Study of Atmospheric Corrosion of Reinforcement Steel in Havana, Cuba.

Estudio de la Corrosión Atmosférica del Acero de Refuerzo en la Habana, Cuba.

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Abstract

The atmospheric corrosion of reinforcement steel phenomenon has been frequently investigated under accelerated exposure, throughout diagnostic studies on site and no so much study under natural environmental conditions using probes with different concrete qualities. An exposure site placed at 20 m from the seashore without the presence of artificial of natural screening in the Havana northern coast was selected. Six reinforced concrete probes with water/cement ratios of 0.4, 0.5 and 0.6 and a wooden with four atmospheric pollutants devices, two of them for chloride deposition and the other two for the sulphur compounds deposition were placed in the exposure site. In each probe were placed two reinforced steel with recovering thickness of 20 and 40 mm. The increment of the atmospheric corrosion of the reinforcement steel inside in the time; permit us to estimate the service life of the structures that will be built in coastal zones of Havana with a high level of corrosion aggressivity of the atmosphere and without the presence of any kind of artificial screening. The reinforced concrete probes with water/cement ratios of 0.5, 0.6 and 0.4only with 2 cm of concrete coating thickness do not assure a suitable primary protection as a physic barrier, between the concrete structures.

Keywords: Atmospheric Corrosion, Chloride, Corrosion Aggressivity, Reinforced concrete.

INTRODUCTION

The deterioration in the reinforced concrete structures in coastal cities, provoked by the atmospheric corrosion of the reinforced steel, is a social problem of the science and technology very difficult to solve in the world actually. The major incidence of this problem in Cuba has been detected in the coastal zone without screening of the north Havana littoral [Castañeda, 2006, 2012].

This phenomenon has been more frequently investigated under accelerated exposure tests with reinforced concrete probes, throughout diagnostic studies on site and no so much study under natural environmental conditions using probes with different concrete qualities [Castro, 2013; Vera, 2013]. The poor studies realized for this last conditions, had not valued the performance of the phenomena for exposure times over one year [Trocónis, 2006, 2007]. In this last case, was not only with the objective to prevent the deterioration, but the objective of prolonged too the service life of the concrete structures before its constructions in coastal zones with very high constructive potential and without artificial screening.

In Cuba, the poor realized studies during short periods of time, under natural environmental expositions with steel reinforced probes, had two principal objectives: The first was the interest to demonstrate the impact of the reinforced steel corrosion using marine sand in the concrete production. The second was the interests to evaluate the efficiency of a group of corrosion inhibitor of the reinforced steel [Rosental, 1982].

About the accelerated tests conditions in the natural atmosphere, it has been made some comparative studies between electrochemical and conventional techniques under the direct influence of chloride ions salt in reinforced concrete probes elaborated with different concrete qualities. The obtained results did not permit to estimate the service project life of the reinforced concrete structures, in spite of the performance of the corrosion current intensity during the time of exposure was evaluated [Castañeda, 2003, 2010].

In 1982, Tuutti established with his mathematical model based on the increasing of the atmospheric corrosion stage, two periods defined as the initiation time and propagation time of the corrosion [Tuutti, 1982]. With the sum of these two times it is possible to estimate the service life of the reinforced concrete structures that to expect to build. The corrosion propagation time is equivalent with the appearance of the first visible symptoms of deteriorations (concrete fissures and cracks) in the reinforced steel probes submitted under conditions of accelerated tests in saline chambers [Zhao et all, 2011b].

The estimation of the service life of the structures that will be constructed, starting from the performance of the phenomena in the time over reinforced concrete probes elaborated with different concrete qualities in function of the aggressivity corrosion level of the atmosphere, may be one useful tool to prevent the deterioration in the north coastal zone of Havana, without the presence of shielding. For this it is so necessary to take in account the steel recovering thickness and the reinforced concrete quality.

The performance of the phenomena with the time is useful to demonstrate if the estimated level of atmospheric corrosivity for the most usable metallic materials in the construction industry, as the mild steel (Fe-C), the copper (Cu), the zinc (Zn) and the aluminum (Al), is adequate too for the reinforced steel immerse in the reinforced concrete exposed in a coastal zone without screening.

The model has been modified with the addition of the increment in time of the chloride ions concentration up to the chloride threshold, in the reinforced steel depth in conjunction with the atmospheric corrosion level [Angst, 2011]. However, it was not specified if the increment of chloride ions was total or only the free ions in the concrete weight in the time.

