

## Analysis of the Repassivation of Corroded Bars in Cementitious Materials Subjected to Realkalisation

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**Abstract.** *The effect of concrete realkalinisation on reinforcement repassivation was evaluated by means of electrochemical measurements considering different previous corrosion degrees of reinforcements and different environmental conditions. Reinforcements obtained from a real concrete structure which were activated due to concrete carbonation were used for this purpose. Five different corrosion degrees were considered. All these reinforcements after being classified, were embedded in fresh mortar specimens and were cured in wet chamber for 7 days. After that, they were sequentially subjected to two different environmental conditions; laboratory environment (65% of relative humidity) and 80 % of relative humidity environment. Along all the testing period, reinforcements were monitored on corrosion potential and instantaneous corrosion current density by linear polarisation measurements. Results show that as the previous corrosion degree increases it becomes harder to reach the repassivation condition for reinforcements. This shows that the effectiveness of concrete realkalisation on reinforcement repassivation depends on the previous corrosion degree of reinforcements. The influence of the relative humidity was not significant under the experimental conditions adopted in this work.*

**Keywords:** *Corrosion degree; Realkalisation; Reinforcement repassivation.*

### 1 Introduction

When the reinforcement is embedded in concrete it provides a double protection: a physical one as a consequence of the cover depth thorough which aggressive agents need to be transported and reach reinforcement level for starting corrosion; and the chemical one provided by the high alkalinity of cement paste. This alkaline media makes possible the passive film formation throughout a short and intense corrosion process and also enables the stabilization of this film protecting the reinforcement from further corrosion (Gouda 1970, Andrade 1988).

When aggressive agents reach the reinforcement level and change its surrounding environment due to the presence of chlorides over a threshold value or concrete carbonation, the passive film has a high probability of being broken and corrosion process to start (Tuuti 1982, Bertolini *et al.* 1994). As a result, the propagation phase of corrosion takes place.

The realkalisation treatment was proposed aiming to recover the concrete alkalinity levels before its carbonation and thus reestablishing the conditions to a possible reinforcement repassivation. In this context, there is the possibility of this method to be used as a preventive or as a rehabilitation method, depending on the moment in which it is applied (Aguirre *et al.* 2016, Reus and Medeiros 2020). This kind of treatment has the advantage of being a non-destructive method, that is applied for a short period (Ribeiro *et al.* 2013)

The realkalisation procedure can be classified in electrochemical realkalisation (Andrade *et*

*al.* 2022) and chemical or passive realkalisation (Mattila and Pentti 1996, Reus and Medeiros 2020). The first one consists in applying an electric field between the structure's reinforcement and an external anode in the presence of an alkaline solution, which enables the high concrete alkalinity to be recovered in the reinforcement concrete cover region. The second one is based on ions transport from an external alkaline source into concrete or a replacement of the carbonated material by a fresh one (Reus and Medeiros 2020, Carvalho *et al.* 2022)

Regarding reinforcement repassivation, some authors consider that repassivation condition of reinforcement, after realkalisation treatment, is only reached when its previous corrosion degree is low (Bastidas *et al.* 2008, Carvalho *et al.* 2022). However, other authors consider that repassivation condition would be reached independently of the previous corrosion degree (Andrade *et al.* 1999, Redaelli *et al.* 2014).

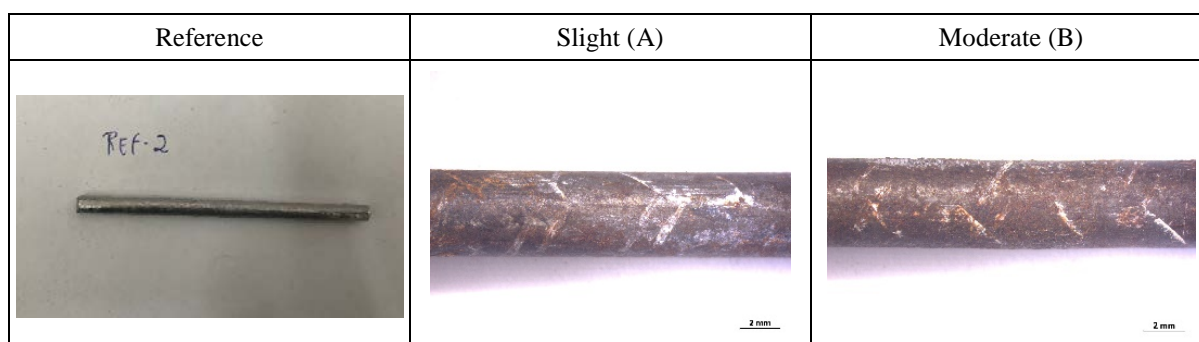
As a consequence, this work takes into account this gap in knowledge and evaluates the efficiency of the passive realkalisation treatment on reinforcement repassivation considering different previous reinforcement corrosion degrees, which were directly obtained from an existing reinforced concrete structure that was under corrosion process due to the concrete carbonation.

