

Corrosion behaviour of new stainless steels reinforcing bars embedded in concrete

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Abstract

The activities concerned with the evaluation, repair and restoration of structures are estimated to amount to 35% of the total volume of the work in the building sector and this continues to increase. The corrosion of rebars in the reinforced concrete structures (RCS) is the main reason for their degradation, so the use of reinforcing stainless steels seems to be one of the possible solutions with most probabilities of solving this problem. In this work, in order to demonstrate the advantages of using reinforcing stainless steels, the corrosion behaviour of AISI 304 and 316 reinforcements embedded in concrete slabs (C35/45 and C60/70 concrete) with two chloride contents are compared with three low-cost and low-Ni austenoferritic stainless steels and with the conventional carbon steel. The lower chloride contamination selected in this research, was enough to cause the corrosion in the active state of the carbon steel reinforcements, whereas the highest one exceeded the expected contamination in the natural environments, including sea media. The metallic materials remaining in the passive state can be considered, from the point of view of corrosion resistance, adequate as reinforcements in the RCS.

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1. Introduction

For more than a century, it has been known that steel embedded in concrete is in the passive state, due to the high basicity of this medium. Thus, the steel is not subject to corrosion and possesses almost unlimited durability. However, in some circumstances, such as carbonation of the concrete favoured by inappropriate dosing or the presence of chloride levels in excess of a critical concentration, this passivity is destroyed and the durability of reinforced concrete structures (RCS) may be drastically limited.

When the corrosion in the active state of RCS is established, the structures need to be repaired, renewed or replaced within a

short period of years. This is extremely expensive, as can be seen for instance in the estimated 1.200 € million annual cost of RCS corrosion in Spain [1]; the 50 € million that are spent each year just on bridge repairs in Great Britain [2]; or the fact that 44% of the more than 500.000 road bridges in the USA are considered to be structurally deficient and to require some kind of repair [3–5].

A wide variety of protection methods have been used to prevent RCS corrosion in highly aggressive environments, such as rebar galvanising, rebar coating with epoxy paints, the incorporation of inhibitors during concrete mixing, and the waterproofing or impermeabilising of the concrete. However, all of these techniques are subject to certain limitations which justify the search for more efficient solutions [6].

Cathodic protection, which can halt RCS corrosion whatever the chloride contamination [7–10], or replacement of the usual

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Table 1
Chemical composition (weight percentage) of carbon steel and stainless steels tested

	AISI 304	AISI 316	HSS1	HSS2	Carbon steel
C	0.06	0.03	0.06	0.04	0.25
Mn	1.14	1.64	8.0	8.5	0.69
Si	0.35	0.36	0.2	0.2	0.2
P	0.02	0.02	0.02	0.01	0.012
S	0.01	≤0.01	0.002	0.001	0.05
Cr	17.4	16.7	16.3	16.5	0.21
Ni	8.3	10.4	0.22	1.5	0.22
Mo	0.12	1.9	–	2.0	0.05
Cu	0.4	0.6	2.0	0.25	0.43
N	–	–	0.23	0.25	0.012
Fe	Balance	Balance	Balance	Balance	Balance

carbon steel rebars with stainless steel rebars in structural elements with the highest risk of corrosion, both seem to provide satisfactory solutions [2,6,11,12]. In this research the aspects related to the use of reinforcing stainless steels in the prevention of the corrosion in the RCS will be analysed.

The decision to use stainless steel rebars depends on the aggressiveness of the environment and the desired degree of corrosion protection, as well as on the fulfillment of minimum demands regarding mechanical properties and weldability, the increase in construction costs, and the expected prolongation of the RCS service life [6].

Austenitic and austeno-ferritic (duplex) stainless steels seem to offer an acceptable combination of corrosion resistance and mechanical properties, together with suitable cost and availability to prevent the corrosion of RCS in aggressive environments [4].

The corrosion resistance of various types of steel in mortar with different chloride concentrations, assessed by determining the pitting corrosion potential, is greatest in austenitic and duplex stainless steels, and gradually decreases in ferritic steels with a Cr content $\geq 11\%$ mass, ferritic steels with Cr contents $\leq 7\%$, and unalloyed steel [13]. Other authors report that the critical chloride concentration is at least 10 times higher in austenitic steels than in carbon steel, finding a marginal improvement in Cr–Ni–Mo steels compared with Cr–Ni steels [14]. But without doubt the best evidence in favour of stainless steel rebars is offered by Progreso Pier in Yucatan (Mexico), with a length of 2100 m, built between 1937 and 1941 with AISI 304 steel rebars, which after more than 60 years shows no serious signs of corrosion [15].

While the yield strength of rolled stainless steel rebars may be insufficient, suitable cold or warm working allows them to reach high yield strengths [6,16]. So, stainless steels combine very good corrosion resistance with excellent mechanical properties (strength and toughness), especially in the case of LN grades, characterised by a very low carbon content to improve weldability and prevent intergranular corrosion and N additions in order to increase mechanical strength [16].

With slight fluctuations, depending essentially on their Ni and Mo contents, the price of stainless steel rebars is 4–9 times higher than that of carbon steel rebars [2,6,16], and this is the main reason restricting their use. However, stainless steel rebars

represent an increase of only 10% of the total project cost, and it is estimated that cumulative maintenance costs may be cut by 50% during a service life which, with their use, may last up to 120 years in bridges in coastal areas [4]. That is, the selection of stainless steel rebars is advantageous, if the calculation of costs takes into account the entire RCS life cycle.