From the chemical point of view, the free chloride ions have major influence in the corrosion, because the attached ions lose the reactivity. On the other hand, the free chloride ions have more activity, and determined the corrosion process.
For similar tests conditions, the corrosion current intensity strength in conjunction with the chloride free ions concentration (percentage in the concrete mass) obtained at 20 mm of concrete recovering depth increased at the time of exposure in concrete reinforced probes elaborated with ordinary Pozzolanic Portland cement. The concentration of free chloride ions (threshold), was reported minor in the reinforced concrete probes elaborated with pozzolanic Portland cement [Pradhan, 2011], so it was convenient to demonstrate the influence between the total and free chloride ions concentration at different concrete recovering depths over the atmospheric corrosion of the reinforced steel under environmental conditions of exposure in the coastal zone at short distance of the seashore, without the presence of structures and other kind of natural and artificial screening, characteristics of a city. The type of chloride ions concentration at the depth of the reinforced steel that could have more influence in the atmospheric corrosion, may be a very useful tool too for prevent the deterioration.

MATERIALS AND METHODS

Selection of the exposure site

An exposure site placed at 20 m from the seashore without the presence of artificial of natural screening in the Havana northern coast was selected. The distance was measured using the software Google Earth, taking as reference the north direction. On the exposure site were placed:

- A wooden support with the form of a triangular prism with four atmospheric pollutants devices, two of them for chloride deposition and the other two for the sulphur compounds deposition. These supports remained during the first year of the study, corresponding to a period from October of 2007 to September of 2008. The face obverse of the devices in the supports was positioned to the north direction of the predominant winds.
- Three probes of reinforced concrete with different water/cement ratio remained for an exposure time of three years. The first year from October/2007 to September/2008, the second year from October of 2008 to September of 2009 and the third year from October of 2009 to September of 2010.

Determination of the Chlorides deposition

The determination of the Chloride deposition (Cl-D in mg/m^{2}d) was realized in agreement with the methodology of the Cuban Normative [NC 12-01-09:1988]. The device used was the dry plate. This device consists in a piece of antiseptic cloth with a high adsorbing capacity with rectangular form and dimensions of 320 x 220 mm. The two devices in the support were installed at an angle of 45° respect to the horizontal line, and the change of them was made each month. By this way, two values were obtained of chloride deposition in each month from October 2007 to September 2008. With these values was calculated the annual average value.

Determination of the Sulphur compounds deposition

The determination of the sulphur compound deposition (SOxD in mg/m2d) was made in agreement with the specifications of the Cuban Normative too [NC 12-01-09:1989]. The device used was a filtrating plate of cellulose with dimensions of 150 x 100 mm, positioned with the same inclination angle. Two values of deposition in each exposure month were determined too, with the purpose to of obtain the annual average value. The monthly average values of relative humidity and temperature for the estimation of the time of wetness (TOW), were obtained in the meteorology station of the Havana Meteorology Institute.

Preparation of the reinforced concrete probes

Six reinforced concrete probes in the form of straight rectangular prisms with dimensions of 200 x 200 x 200 mm, two for each concrete mix with water/cement ratios of 0.4, 0.5 and 0.6 were elaborated. In each probe were placed two reinforced steel with recovering thickness of 20 and 40 mm. The water/cement ratios of 0.5 and 0.6 and the recovering thickness of the steel of 20 mm correspond with one of the design conditions more used in the structures construction in Cuba. Another three probes of each water/cement ratio remained in the laboratory with the objective to be used as reference in the comparative analysis of the results.

The concrete used was calculated bearing in mind in its design to obtain a minimum percentage of holes between the fine and coarse aggregates. The composition of the concrete mix was: Ordinary Portland Cement: 365 kg; Havana calcareous sand: 750 kg; Hard limestone gravel: 1 030 kg. A superplasticizer admixture based of Naftalen Formaldehide Sulfonat (NFS) to obtain a concrete mix with fluid consistency and assure a good compacted too (Table 1). The reinforced concrete probes elaborated were submitted to the water immersion curing process during 28 days at environmental temperature [NC ISO-1920-3 2010].The mild steel used in the reinforced of d = 12 mm and l = 200 mm, were submitted to a chemical cleaning in a solution of 36% of hydrochloric acid with the objective to eliminate the poor corrosion products existing [ISO 9226: 1992]. From its total length, 160 mm were immersed in the concrete mix and the others 40 mm remained in the exterior to be connected with the equipment to measure the corrosion current intensity. These exterior zones were covered with an adhesive tape as a temporal protection against the atmospheric corrosion.

Determination of the concentration of chloride ions total and free in the concrete

The probes were removed of the sites and placed after the first, second and third year of exposure. These probes joined with the probes used as reference, were used to make different tests, for example the extraction of samples of dust with a British drill mark ROCWELL DELTA, with a scale to measure the extraction deep.

