chlorides. But, its effect is less than the one of chlorides.

The effect of rust on the corrosion behaviour is expressed by a significant narrowing in the passivating plateau, an increase in the corrosion current density and a decrease in polarization resistance. Also, the obtained EIS spectra confirm this negative effect by the fact that the presence of the rust leads to a reduced total impedance of the system. Its presence provokes a decrease of the electrolyte resistance at the metal-concrete interface and reduces the repassivating ability. On the other hand, the rust layer acts as a physical barrier against the diffusion of ions hydroxyl, which prevents the re-alkalinization phenomenon.

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