The present work compares the corrosion behaviour of reinforcing carbon steel with AISI 304 and AISI 316L stainless steels and with two innovative stainless steels, HSS1 and HSS2, in which a considerable part of the Ni has been replaced with Mn in order to lower their cost, in two types of concrete with different chloride additions.

2. Materials and methods

The composition of the 5 steels tested is detailed in Table 1. All the metallic materials were tested, embedded in two types of concrete: a normal strength concrete (C35/45) and a high performance concrete (C60/70).

Three $60 \times 60 \times 10$ cm slabs of each type of concrete, C35/45 and C60/70, were manufactured with Cl^- ion additions of 0%, 2% and 4% with respect to cement weight. Five bars of 12 mm in diameter, one of each steel, were embedded in each of the slabs, with a separation of 10 cm between bars (Fig. 1). In order to prevent localised corrosion at the triple concrete/steel/atmosphere interface, 5 cm of the bars were protected with epoxy paint at the point where they emerged into the atmosphere.

The two slabs without chlorides were partially submerged in a 3.5% NaCl solution 2 months after their manufacture in order to check whether the penetration of chlorides by diffusion caused destruction of the passivating layers.

The slabs with chloride additions were kept constantly wetted using pads soaked in water. The pads were wetted twice a week and were covered with an impermeable plastic sheet in order to prevent the water evaporating. The detailed experimental scheme is described in Ref. [17].

In addition, small cement mortar specimens of $2 \times 5.5 \times 8$ cm were also manufactured, with a cement/sand/water ratio of 1/3/0.5 and Cl^- additions of 2% and 5% with respect to the cement weight. The same 5 types of steels as in slabs were embedded in mortar specimens after machining the rebar to achieve cylinders

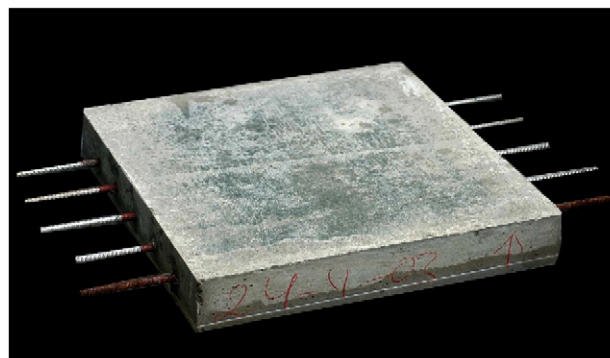


Fig. 1. Example of slab with the five types of reinforcing steels tested.

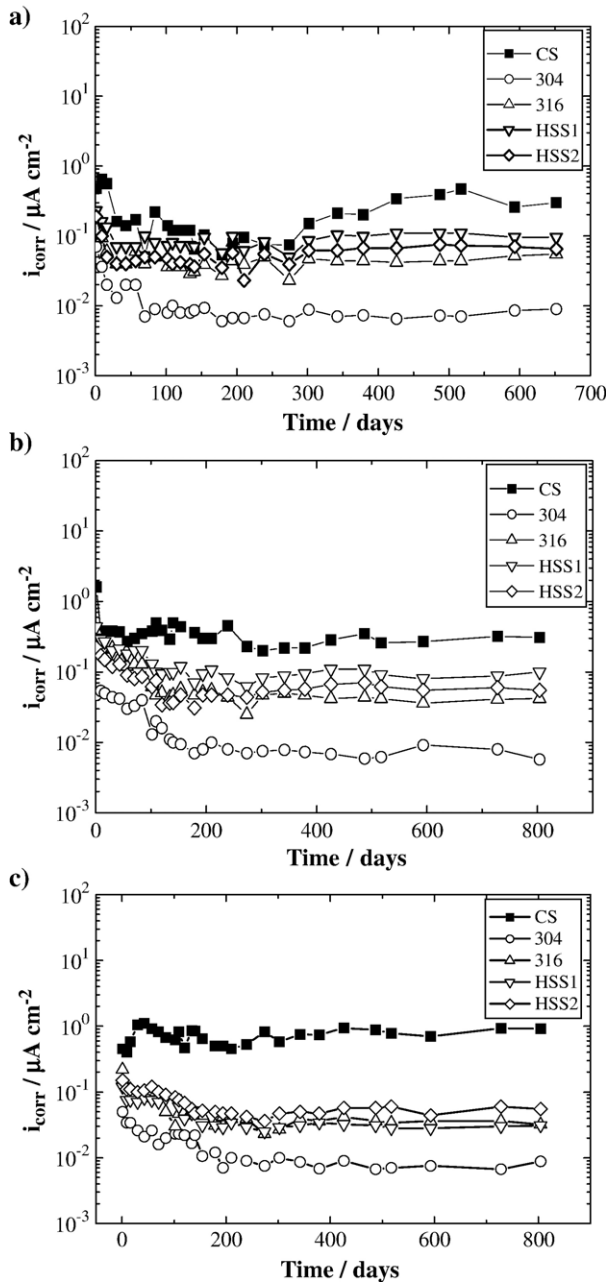


Fig. 2. Evolution of i_{corr} values over time of the 5 types of steels embedded in C35/45 concrete slabs: a) without chloride; b) with 2% Cl^- ; c) with 4% Cl^- .

of 8 mm diameter. These specimens were successively exposed in a very humid atmosphere ($RH \approx 95\%$), in the dry laboratory environment ($RH \approx 40\%$), and again in the very humid environment. With this humidity cycle it was intended to discover whether the ennobling of the E_{corr} when the mortar dries could reach the breakdown potential of the passivating layers, thus facilitating corrosion when returned to the humid environment. Some results for these types of specimens will be presented in this paper for comparative purposes which have been taken from a more detailed work [18].