Dust sample of 20 g and the replay too, that is 40 g in general for each exposure year in the three probes of reinforced concrete, in the surface and in 20, 30, and 40 mm of depth were extracted. The samples were placed in plastic flasks. In the surface of the probes the extraction was made at a depth not lower than 3 mm. A previous cleaning to the drill (diameter of 14 mm) with a brush of synthetic fibers, between the changes of probes and depth was executed always.

To each sample, four values of total and free chloride ions concentration (in percentage of concrete mass) in 5 g of dust, for a total of eight in the surface and for each penetration depth were calculated [ASTM C-1218/M: 2008, NC 272-2003]. The obtained eight values were plotted in the time of exposure (first, second or third year of the study). The pH of the solutions in the determination of the concentration of chloride ions total and free in the concrete always varied between 12.3 and 12.7 during the three years of study. Therefore, there was no alteration in its decrease, perhaps caused by the penetration of sulfate ions or carbonation processes that may have occurred within the concrete.

Determination of the corrosion current intensity

The corrosion current intensity (Ic in μA/cm^2), as an indicator of the atmospheric corrosion, was measure annually, that is to say the first, second and third year of exposure, with an Spanish instrument (corrosimeter) GECOR-8TM brand GEOCISA, before the extraction of the dust samples. First, the zone of measurement of the reinforced concrete probe that remained in front of the sea was well moistened. A moisten cloth was placed between the surface of the probe and the sensor of the instrument, with the purpose to improve the electric conductivity of the measurement system. The sensor of the instrument was placed pressuring with the hand above the probe in the zone where the reinforced steels of 20 and 40 mm of recovering thickness (Figure 1). The polarization area introduced to the instrument equipment was 65.25 cm^2.

Table 1. *Volume of water and admixture used in the concrete probes preparation. Source: own elaboration, 2013.*

W/C	Cone Settlement (cm)	Real water volume (L)	Admixture (%)
0.4	15	148	1.7
0.5	17	186	1.5
0.6	18	222	1.0

Figure 1. *Measurement system used to obtain the corrosion current intensity in the probes. Source: own elaboration, 2010.*

Four values of the corrosion current intensity for each reinforcement steels with 20 and 40 mm of recovering thickness in the three probes with water/cement of 0.4, 0.5 and 0.6 ratio were obtained. Therefore, the eight values of the current corrosion intensity obtained for each recovering depth were plotted in the time of exposure. The values of the corrosion current intensity were classified in according with the demanded intervals in the document of the DURAR NET OF CYTED [Trocónis, 1997].

RESULTS AND DISCUSSION

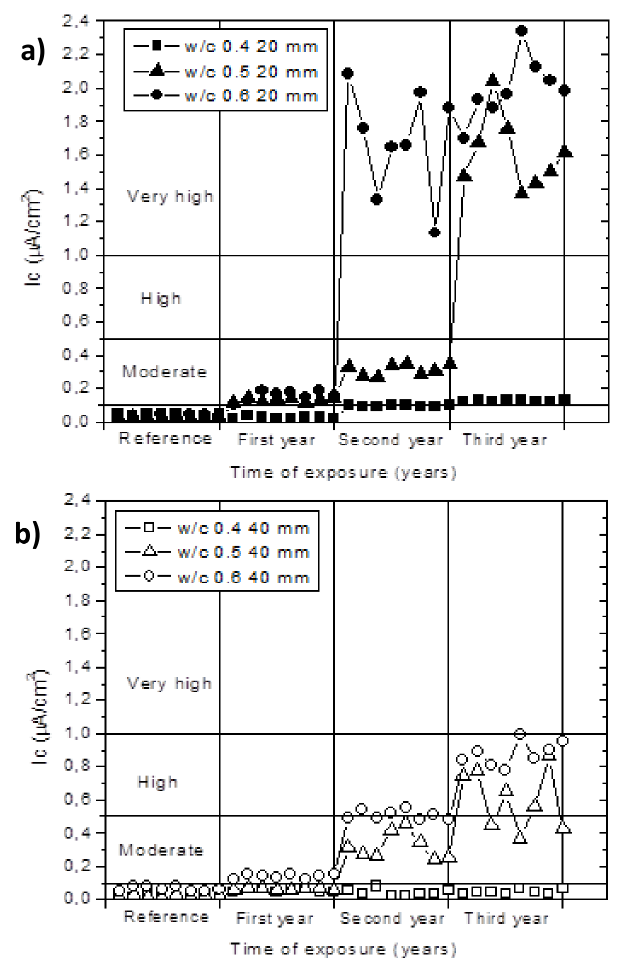
Estimation of the corrosion aggressivity levels of the atmosphere

The estimation of the corrosion aggressivity levels in the exposure site at 20 m from the seashore for the principal metallic materials more used in the construction industry, was realized bearing in mind the first variant established in the International Normative ISO 9223. This variant is based on the time of wetness in function of the annual average values of the chloride deposition and the sulphur compounds deposition [ISO 9223:1992]. In general form, there is a very high corrosion aggressivity level of the atmosphere (C5) to the four metallic materials in spite of to bear in mind the determination of the of the deposition chloride by the dry plate device.