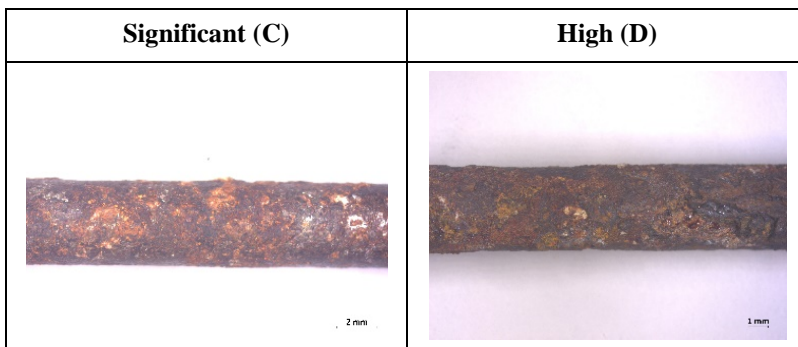
## 2 Experimental Work

### 2.1 Obtaining corroded reinforcements

The corroded reinforcements used in this work were directly obtained from an existing 20-year old reinforced concrete slab that was partially demolished and had a significant depth of carbonation front, that significantly surpassed the reinforcement concrete cover depth in more than 80% of the inspected points, which indicated that reinforcement corrosion had been started several years before.

These bars, which were 4.2 mm in diameter, were carefully removed from the concrete structure and then were classified considering the superficial corrosion state condition. As a consequence, the reinforcements were grouped in five different corrosion degrees (CD) and one of them was represented by the bars that were still passive (reference). The other four groups were classified as: slight (A), moderate (B), significant (C) and high (D), which represent an increasing corrosion condition. Figure 1 exemplifies these previous four superficial corrosion state conditions.





**Figure 1.** Previous corrosion conditions of reinforcements.

After being classified, the reinforcements were cut into 10 cm samples length. Three bars representing each corrosion surface condition were used for the experimental tests.

## 2.2 Preparing the reinforcements and realkalisation media

The bars had their extremities mechanically cleaned delimiting an exposure length of 4 cm. Then, the cleaned area was protected by an insulating tape and afterwards, they were embedded in a fresh cementitious matrix, which represented the realkalised media. The reference bar was entirely mechanically brushed to obtain a clean surface as shown in Figure 1.

A mortar made with a Brazilian high-early strength cement was used (European CEM-I). The mass-based mixture adopted was 1:2:0.5 (cement: sand: water). The fine aggregate was a quartz river sand with a maximum size of 4.8 mm. Then, mortars prisms with the dimensions 2.5 x 2.5 x 8 cm were cast with a centered bar, leaving one centimetre projection of the bar out of the specimen, as can be seen in Figure 2.



**Figure 2.** Specimens used in the present work.

## 2.3 Exposure conditions and electrochemical monitoring

After being demolded, the specimens were cured for seven days in wet chamber and then remained in laboratory environment for 150 days. After that, they were subjected to an environment with 80% of relative humidity.

Along this period, electrochemical measurements were performed by using a Palm Sens potentiostat with ohmic drop compensation. Open circuit corrosion potential ( $E_{corr}$ ) and instantaneous corrosion current density ( $i_{corr}$ ) were the electrochemical parameters monitored. This last one was obtained by the linear polarization technique. An Ag-AgCl reference electrode and a counter electrode of stainless steel were used to take the LPR measurements (Figure 3) with a scan rate of 0,167 mV/s.

**Figure 3.** Specimens used in the present work.

### **3 Results and discussion**

#### **3.1 Electrochemical response of reinforcements**

Electrochemical monitoring of reinforcements is presented throughout Figures 4 and 5, where average results of corrosion potential ( $E_{corr}$ ) and corrosion current density ( $i_{corr}$ ) are depicted along time, considering the short curing period, the period in laboratory environment (RH=65%) and the period under controlled relative humidity of 80%.

Regarding  $E_{corr}$  results, it is not possible to see significant differences among the distinct corrosion degrees. Bars with any level of previous corrosion presented corrosion potentials roughly ranging between 0 and -100 mV (Ag-AgCl) and the reference ones remained between -100 and -150 mV (Ag-AgCl).