For the electrochemical measurements a saturated calomel electrode was placed in a hole in the centre of a stainless steel cylinder in order to assure its stability, on the surface of the

slabs. One of the rebars acted as the working electrode and the two adjacent rebars as the counter electrode, in such a way as to achieve a uniform distribution of the electrical signal across the entire surface of the working electrode. The characterisation was performed by periodic evaluation of the corrosion potential, E_{corr} , in relation to the saturated calomel electrode, and the corrosion rate, estimated as the corrosion current density, i_{corr} , obtained from the determination of the polarization resistance, R_p . The polarization resistance was calculated from the relation between the potential applied, 20 mV, and the current response. The corrosion current calculations were performed from the

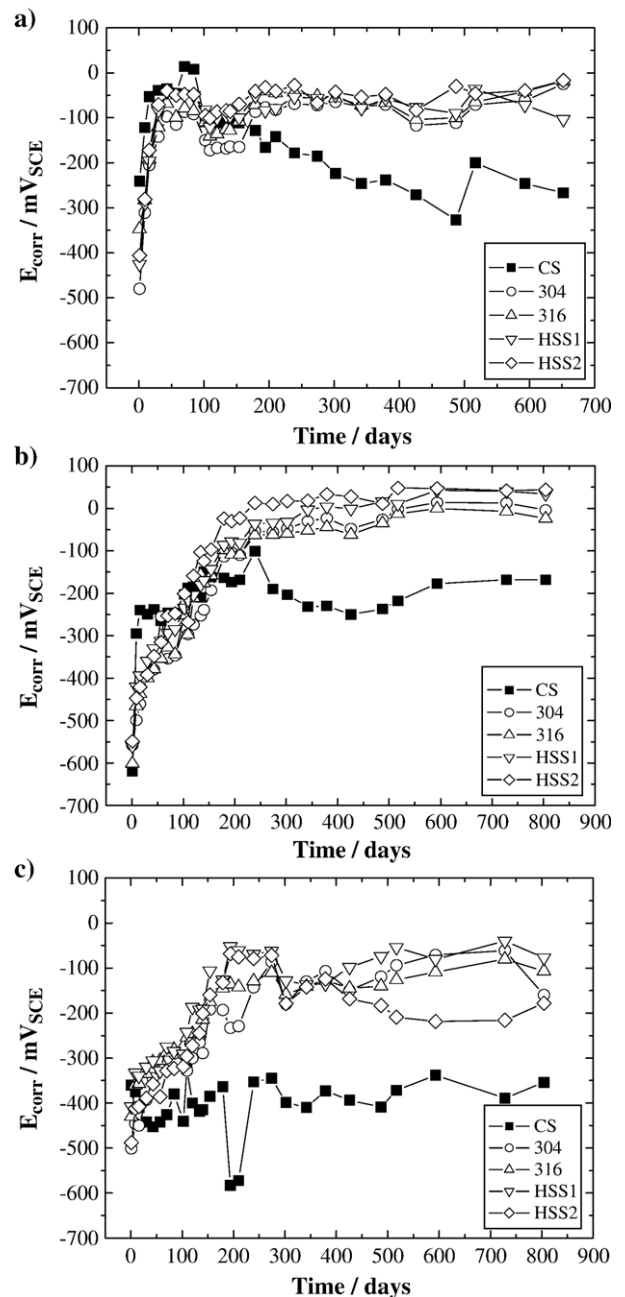


Fig. 3. Evolution of corrosion potential, E_{corr} , over time of the 5 types of steels embedded in C35/45 concrete slabs: a) without chloride; b) with 2% Cl^- ; c) with 4% Cl^- .