Table 2. *Corrosion aggressivity levels estimated in the studied site. Source: own elaboration, 2013.*

TOW (h/a)	$Cl^{-}D$ (mg/m^{2}d)	SO_xD (mg/m^{2}d)	Aggressivity corrosion levels			
			Fe-C	Cu	Zn	Al
3 408	769.43 (S3)	57.66 (P2)	C5	C5	C5	C5

Figure 2. *Performance of the reinforced steel atmospheric corrosion, in dependence of the time of exposure. Classification ranks established in the DURAR Net of CYTED. Source: own elaboration, 2013.*



The time of wetness (TOW in hours/year) value is suitable with the category four of the classification according to the established time in the normative (Ʈ4), this is an indication of the existence of a coastal tropical climate very humid in external conditions. It is further noted, as the annual average value of the chloride deposition results very high in comparison with the sulphur compounds deposition. This is useful to confirm that the predominant atmosphere in the zones of the city without screening classify as coastal-industrial atmosphere.

Analysis of the performance of the atmospheric corrosion in the time of exposure

The atmospheric corrosion in the reinforced steel placed at 20 mm of recovering thickness, was lightly increased in the time of exposure for the probe with water/cement ratio of 0.4 and in form much more significant for 0.5 and 0.6 (Figure 2a). For the reinforced steels placed at 40 mm of recovering thickness, the increment was less significant too in these latest probes and particularly in the probe with water/cement ratio of 0.4 does not had a significant increase of the phenomena in the time of exposure (Figure 2b). The atmospheric corrosion in the time of exposure was higher in the reinforced concrete probes for the three water/cement ratios where the reinforced steels were placed at 20 mm of recovering thickness (Figure 2a) and b)). The influence of the recovering thickness, under environmental conditions of exposition was demonstrated.

In general it was proved that for a level very high of corrosive aggressivity for the main metallic materials more frequently used in the construction industry, the atmospheric corrosion of the reinforced steel tends to increase in the time of exposure for concretes with water/cement ratios of 0.5 and 0.6 for both recovering thickness used, just like to the concrete with water/cement ratio of 0.4 where the reinforced steels were placed at 20 cm of recovering thickness. Therefore, may be expected in these cases, and for this aggressivity condition (zones of the city very close to the sea and without screening effect), an outstanding deterioration in a short period of time.

Estimation of the project service life of the reinforced concrete structures

The increment of the atmospheric corrosion in the reinforced steel of the concrete probes with different water/cement ratios, permitted to estimate the project service life of the structures that are trying to construct under very high aggressivity corrosion of the atmosphere.

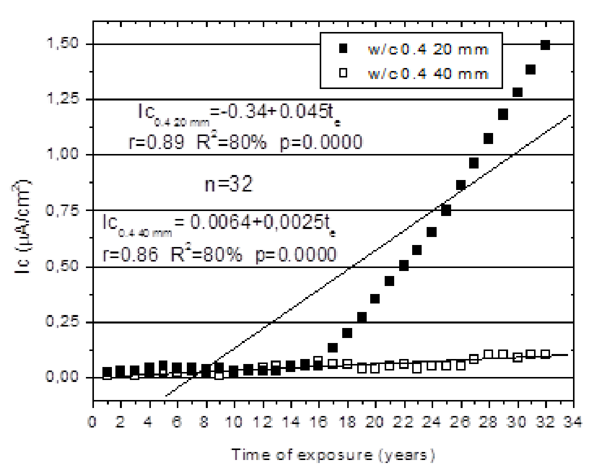
The estimation was made from the sum of the initiation times (ti) and propagation times (tp) during some years of occurring the phenomenon of atmospheric corrosion in the reinforced steel, according to the demanded specifications in the Tutti model. The initiation time was considered when the values of the corrosion current intensity were found between 0.1 and 0.5 µA/cm^2, which one correspond to certain moderate level. The propagation time, when the values were between 0.5 and 1 µA/cm^2, that correspond to a high level, or more higher that this last value characteristic of a very high level of corrosion according with the classification levels demanded by the document of the DURAR NET OF CYTED.

