Corrosion Behavior of Stainless Steel Rebars Embedded in Concrete by EIS

R. G. Duarte[a,b], A. S. Castela[a,b], Rui Neves[b], L. Freire [a,c], M. F. Montemor[a]

[a]*ICEMS, Instituto Superior Técnico, Technical University of Lisbon, 1049-001, Lisboa, Portugal*
[b]*Instituto Politécnico de Setubal, ESTBarreiro, 2389-001 Barreiro, Portugal*
[c] *ENCOMAT, Universidade de Vigo, E.E.I., Campus Universitario, 36310 Vigo, Spain*
raquel.duarte@estbarreiro.ips.pt

Introduction

Reinforced concrete is the most economic, versatile and successful construction material. It presents long lifetime and generally performs well. However, corrosion of reinforcing steel, may dramatically affect the performance of the structure, causing economic and safety problems. When carbon steel is embedded in concrete it becomes passive due to the formation of a very protective oxide layer (about 10 nm thick). This layer is very stable in the alkaline pH ranges typical of the concrete pores (pH around 12.5). However, the presence of aggressive species that contaminate concrete, like chloride ions and carbon dioxide may cause corrosion problems. Chlorides induce localized pitting corrosion of the steel and carbonation induces a uniform depassivation of the rebars and thus, uniform corrosion.
In order to mitigate the corrosion induced damages of reinforced concrete structures, several solutions have been proposed. Among these, the use of stainless steel (SS) rebars appears as an interesting solution due to the attractive benefit/cost ratio in specific applications[1]. It has been reported [2] as expected, that stainless steel presents higher corrosion resistance than normal carbon steel. However, detailed quantification of the corrosion processes and the gain relatively to carbon steel is not available. The performance of different rebars was also investigated and stainless steel rebars showed the best performance [3]. Recently austeno-ferritic (duplex) stainless steels have been also studied [4, 5]. In these studies, it was demonstrated that the duplex SS corrosion resistance in alkaline simulated concrete pore solutions is higher, depending on the composition of the studied duplex stainless steel.
In this study, electrochemical austenitic (AISI 304 and AISI 316) and duplex (SAF 2205 and SAF 2304) stainless steels, when embedded in concrete specimens was studies by Electrical Impedance Spectroscopy (EIS). Concrete specimens were exposed to chloride containing sources (NaCl saturated solution) simulating the aggressive conditions of the sweater environments.

Experimental

Prismatic concrete specimens with 4 steel rebars embedded in symmetric position were prepared using poor quality concrete (w/c = 0.6). Since the corrosion processes are very slow it is necessary to prepare low quality concrete to accelerate the corrosion onset.
These concrete specimens were exposed to chloride containing sources, like NaCl solutions, simulating the aggressive conditions of the seawater environments. Samples were fully immersed and submitted to periodic immersion/emersion cycles.
Monthly, electrochemical measurements as EIS and OCP monitoring were being performed. Samples with only carbon steel will allow us to compare the corrosion rates between the different materials.
EIS measurements were performed in situ at the open circuit potential (OCP) using a Gamry 600 potentiostat. All EIS tests were carried out applying a r.m.s. voltage of 10 mV in a frequency range from 100 kHz down 5 mHz, registering 7.13 points per decade.
A two electrodes arrangement electrochemical cell was used using as reference+counter-electrode a graphite bar and as working electrode the steel rebar

Results and Discussion

The potential evolution for the carbon steel and the different SS embedded in concrete are presented in figure 1.

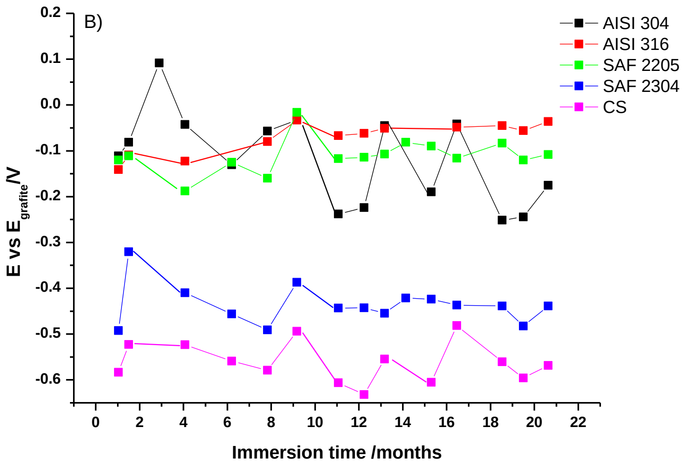

Figure 1. OCP variations for the different rebars embedded in the concrete specimens.