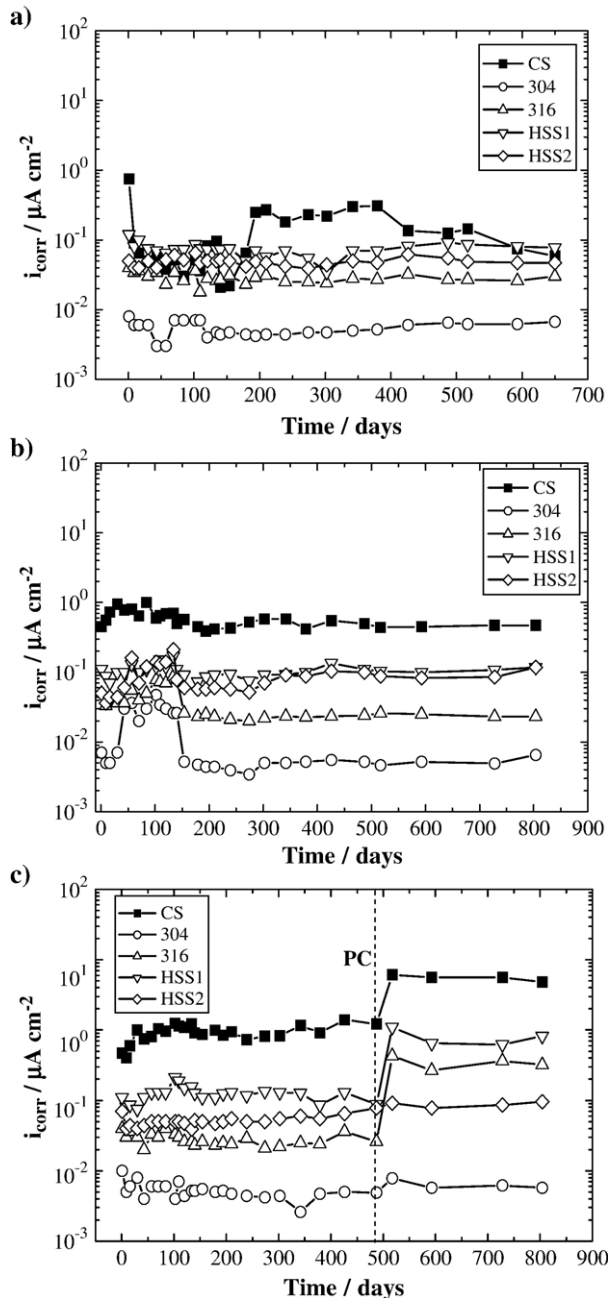


Fig. 4. Evolution of i_{corr} values over time of the 5 types of steels embedded in C60/70 concrete slabs: a) without chloride; b) with 2% Cl^- ; c) with 4% Cl^- .

Stern and Geary equation [19] assuming a B of 0.026 V for all the samples studied. The anodic polarization curves were drawn in the reinforcing steels of the slab elaborated with C60/70 concrete and the maximum chloride concentration, 4%. The polarization curves were carried out at the end of the two-year testing period, in order to avoid affecting the electrodes with the large potentials that need to be applied, which could foreseeably exceed the breakdown potentials of the passive layers. The potential scanning rate was 0.6 V/h applied from the corrosion potential to the breakdown potential and at which point the sense of the scan was reversed until the corrosion potential was reached again.

3. Experimental results

Fig. 2a, b and c show the evolution of the i_{corr} values of the five steels over time in C35/45 concrete, for slabs with 0%, 2% and 4% Cl^- , respectively. As can be seen, in the absence of chlorides, all the steels exhibit i_{corr} values of the order of $0.1 \mu\text{A}/\text{cm}^2$ or slightly lower, except for AISI 304, which stabilises after the first 3 months at corrosion current densities of slightly lower than $0.01 \mu\text{A}/\text{cm}^2$. After 300 days the i_{corr} value of carbon steel (CS in Fig. 2a) tends to increase, moderately but progressively, perhaps as a consequence of the diffusion of chlorides that reach the rebar surface (note that after 2 months the slab was transferred from the atmosphere to partial immersion in a 3.5% NaCl solution). In the slab with 2% Cl^- (Fig. 2b), the i_{corr} value of CS is 3–5 times higher than that of HSS1, HSS2 and AISI 316 steels, and decreases very slightly in this order, with i_{corr} values of $0.1 \mu\text{A}/\text{cm}^2$ or slightly lower. However, in the slab with 4% Cl^- (Fig. 2c), the CS is attacked at least 10 times more than the stainless steels. The AISI 304 steel shows a special response with i_{corr} values of $0.01 \mu\text{A}/\text{cm}^2$, almost one order of magnitude lower than the other stainless steels. The evolution of corrosion potential over time for these type of steels in C35/45 concrete slabs is shown in Fig. 3a, b and c. The difference of 200 mV in corrosion potential between the carbon steel and the stainless steels is remarkable, indicating the active state in some points of the surface of carbon steel.

Fig. 4a, b and c contain the same information as Fig. 2a, b and c, respectively, for C60/70 concrete slabs. The point PC in Fig. 4c refers to the day in which the polarization curves were drawn for each reinforcing steel (at around 500 days of testing). In the slab without Cl^- , the i_{corr} values of CS are similar to that of HSS1, HSS2 and AISI 316 steels until after around 200 days, when its value becomes 2–3 times higher (Fig. 4a). This response is due to local breakages in the passivating layer produced by the access of chlorides to the rebar surface, as could be appreciated in the carbon steel reinforcing at the end of the test (Fig. 5). In the slabs with 2% and 4% Cl^- (Fig. 4b and c), the CS corrodes at an approximately 10 times higher rate than AISI 316, HSS1 and HSS2 stainless steels. The AISI 304 stainless steel, as in the case of the C35/45 concrete, shows



Fig. 5. Corrosion of carbon steel embedded in C35/45 concrete slabs without chlorides and partially immersed in 3.5% NaCl solution at the end of the tests.

special behaviour with an i_{corr} of $\leq 0.01 \mu A/cm^2$, around 2 orders of magnitude lower than the CS, irrespective of the chloride content. The HSS1 stainless steel shows slightly higher i_{corr} values than the HSS2 stainless steel, and the latter slightly higher than AISI 316 steel, being between 0.1 and 0.03–0.05 $\mu A/cm^2$, irrespective of whether the slab is without chlorides or with 2% or 4% Cl^- .

Fig. 6a and b, which show the i_{corr} values after 1 month and 1 year in the C35/45 and C60/70 concrete slabs, offer a good summary of the behaviour of the different types of steel. In the absence of chlorides, the i_{corr} values of CS and stainless steels are practically the same, but the i_{corr} values of AISI 304 stainless steel is around 10 times lower. In the slabs with 2% or 4% Cl^- , the corrosion rates are some 10 times higher for CS than for HSS1, HSS2 and AISI 316 stainless steels and some 100 times higher than AISI 304 stainless steels. Both kind of concrete (C35/45 and C60/70) exhibit a high passivating capability for the stainless steels, even in the presence of high chloride contents. The differences in i_{corr} values between both types of concrete are so small that it can be attributed to a normal dispersion of the results.