Starting from the aforementioned, it is appreciated that the initiation time of the phenomenon was one year in the probe with water/cement ratio of 0.6 for both recovering thickness, and two years in the probe with water/cement ratio of 0.5 and a recovering thickness of 40 mm (Figure 2a and 2b). The initiation of the phenomenon is an indicative of a rapid reach of the chloride ions threshold in the surface of the reinforced steels. The propagation times were equals in the two probes for the two used recovering thickness, therefore the service life of one structure built using a reinforced concrete with water/cement ratio of 0.5 and 0.6 should not to reach the five years for the two recovering thicknesses under the conditions of atmospheric corrosion aggressivity very high. (Table 3).

Table 3. *Initiation (ti) and propagation (tp) time of the atmospheric corrosion of the reinforced steel, and the service life (Vu). Source: own elaboration, 2013.*

W/C	Recovering thickness of 20 mm			Recovering thickness of 40 mm		
	t_i (years)	t_p (years)	V_u (years)	t_i (years)	t_p (years)	V_u (years)
0,4	3	20	23	50	-	-
0,5	1	3	4	2	3	5
0,6	1	2	3	1	2	3

Figure 3. *Performance of the atmospheric corrosion of the reinforced steel in the concrete probe with water/cement ratio of 0,4 for the two recovering thickness. Source: own elaboration, 2013.*



This time is also considered as the end of the service life of the reinforced concrete structures and then they go to stay in a "residual life". During this period of the "residual life", reparation works must be executed being much more expensive, including the substitution of the more affected elements for this phenomenon, with the objective to give back to these elements, the initial service life conditions, for example the esthetic, functionality and security, similarly o higher to the initial specifications that are demanded in the original construction project. In relation to the probe with water/cement ratio of 0.4 and a concrete recovering thickness of 20 mm, it is possible to observe that in the third year of exposure, the values of the corrosion current intensity were in the interval of 0.1 – 0.5 μA/cm^2, that is indicative of the initiation time of the phenomenon (Figure 2a).

To shed light on the performance of the atmospheric corrosion in the time with the purpose to establish the service life that could be offered one structure constructed with a reinforced concrete that have a water/cement ratio of 0.4, for the two concrete recovering thickness and under the severe conditions of a very high corrosion aggressivity of the atmosphere, it was necessary to use the statistical method of the Cumulative Sum (CUSUM) (Figure 3). It is possible to see a more significant increment in the reinforced steels placed at 20 mm of recovering thickness, as happened in the probes with water/cement ratio of 0.5 and 0.6.

Using the equations of adjusted growing linear regressions, it is possible to see that starting from a time of 20 years, the corrosion velocity could reach a value near to 0.5 μA/cm^2 and the phenomenon will reach a high level, in the case that the tendency of the atmospheric corrosion will be maintained in the time. This permit to assert that the service life of a structure built with a reinforced concrete with water/cement ratio of 0.4 and with recovering thickness of 20 mm, could be approximately of 23 years with the sum of these two times (Table 3). In the case of the reinforced steels with 40 mm of recovering thickness, if the tendency will be maintained according to the linear regression obtained, most to pass near 50 years to reach at least the initiation of the atmospheric corrosion of the reinforced steel (Table 3). According to that the reinforced concrete structures those that will be built under these design conditions and exposed to a very high corrosive aggressivity level, would be have a most extensive service life and with more extended periods of maintenance and reparation. It's necessary to have in mind too as fundamental elements on site, the guarantee of a very good construction practices: A good concreting operations, compaction and curing of the concrete.

A fast appearance of the corrosion initiation time is an indicator about the need to make the maintenance works with the purpose to prevent that the phenomenon acquires a strong growth in the time. Moreover it permit to confirm the insufficient quality that could have a reinforced concrete made with a water/cement ratio between 0.5 and 0.6 and the case of a concrete with water/cement ratio of 0.4 but with the reinforced steel placed with a recovering thickness only of 20 mm. It is necessary to have in mind too in this case that a concrete with an effective porosity major to the 8%, obtained by the capillary absorption of water, can increase the penetration of the aggressive agents (for example the chloride ions) under conditions of very high corrosion aggressivity. It is also demonstrated that the recovering thickness of a concrete with water/cement ratio of 0.4 or lower must be at least of 40 mm or bigger.

Influence of the chloride ions concentration inside the concrete in the atmospheric corrosion of the reinforced steel

The chloride ions concentration total (t) and free (f) show an increment in function of the time of exposure and the water/cement ratio starting from the values obtained in the surface (Cl-ts Cl-fs, Figure 4a and 4c) as well as at 20 and 40 mm of recovering thickness (Cl-t 20 and 40 mm, Cl-f 20 and 40 mm, Figure 4b and 4d) where precisely were placed the reinforced steels. In general form, the increment was more significant in the probes with water/cement ratio of 0.5 and 0.6 , that is to say in the concretes that present the higher values of capillary porosity percentage as had succeed for the atmospheric corrosion.

