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Evaluation of chloride deposition using the wet candle method: a study in the city of Cabo Frio, RJ

Avaliação da deposição de cloretos através do método da vela úmida:
um estudo na cidade de Cabo Frio, RJ

Renata Cristina Fernandes Barbosa^I , Rodrigo César Fernandes Barbosa^{II} ,
Rafael Carlos Fernandes Barbosa^{III} , Carolina de Medeiros Strunkis^{IV} ,
Evelton Alves Casartelli^{II} , Gustavo Bosel Wally^{IV} , Fábio Costa Magalhães^I 

^I Universidade Federal do Rio Grande, Rio Grande, RS, Brazil

^{II} Universidade Federal Rural do Rio de Janeiro, Rio de Janeiro, RJ, Brazil

^{III} Estácio de Sá Universidade de Cabo Frio, Cabo Frio, RJ, Brazil

^{IV} Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brazil

ABSTRACT

In the context of the durability assessment of reinforced concrete structures, it is necessary to establish the divisions of the aggressiveness classes of the different maritime and coastal environments, in order to contribute to the study of the classification of environmental aggressiveness. In this paper, the deposition of aggressive ions and the general climatic aspects of the coastal region of the city of Cabo Frio, RJ are evaluated. For the analysis, the wet candle method (Brazilian NBR 6211:2001) was adopted. The exhibitions were held at five different points throughout the city, each with three wet candles. To quantify the chloride content, the conductimetry method was used, which is done by measuring the electrical conductivity of an electrolyte solution, due to ion migration. The results point to a high level of chlorides in the initial range of distance from the sea and a considerable decrease from approximately 900 meters from the seashore. In this way, it was possible to verify that the city, in its interior, is under moderate to minimal aggressiveness. In the initial distances of the seashore, there is high aggressiveness. These results show the importance of considering micro-exposure environments during the design phase of reinforced concrete structures.

Keywords: Durability; Reinforced concrete; Ambiental aggressiveness; Chloride

RESUMO

Em um contexto de projeto de durabilidade das estruturas de concreto armado, há necessidade de estabelecer as divisões das classes de agressividade das diferentes regiões marítimas e costeiras, a fim de contribuir para o estudo da classificação de agressividade ambiental. Neste trabalho são avaliados

a deposição de íons agressivos e os aspectos climáticos gerais da região litorânea da cidade de Cabo Frio, RJ. Para a análise, foi adotado o método da Vela Úmida (NBR 6211:2001). As exposições foram realizadas em cinco pontos distintos ao longo da cidade, contando cada um com três velas úmidas. Para quantificar o teor de cloretos utilizou-se o método de condutimetria, o qual se baseia na variação da condutividade elétrica de uma solução eletrolítica devido à migração de íons. Os resultados parciais apontam teor elevado de cloretos na faixa inicial de distanciamento do mar e diminuição considerável a partir de aproximadamente 900 metros da orla marítima. Dessa forma, foi possível verificar que nas distâncias iniciais da orla marinha, a cidade encontra-se sob elevada agressividade e, em seu interior, sob agressividade de moderada a mínima. Esses resultados evidenciam a importância da consideração de micro ambientes de exposição durante a fase de projeto de estruturas de concreto armado.

Palavras-chave: Durabilidade; Concreto armado; Agressividade ambiental; Cloretos

1 INTRODUCTION

Historically, the population distribution was from the coast, reaching today the largest urban affluence to the next coastal regions. According to the Brazilian demographic census of 2010, the highest concentration of population is in the coastal zone. By looking at the history of civilizations, it is possible to observe, together, the evolution of constructions and construction materials (IBGE, 2010).

Since the 20th century, reinforced concrete has played an important role in civil construction, being among the most widely used materials since then. Despite being a resistant material, when exposed to coastal regions, it is subject to significant weather interference. Considering this reality and taking into account the urban and simultaneously marine aspect region, this characteristic presents the challenge of determining parameters and the need for caution, as the action of the environment is directly linked to the performance and safety of the structure.

The marine interferences can reach variable intensities, a marine atmosphere zone has particular and interdependent physical and chemical aspects. Thus, it is necessary to carefully analyze the general conditions of the region, which brings the challenge of understanding the characteristic aspects of aggressiveness, in order to achieve adequate parameters of structural performance, durability, and safety.