The anodic polarization curves obtained for the carbon steel in concrete are significantly different, depending on the absence

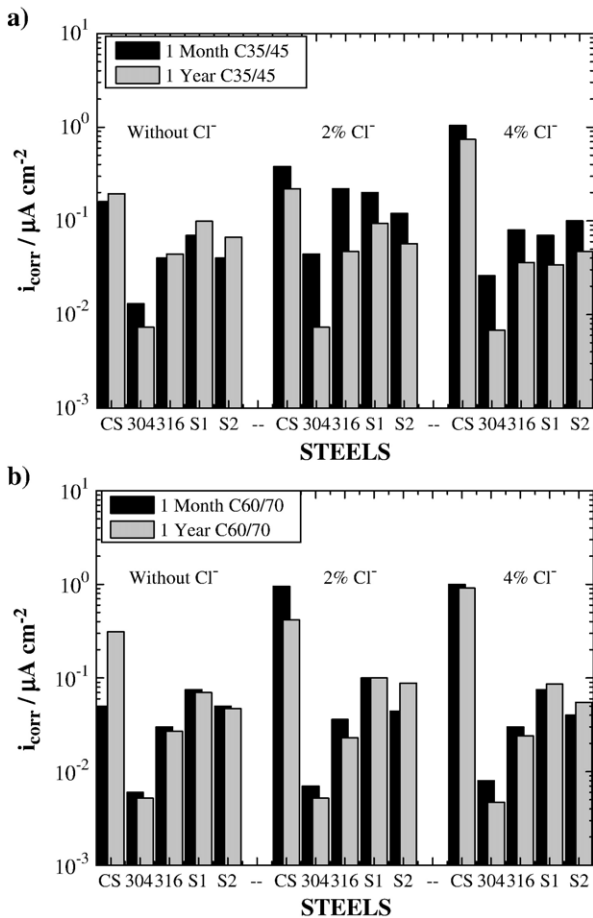


Fig. 6. Comparison of i_{corr} values of the five types of steels, after 1 month and 1 year of exposure in a) C35/45 concrete slabs and b) C60/70 concrete slabs at different Cl^- concentrations.

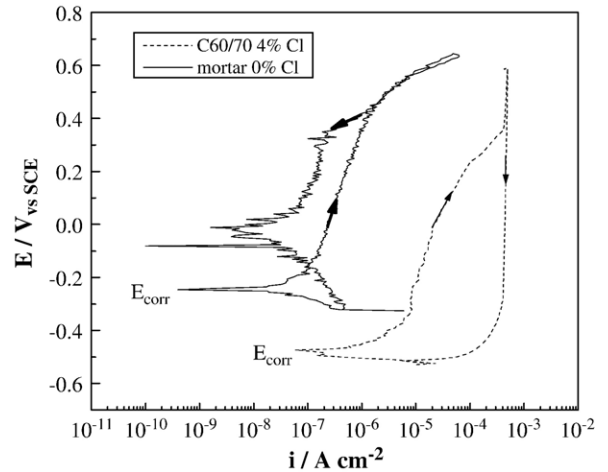


Fig. 7. Anodic polarization curves of carbon steel in mortar without chlorides and in C60/70 concrete slab with 4% Cl^- .

or presence of chloride ions in the concrete. As can be seen in Fig. 7, in the absence of chlorides, the current density increases slowly in a wide range of potentials, typical behaviour of the passive state, until polarizations of about 500 mV are achieved, where oxygen evolution is produced. At this point, a progressive increase of the current density is observed and the return curve is drawn at lower current density than those drawn in the previous anodic sense. In carbon steel embedded in C60/70 concrete slab with 4% Cl^- (Fig. 7), a continuous increase of the current density is observed, characteristic of the active state, finishing when the fixed limit value of current, established previously in the set up of the test, is achieved. The return curve is drawn at higher current density, which is typical behaviour of reinforcements in the active state.

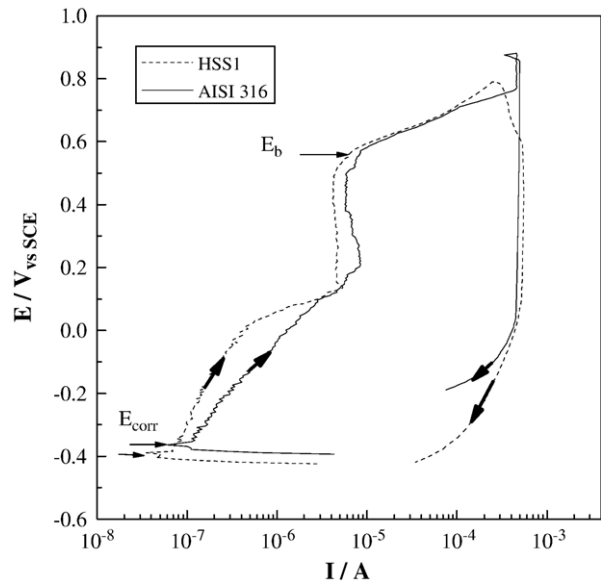


Fig. 8. Anodic polarization curves of AISI 316 and HSS1 stainless steels in C60/70 concrete slab with 4% Cl^- .