This result, under real conditions of exposure in a site with very high corrosion aggressivity, it is something similar to the obtained for accelerate conditions in the laboratory where the corrosion current intensity obtained by the electrochemical techniques of polarization resistance and impedance spectroscopy, had an increment in function of the time of exposure as a whole with the chloride ions concentration free at 20 mm of recovering [[Castañeda, 2003, 2010].

On the other hand it is possible to observe how only the probe with water/cement ratio of 0.4, where the reinforced steels were placed at 40 mm of recovering thickness, do not it was obtained an statistical relation from the multiple regression, that confirm the influence of the chloride ion concentration (total and free) at this thickness and in the surface of the atmospheric corrosion of the reinforced steel (Table 4). Therefore it is possible to confirm again that a concrete elaborated with a water/cement ratio of 0.4 and with the reinforced steel placed at 40 mm of recovering thickness, has the higher resistance to the ion chloride salts penetration under conditions of very high corrosion aggressivity of the atmosphere. It was demonstrate too that do not exist a critical concentration of these ions (threshold) that at its arrival to the reinforced steels produced the rapid initiation and propagation of the phenomenon during the three years of the study.

The minus sign of the statistic coefficient “c” for the chloride ions concentration in the probes surface for the three water/cement ratios and particularly for the total chlorides indicate that in occasions the concentration of this dangerous aggressive agent, may diminish because of its rapid penetration or may be too because the washing by the rain of these ions (Table 4). This aspect favors a major higher atmospheric corrosion to the reinforced steel inside the concrete under real conditions of exposure outdoors.

On the other hand, it was demonstrated throughout the regression equations, the nonexistence of a big difference about the major influence between the total chloride ions concentration and the free ones over the atmospheric corrosion of the reinforced steel, under conditions of very high corrosion aggressivity of the atmosphere. The two ions concentrations influence significantly over the two recovering thickness, in spite of the free chloride ions are considered as the principal responsible of the atmospheric corrosion of the reinforced steel, principally under accelerated conditions of exposure. Nevertheless, it is confirmed under real conditions of exposure, that the concentration of total chloride ions is a very safe indicator in the initiation and propagation of the atmospheric corrosion of the reinforced steel.

Table 4. *Statistical regressions that confirm the dependence of the corrosion current intensity of the total and free chloride ions concentration inside the concretes. Source: own elaboration, 2013.*

Total chloride concentration				
Recovering Thickness (mm)	**w/c**	**Regressions** $Ic = a \pm bClt^{-}_{20\,mm} \pm cClt^{-}_{s}$ **n = 32**	**P**	**R^2 (%)**
20	0.4	$Ic = 0.045+0.041Cl_{t}^{-}{}_{20\,mm}+0.013Cl_{t}^{-}{}_{s}$	0.0000	92
	0.5	$Ic = 0.008+1.023Cl_{t}^{-}{}_{20\,mm}-0.722Cl_{t}^{-}{}_{s}$	0.0000	98
	0.6	$Ic = 0.006+1.731Cl_{t}^{-}{}_{20\,mm}-1.072Cl_{t}^{-}{}_{s}$	0.0000	95
		$Ic = a \pm bClt^{-}_{40\,mm} \pm cClt^{-}_{s}$ n = 32		
40	0.4	$Ic = 0.022+0.409Cl_{t}^{-}{}_{40\,mm}+0.035Cl_{t}^{-}{}_{s}$	0.543	19
	0.5	$Ic = 0.028+0.196Cl_{t}^{-}{}_{40\,mm}-0.866Cl_{t}^{-}{}_{s}$	0.0000	78
	0.6	$Ic = 0.053+1.651Cl_{t}^{-}{}_{40\,mm}-0.201Cl_{t}^{-}{}_{s}$	0.0000	97
Freechloride concentration				
Recovering Thickness (mm)	w/c	Regressions $Ic = a \pm bCl_{l}^{-}{}_{20mm} \pm cCl_{l}^{-}{}_{s}$ n = 24	P	R^2 (%)
20	0.4	$Ic=-0.062+1.411Cl_{f}^{-}{}_{20\,mm}+0.101Cl_{f}^{-}{}_{s}$	0.0000	97
	0.5	$Ic=-0.686+2.816Cl_{f}^{-}{}_{20\,mm}-1.231\,Cl_{f}^{-}{}_{s}$	0.0000	98
	0.6	$Ic=-0.731+6.365Cl_{f}^{-}{}_{20\,mm}-4.343Cl_{f}^{-}{}_{s}$	0.0000	99
		$Ic = a \pm bCl_{l}^{-}{}_{40\,mm} \pm cCls^{-}_{s}$ n = 24		
40	0.4	$Ic=-0.009+1.803Cl_{f}^{-}{}_{40\,mm}+0.578Cl_{f}^{-}{}_{s}$	0.709	24
	0.5	$Ic=-0.223+5.661Cl_{f}^{-}{}_{40\,mm}-0.313Cl_{f}^{-}{}_{s}$	0.0000	76
	0.6	$Ic=-0.238+1.215Cl_{f}^{-}{}_{40\,mm}-0.645Cl_{f}^{-}{}_{s}$	0.0000	98