In spite of the dispersion in the readings, some trends can be observed. The readings for austenitic (AISI 304, AISI 316) and duplex SAF 2205 stainless steels were in the range of -250 to -150 mV corresponding to a state of passivity, according to the Pourbaix diagram. However, a potential decay with more negative values was observed for duplex stainless steel SAF 2304 and for the carbon steel. Those readings were close to -600 mV and are stable in both cases, indicating an active corrosion process.

Impedance spectra obtained for the different steels after 12 and 20 months of immersion.

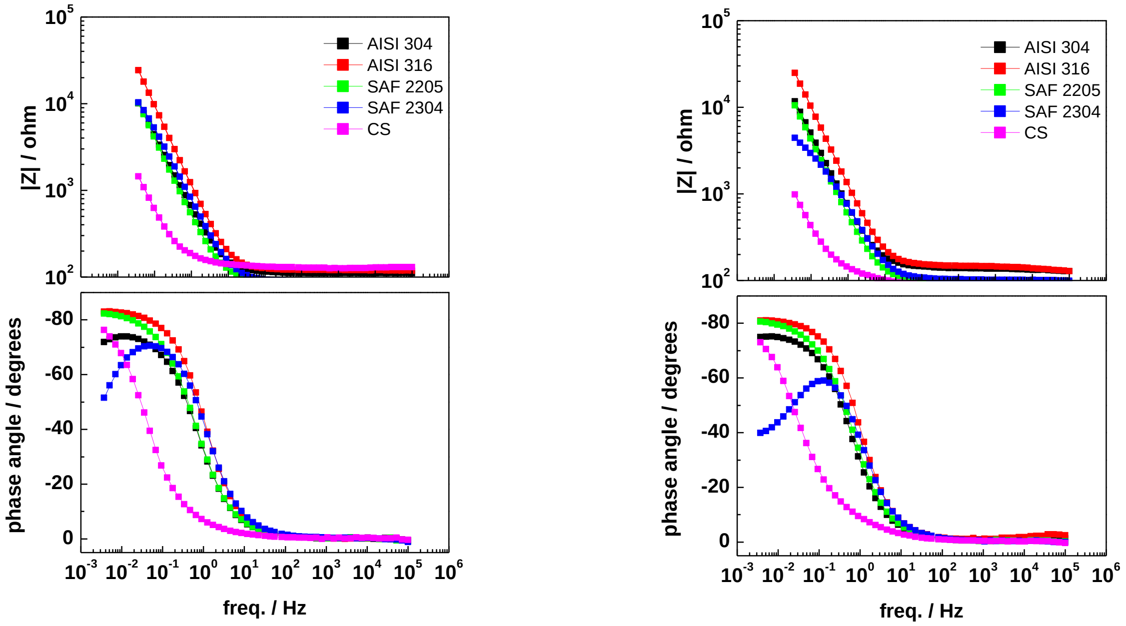

Figure 2 EIS spectra obtained NaCl saturated solution for 12 (left) and 20 (right) months of immersion

As it can be observed in Figure 2, the lowest corrosion resistance was observed in the carbon steel rebars, as expected. In the case of SS reinforcements, AISI 316 is definitely more resistive than the others. This fact is more evident when the $|Z|_{f\to 0Hz}$ is plotted (Figures 3)

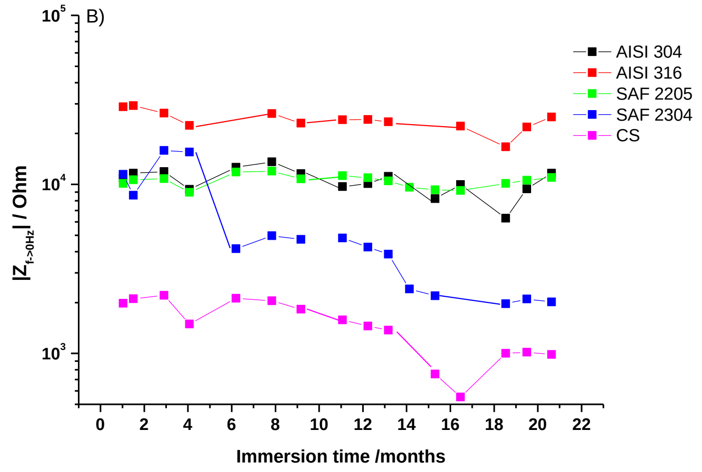

Figure 3. $|Z|_{f\to 0}$ variations for the different rebars embedded in the concrete specimens.

The fittings and interpretation of the periodic OCP and EIS measurements suggests an increase of more than one order of magnitude in the corrosion resistance of the duplex steels and AISI 316 comparatively to carbon steel rebars.

Conclusions

The tests performed with the concrete specimens, the evolution of the potential and impedance parameters with time indicates that the best corrosion resistance is presented by AISI 316 rebar, improving meaningfully the results obtained for carbon steels reinforcements.

Acknowledgements

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