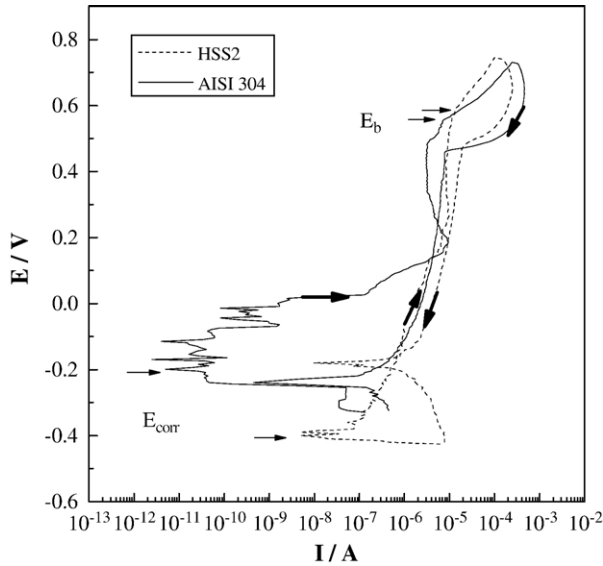


Fig. 9. Anodic polarization curves of AISI 304 and HSS2 stainless steels in C60/70 concrete slab with 4% Cl^- .

In the case of stainless steels, the anodic polarization curves for C60/70 concrete with an addition of 4% Cl^- ions, show two types of behaviour:

- In reinforcing AISI 316 and HSS1 innovative stainless steels (Fig. 8), the anodic polarization curves begin from the corrosion potential with a gradual increase of the current density that is maintained for several hundreds of mV until achieving the passive plateau. This situation continues until the breakdown potential (E_b) is achieved, at which the current suddenly increases. The breakdown potentials of these curves practically fit with the beginning of oxygen evolution but the drawing of the return curve with intensity values of two orders of magnitude above those obtained in the passive plateau indicates that the breakdown of the passivating layers is produced on the electrodes.
- In the case of AISI 304 and HSS2 innovative stainless steels (Fig. 9), the first two stretches of the curves are very similar, sometimes showing sudden fluctuations that can be due to the formation of micropits and repassivation in the films. The passive plateau moves to a progressive increase of the current density after potentials higher than 500 mV, as in the case of AISI 316 and HSS1 innovative stainless steels, but in this case the return curve shows current values that decrease quickly. This behaviour indicates that if the local breakdown of the film is produced, the pits do not evolve and the surface is again protected by a passivating film, in contrast to the behaviours of AISI 316 and HSS1 innovative stainless steels (Fig. 8).

4. Discussion

Many civil engineers are unjustifiably reluctant to use stainless steel reinforcements in RCS, basically because the same level of detailed knowledge of their mechanical and corrosion resistance characteristics is not available as there

exists with carbon steel reinforcements after more than a century of experience; or simply due to their much higher cost. In the introduction it has been clearly shown that adequate cold or warm working raises their mechanical strength to high enough levels [4,6,16]; that the stability of their passive state greatly outweighs those of carbon steel reinforcements in highly corrosive environments [2,4,6,13,15]; and that in such environments the greater initial cost of stainless steel nevertheless leads to significantly lower expenditure if all the life cycle of the structures is considered [2,4]. Naturally, the partial or total replacement of carbon steels reinforcements is not justified when the concrete is of sufficient quality to eliminate the risk of carbonation, or when the chloride contamination of the environment is sufficiently low to rule out the risk of reaching the critical depassivation levels.

Nevertheless, sometimes there continues to be an unfounded fear of the use of carbon steel and stainless steel rebars in the same structure because of possible galvanic corrosion [2]; or stress-cracking corrosion, as the more or less generalised corrosion of carbon steel is transformed into pitting corrosion, which may act as stress concentrating defects.

4.1. Corrosion resistance

The data in Figs. 2, 4 and 6, obtained for the slabs manufactured with C35/45 and C60/70 concrete, show a certain similarity between the behaviour of CS and the stainless steels in the absence of chlorides, which is logical since all are in the passive state. Nevertheless, in the slabs without chloride additions, the low penetration of chloride ions produced, when the slabs are immersed in a 3.5% NaCl solution, seems to be enough to cause a slight increase in the i_{corr} values (Figs. 2a and 4a). This effect is due to the beginning of the corrosion process in isolated points on the reinforcing surface (Fig. 5). Figs. 2b, c and 4b, c also show differences in i_{corr} of around one or two orders of magnitude in the slabs with 2% or 4% Cl^- , conditions in which CS has lost its passivity while the stainless steels, including the innovative low-Ni steels, still retain this passive state. Bearing in mind that 0.4% Cl^- , in relation to cement weight, is the critical chloride limit usually accepted for CS [20], it seems evident that the threshold tolerated by stainless steels is much higher.

The reading of the evolution of the corrosion potential over time agrees with the i_{corr} results, as the CS shows a decrease of E_{corr} , indicating a depassivation, whereas for stainless steels it stays high. However, the corrosion potentials of Fig. 3a, b and c for C35/45 concrete slabs offer limited information about the corrosion behaviour, because all the stainless steels show similar corrosion potentials values, but as can be seen in Fig. 2a, b and c, the AISI 304 stainless steel shows significantly lower i_{corr} values. For this reason, reading only the corrosion potentials can induce us to make wrong interpretations if these are not taken together with other parameters related to the corrosion kinetics.