This analysis about of the obtaining of a good relationship statistically significant between the values of the corrosion current intensity and the ions chloride concentration (totals and free), is useful to continue corroborating that the phenomenon may be considered as atmospheric corrosion, because of the atmospheric source of this dangerous aggressive agent, submitted to conditions of corrosion aggressivity very high of the atmosphere in coastal sites without the presence of some kind of screening, especially when it is artificial, because the numerous structures of big height that are situated in the littoral north of Havana.

Figure 4. *Behavior of the chloride ions concentration: Total (a and b) and Free (c and d) in the time of exposure, the recovering thickness and the water/cement ratio. Source: own elaboration, 2013.*

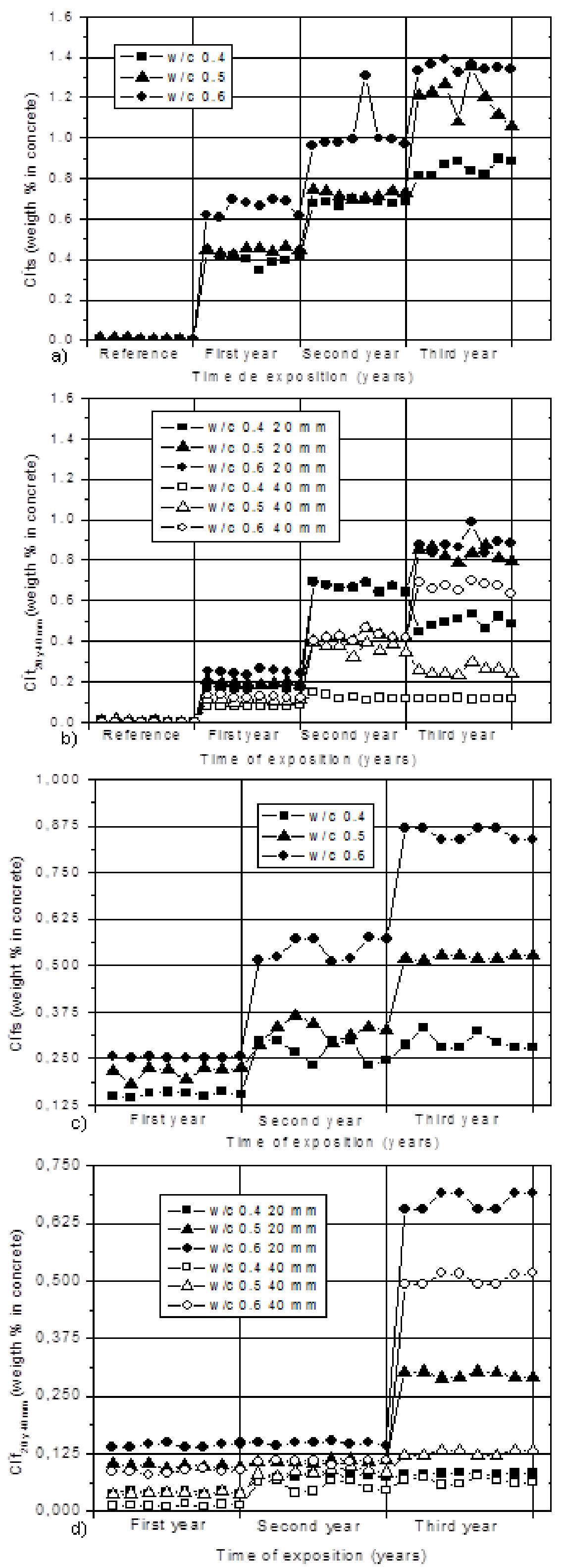
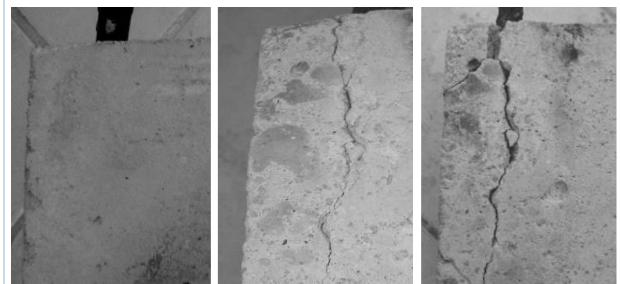