In addition to mechanical stresses, it should be noted that the chemical and

physical actions of the environment are directly related to the good performance of a structure. Thus, the prediction of risks must safely and consciously include the definition of the class of environmental aggressiveness to be adopted for the design and execution of reinforced concrete structures.

The prescriptive approach traditionally used in specifying concrete for durability is limited to setting limit values for parameters such as nominal cover of reinforcement, water/cement ratio, compressive strength, and cement consumption depending on the class of aggressiveness to which the concrete will be subjected (Wally et al., 2022). However, Beushausen et al. (2021) emphasize that aggressiveness classes cannot be generalized nor indiscriminately applied to different regions, requiring a more rigorous and detailed characterization of the exposure environment. The main international regulations classify the exposure environment based on different degradation mechanisms. The exposure classes adopted in different international standards are commonly divided into categories defining the environment in question, and subclasses related to the intensity of aggressiveness.

Meira (2004) highlights the relevance of studying microregions of aggressiveness. For example, the author proposes that the marine atmosphere zone be divided into three different levels of aggressiveness depending on its distance from the sea and chloride deposition rate. Table 1 shows the proposed limit values.

Table 1– Levels of aggressiveness in marine atmosphere zone

Aggressiveness	Chloride deposition mg.(m².day)⁻¹	Distance from the sea [m]
Elevated	> 100	< 100
Moderate	Between 10 and 100	Between 100 and 750
Minimum	< 10	> 750

Source: Meira (2004)

For regions with higher wind intensities, up to $18 \text{ m}\cdot\text{s}^{-1}$, Morcillo et al. (2000) considered that chloride deposition values below $100 \text{ mg}\cdot(\text{m}^2\cdot\text{day})^{-1}$ characterize a low aggressiveness region, while zones of high aggressiveness are those where depositions higher than $400 \text{ mg}\cdot(\text{m}^2\cdot\text{day})^{-1}$ are observed, emphasizing the relevance of the aggression characteristics specific to microregions.

The adoption of classification mechanisms in microenvironments, however, presents great challenges since several characterization campaigns in different points are necessary to obtain reliable results. As a way of expanding the volume of data regarding the aggressiveness of marine atmosphere zones, this paper presents the environmental characterization in microenvironments of the Cabo Frio region, located in the Lakes region, north coast of the state of Rio de Janeiro.

2 METHODOLOGY

2.1 Preparation of candles and collection of samples

The determination of chloride content in the atmosphere was carried out according to the wet candle method (NBR 6211:2001). The equipment used consists of an Erlenmeyer flask containing 200 ml of glycerinated water, to which is attached a tube with a diameter of 25 mm and a height of 150 mm wrapped in gauze, and two test tubes with a diameter of 15 mm inside the flask, through which the gauze descends until it comes into contact with the bottom of the flask.

Through the process of capillarity, the gauze becomes moistened and captures the ions present in the atmosphere, which move into the solution contained in the flask. The equipment was exposed for 45 consecutive days in summer, autumn, winter, and spring. The partial results presented in this work refer to the first two seasons of the year and are compared to other studies previously carried out in different regions. Each of the exposures had five monitoring points, as shown in Figure 1, in triplicate, as illustrated in Figure 2. The analysis points P1, P2, P3, P4, and P5 are located at distances of 35, 55, 710, 1045, and 1400

m, respectively, from the seaside. Subsequently, the candles were collected and the gauzes were washed. The wash water was added to the content of the original wet candle, and the final volumes of all samples were determined.

Figure 1 – Allocation points of the stations



Source: Author/Private collection of the authors (September, 2022)