Whether the corrosion resistance of stainless steels is evaluated by the critical Cl^- level for the triggering of pitting corrosion or by breakdown potentials, an enormous difference

Table 2
Breakdown potential, E_b , and corrosion potential, E_{corr} , obtained from anodic polarization curves drawn in the five steels embedded in C60/70 at 4% Cl^-

C60/70, 4% Cl^-			
	E_{corr} , mV	E_b , mV	$E_b - E_{corr}$, mV
Carbon steel	-474	-	-
HSS1	-389	576	965
HSS2	-400	590	990
304	-199	556	755
316	-364	571	935

is seen when compared with carbon steel. The difference between the corrosion potential and the breakdown potential, $E_b - E_{corr}$, is used to evaluate the corrosion risk. It is generally admitted that the higher the difference between E_b and E_{corr} , the lower the probability to pitting corrosion [21]. In Table 2, a summary about the most important parameters obtained from the anodic polarization curves is shown. The difference between E_b and E_{corr} is approximately 900 mV, in the case of AISI 316 and HSS1 innovative stainless steels (Fig. 8). As a consequence, it is very improbable that in the natural media—in the absence of external polarizations—there exist corrosion cells able to provide the high polarizations needed to cause the corrosion in the active state of the stainless steels reinforcements.

In the case of AISI 304 and HSS2 innovative stainless steels, the current density of the return curve decreases quickly, following a similar path to the anodic branch (see graphs of Fig. 9). So, it is very difficult for the breakdown of the passivating films to be produced. If the local pits are produced, the repassivation is very fast. In any case, the $E_b - E_{corr}$ difference is very high, around 800 and 900 mV, respectively, so the probability of natural breakdown of the passivating films is very small. Logically, if the probability of producing the transition from the passive to the active state is very reduced in the presence of 4% Cl^- , it must be practically non-existent for slabs with an addition of 2% Cl^- .

In the case of the reinforcing carbon steel, the oxygen evolution potential is achieved in the absence of chlorides without the breakdown of the passive state and the return curve is drawn at lower current densities than those in the anodic direction curve (Fig. 7). But in the presence of 4% Cl^- , there is a fast increase in the current density with the potential, typical behaviour of the active state, and for the same potentials the current densities are about two orders of magnitude superior than in concrete without chlorides, as can be seen in Fig. 7.

Although the probability that the corrosion beginning in the active state is very low, if this situation is produced for example by external polarizations, the passivating films are practically restored immediately in the AISI 304 and HSS2 innovative stainless steels because the corrosion current density values are the same before and after the anodic polarization curves (point PC in Fig. 4c). However, as the results of the same figure show, the unfavourable effects of the breakdown of the passivating films continue in the AISI 316 and HSS1 innovative stainless steels, which have corrosion current densities nearly one order of magnitude higher after the anodic polarization curves (point

PC in Fig. 4c). Even in the carbon steel, which corrodes in the active state, an increase in the corrosion rate is detected which is due to the higher percentage of corroded surface as a consequence of the high polarizations applied.

In the literature, it has been found that the corrosion behaviour of the reinforcing AISI 316 stainless steel is the same as or even superior to the reinforcing AISI 304 stainless steel embedded in concrete [6,14,16]. So, it is surprising that in this research: a) the i_{corr} values of the AISI 316 stainless steel, although characteristic of the passive state, are significantly higher than the i_{corr} values of the AISI 304 stainless steel, in the C35/45 concrete (Figs. 2 and 6a) and also in C60/70 concrete (Figs. 4 and 6b) for all chloride contents; and b) the repassivation ability is also inferior (Figs. 4c, 8 and 9). The results seem to indicate that the microstructure produced by cold working can be the responsible for this behaviour. In the mortar specimens used in a previous work [18], with electrodes of identical composition but machined in order to obtain cylinders of a smaller diameter, no significant distinction in the corrosion behaviour was appreciable between both kind of stainless steels, as the results of Fig. 10 show. In this Figure the corrosion results obtained from AISI 304 and AISI 316 stainless steel embedded in both the slabs and in mortar specimens are compared. It can be seen that the AISI 316 stainless steel corrodes approximately 10 times more in the slabs than in the mortar specimens. Changes due to other factors, such as different geometry, content of chlorides, cement type or reproducibility of measurements, should be affect both the AISI 304 and the AISI 316. For this reason, it seems probable that the microstructure, much more altered by the cold working in the AISI 316L steel, is responsible for the worse corrosion behaviour (Fig. 11).

Similar behaviour is observed in the innovative stainless steels which corrode significantly more when corrugated rebar surfaces are exposed in the slabs than after the rebars are machined and embedded in mortar. The results obtained in mortar of all materials after 1 month of exposure, compared in Fig. 12, can help to observe this behaviour.

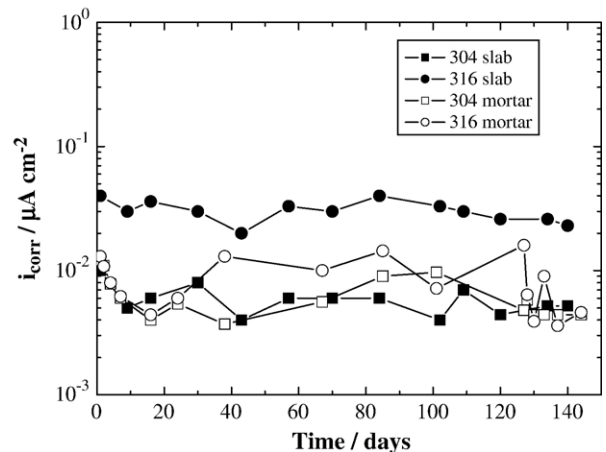
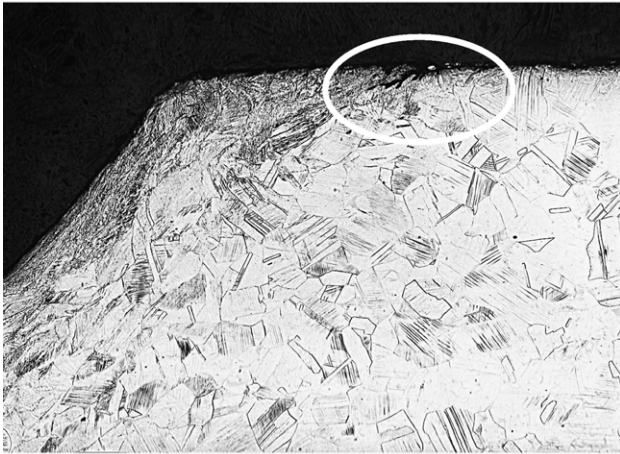