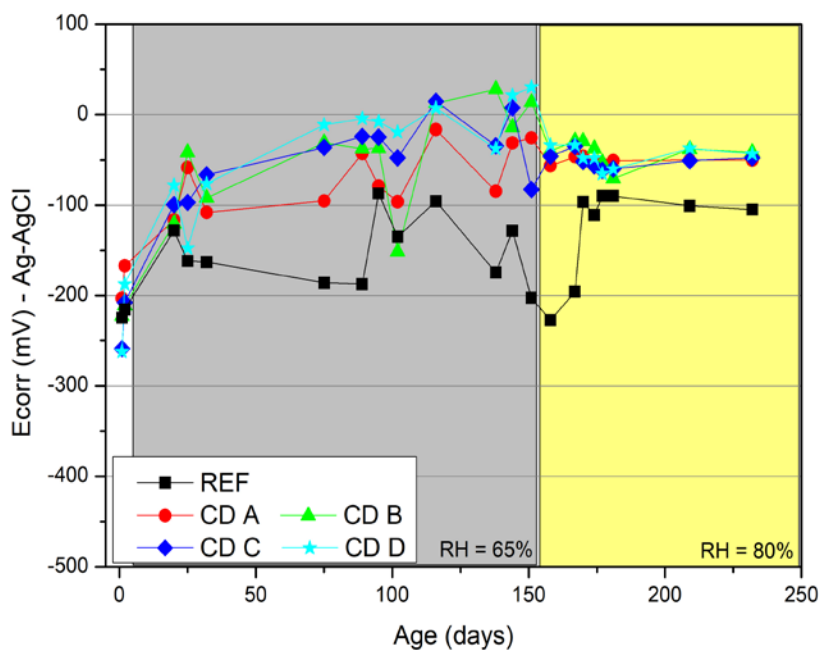


Figure 4.  $E_{corr}$  results monitored along time.

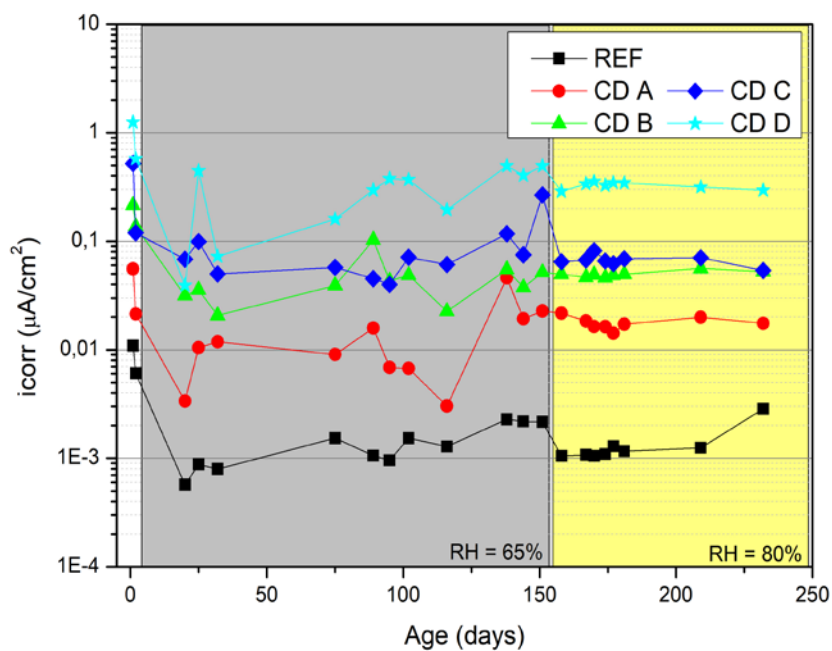


Figure 5.  $i_{corr}$  results monitored along time.

Regarding  $i_{corr}$  results, it is possible to see that there is an increase tendency of  $i_{corr}$  values as the previous corrosion degree increases and that the bars with the highest previous corrosion degree did not reach the passive condition, remained at a level of about  $0,4 \mu\text{A}/\text{cm}^2$ . This means that, depending on the previous surface condition of the reinforcement the passive condition is not reached and that the reinforcement can follow under significant corrosion rates.

In the present work it was not possible to measure the previous corrosion rates of these bars when they were still embedded in concrete structure. However, previous studies carried out by the authors (Ribeiro *et al.*, 2013) show that the corrosion rates significantly decreases even not reaching the passive condition, which means that the realkalisation treatment positively impacts on corrosion rates reaching the passive condition for those reinforcements with lower previous corrosion degrees and reducing the corrosion rates for those ones with higher previous corrosion degrees (Carvalho *et al.*, 2020). In both cases, there is an increase in the service life of the structures.

### 3.2 Influence of relative humidity of the environment

Regarding the relative humidity of the environment after realkalisation, results of  $E_{corr}$  and  $i_{corr}$  do not show clear evidence of significative changes on electrochemical parameters when changing relative humidity from 65% to 80%. It means that, in the present work, the increase of water content in mortar porous network was not enough to change the reinforcement behaviour.

## 4 Conclusions

- The previous surface corrosion condition of reinforcements can significantly affect its performance respect to corrosion after being embedded in a fresh cementitious material. This means that corroded reinforcements due to carbonation of cementitious matrix can reach the passive condition only when the corrosion degree reached before the realkalisation treatment is not so intense.
- Furthermore, there is a gradual increase tendency of  $i_{corr}$  values after the treatment when the previous surface corrosion condition also gradually changes from a less corroded surface to a more corroded one.
- Considering the experimental conditions adopted in this work, it was not possible to observe a significative influence of the change of the relative humidity on the electrochemical parameters.

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