Figure 5. *Visual observation of the reinforced concrete probes placed in the study site. Source: own elaboration, 2010.*

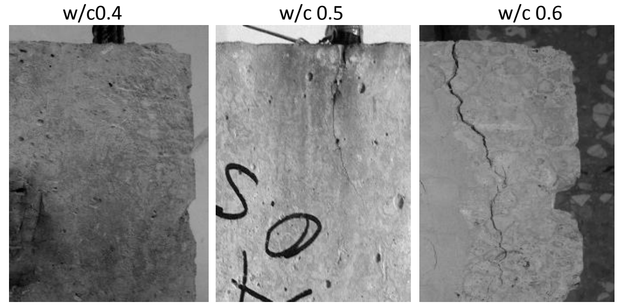
Recovering thickness
20 mm

w/c0.4 | w/c 0.5 | w/c 0.6



Recovering thickness
40 mm

w/c0.4 | w/c 0.5 | w/c 0.6



Visual observation of the reinforced concrete probes

The visual observation of reinforced concrete probes placed in the study site at 20 m from de seashore in the third year of exposure was carried out. It is observed the appearance of cracks in the probes with water/cement ratios of 0.5 and 0.6 because of the effect of the atmospheric corrosion in the reinforcement steels. This cracking provoked by the expansion of the oxides in perpendicular form to the probes surface, was more obvious for the reinforced steels placed at 20 mm of recovering thickness (Figure 5).

The absence of fissures and cracks in the probe with water/cement ratio of 0.4 for the two concrete recovering thickness of the reinforced steel, confirm too the existence of an estimated time of atmospheric corrosion propagation of 20 years for the reinforced steel at 20 mm of recovering thickness, as well as the estimation of an initiation time of the phenomenon of 50 years for 40 mm of recovering thickness.

It is very well known that the cracks in the probes provoke a major penetration of the aggressive agents, principally the chloride ions that coming from the atmospheric marine aerosol, specifically in the zone where the sea waves breaks. It provokes a considerable increment of the deterioration in the reinforced concrete structures. In general form, it was demonstrated that for the exposure site at 20 m of the seashore, where the level of corrosive aggressivity was very high for the metallic materials more used in the Construction Industry, the reinforced concrete with water/cement ratios of 0.5 and 0.6 do not assure a suitable primary protection as a physic barrier, between the atmosphere and the reinforced steel for these two recovering thickness.

The appearance of the cracks confirm that a structure built with a reinforced concrete with water/cement ratios between 0.5 and 0.6 do not exceed the five years of service life under conditions of very high corrosion aggressivity of the atmosphere. It was demonstrated that starting from the propagation time of the atmospheric corrosion reinforcement steel phenomenon, the structures begun to lose its defined characteristics in the beginning of its construction project.

On the other hand it is ratified that the presence of cracks is a direct indicator of the service life end of the structure, with the initiation of a residual period with the necessity of very expensive reparation works, or the total substitution of affected elements and parts because the atmospheric corrosion phenomenon of the reinforced steel. These aspects have considerable influence in the economic losses, specially the direct losses, because of the phenomenon occurrence.

This is the importance to achieve the elaboration of a reinforced concrete with the required quality and the rigorous application of the constructive good practices, with the purpose to increase considerably the durability and the service life of the structures that will be constructed in coastal sites without screening, characterized by to have a corrosion aggressivity very high level of the atmosphere.

CONCLUSIONS

The increment of the atmospheric corrosion of the reinforced steel inside of reinforced concrete probes in the time; permit us to estimate the service life of the structures that will be built in coastal zones of Havana with a high level of corrosion aggressivity of the atmosphere and without the presence of any kind of artificial screening.

The very high level of corrosion aggressivity of the atmosphere, estimated for the principal metallic materials more used in the construction industry, in coastal sites without screening in the north littoral of Havana, can be bearing in mind too for the structures built with water/cement ratios between 0.5 and 0.6 and with recovering thickness of 20 and 40 mm, as well as for a reinforced concrete with water/cement ratio of 0.4 where the reinforced steel is placed at 20 mm of thickness, due to increment of the atmospheric corrosion of the reinforced concrete and of the total and free chloride ions concentration in the time of exposure. The reinforced concrete elaborated with a water/cement ratio equal or lower to 0.4 with a recovering thickness equal or lower than 40 mm until certain limit, represent the necessary design conditions to reach higher durability times and service life of the structures that will be submitted to a very high level of corrosion aggressivity of the atmosphere in coastal sites, not characterized by the presence of natural and artificial screening. The concentration of chloride ions (totals and free), exert the same influence over the phenomenon of the atmospheric corrosion of the reinforced steel inside the concrete structures, for the three water/cement ratios used in the preparation of the reinforced concrete in Cuba.

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