Fig. 10. Comparison of i_{corr} values of AISI 304 and AISI 316 stainless steel rebars in C60/70 concrete slab with 4% Cl^- in corrugated finish and in mortar with 5% Cl^- after machining the stainless steels.

It is worth mentioning that in the literature similar behaviour to the one previously described is observed [6,22], where it is stated that in the case of the stainless steel in concrete, “the corrosion properties appear to be extremely dependent on the state of the steel surface. In particular, all scale and temper colours can aggravate pitting corrosion and therefore the usual welding procedures will lead to a significant reduction in corrosion resistance” [6]. In the as-received rebar, the AISI 316 stainless steel showed a strip structure perpendicular to the surface, with microdefects in the form of crevices (Fig. 11a) that, probably, are responsible for both the higher i_{corr} values with respect to the AISI 304 stainless steel (Fig. 11b) and the failure in the repassivation process when the pits are generated in the drawing of the anodic polarization curves. At the bottom of the crevice the repassivation cannot occur.

The expansive character of steel corrosion products and the low tensile strength of concrete, are often responsible for the cracking of concrete with very low corrosion penetrations, $\leq 100 \mu\text{m}$ [23,24]. In addition, in the presence of the chloride ions, the i_{corr} values are at least 10 times lower in all the stainless steels tested with respect to the carbon steel. It can be concluded, in general terms, that the predictable useful life

a) AISI 316



b) AISI 304

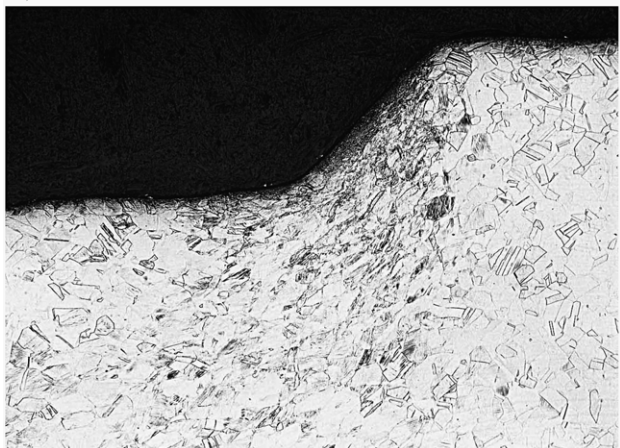


Fig. 11. Optical micrographs of the microstructure of AISI 316 and AISI 304 ribbed stainless steels, a) and b), respectively.

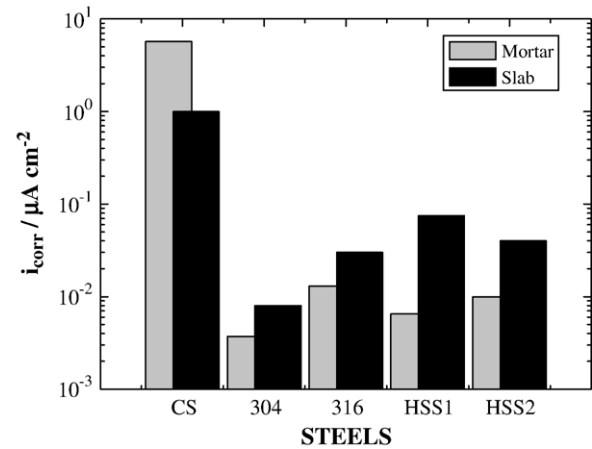


Fig. 12. Comparison of the i_{corr} values of the reinforcing steels after 1 month of testing embedded in mortar (machined rebars) and in C60/70 concrete slabs (corrugated rebars).

could, in very aggressive media, be significantly higher in the concrete structures reinforced with stainless steel rebars than in concrete structures with carbon steel reinforcements, because there is a dramatic reduction of RCS durability when the reinforcing steel is depassivated [25,26].

5. Conclusions

- None of the tested stainless steels presents sudden changes in i_{corr} values indicating the initiation of pitting corrosion, either in the slabs with 2% or 4% Cl^- , maintained at very humid atmospheres.
- Bearing in mind that the critical chloride limit normally accepted for carbon steel is around 0.4% Cl^- in relation to cement weight, and that concentrations 10 fold higher have been tested without producing the lost of the passivity in the stainless steel reinforcing, the chloride threshold for these steels is much higher. The exact date is a matter that would merit detailed research.
- High differences between the breakdown and corrosion potential in the austenitic stainless steels, AISI 304 and 316, and the innovative stainless steels have been found, so the natural formation of corrosion cells that could provide these potential differences and cause the pitting corrosion is very improbable.
- The AISI 304 and HSS2 stainless steels are able to repassivate after causing pits through the anodic polarization curves.
- The CS i_{corr} values are similar to those of the AISI 304, AISI 316, HSS1, HSS2 stainless steels in concrete without chloride additions, and at least 10 times higher in the presence of 2% and 4% Cl^- .

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