Figure 2 – Wet candle exposure station



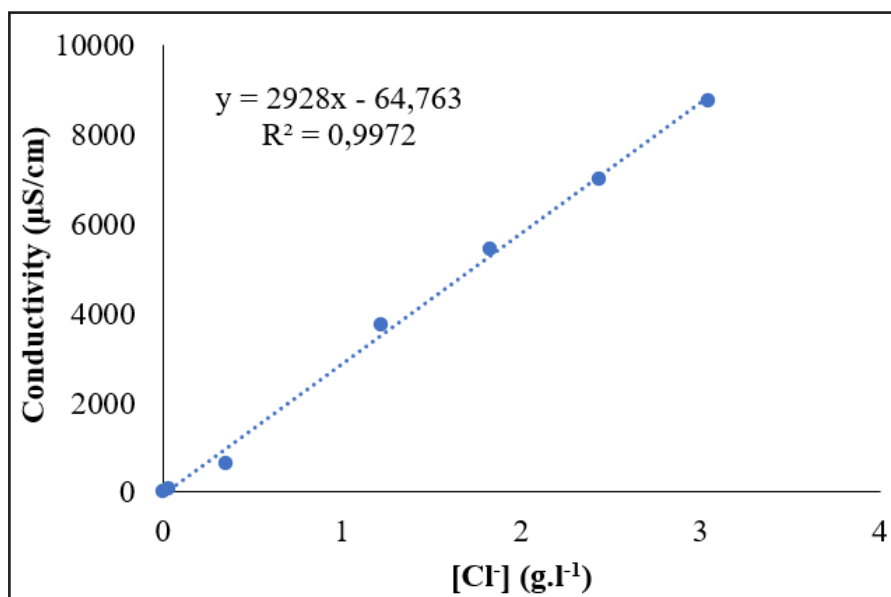
Source: Author / Authors' private collection (September, 2022)

2.2 Determination of total ion content

The chloride content in each of the samples was determined through conductometry. Souza *et al.* (2018) highlight the effectiveness of this method in measuring the content of salts in solution, obtaining values related to electrical conductivity. According to the authors, by measuring electrical conductivity, it is possible to quickly determine the amount of salts that a solution can contain, based on a standard saline solution. This makes it possible to safely correlate the electrical conductivity of a solution with its salinity.

The determination of electrical conductivity was carried out using a microprocessed conductivity meter from the Quimis brand calibrated with a standard solution of potassium chloride (KCl) 0.01 Mol.L^{-1} , which corresponds to 1408.3 mS/cm at $25 \text{ }^\circ\text{C}$. The standard curve of conductivity as a function of the variation in the concentration of chloride ions used in this study can be seen in Figure 3.

Figure 3 – Standard conductivity curve as a function of chloride ion concentration



Source: Organized by authors (2022)

Initially, the conductivity meter was turned on and allowed to stabilize for approximately 30 minutes before taking readings. During this interval, the conductivity measuring probe was washed with deionized water and dried with soft absorbent paper. Subsequently, the equipment was calibrated with a standard solution of 0.01 M KCl. Deionized water used for the construction of the wet candles was used as a blank, followed by the reading of the samples. After each reading, the probe was washed and dried before taking the next sample reading, as established by the manufacturer.

3 RESULTS AND DISCUSSIONS

The local climatology during the study period, monitored by the Admiral Paulo Moreira Sea Studies Institute, was characterized by average maximum temperatures of 32°C for summer and 27°C for autumn. As for the average minimum temperatures, 24°C was observed for summer and 19°C for autumn. The predominant directions of monthly average winds in the region were from NE and ENE (north and northeast) and remained so throughout the exposure period. The average wind speed reached 14.8 km/h in summer and 17.4 km/h in autumn. The average precipitation in the first (summer) and second (autumn) exposures were 115 and 50 mm, respectively.

The monitoring points were determined based on the distance from the sea, obtained from the coastline, and the safety of the location. The partial results of chloride deposition obtained during the first two seasons of the year (summer and autumn), corresponding to 45 days of exposure in each, and the corresponding averages are presented in Tables 2 and 3.

Table 2 – Chloride deposition during summer

Sample	Distance [m]	Volume [l]	Conductivity [μS/cm]	Chloride content [g/l]	Chloride deposition mg.(m ² .day) ⁻¹
P1.1	35,0	0,254	2650,000	0,927	523,340
P1.2	35,0	0,308	3840,000	1,334	912,770
P1.3	35,0	0,400	1048,000	0,380	506,720
P2.1	55,0	0,315	211,000	0,094	65,930
P2.2	55,0	0,385	135,500	0,068	58,520
P2.3	55,0	0,367	145,300	0,072	58,510
P3.1	710,0	0,218	262,000	0,112	54,060
P3.2	710,0	0,320	165,100	0,079	55,830
P3.3	710,0	0,230	169,200	0,080	40,840
P4.1	1045,0	0,354	131,100	0,067	52,620
P4.2	1045,0	0,275	114,300	0,061	37,370
P4.3	1045,0	0,345	134,800	0,068	52,250
P5.1	1400,0	0,245	153,300	0,074	40,550
P5.2	1400,0	0,250	142,500	0,071	39,330
P5.3	1400,0	0,305	153,600	0,075	50,550

Source: Compiled by the authors (2022)

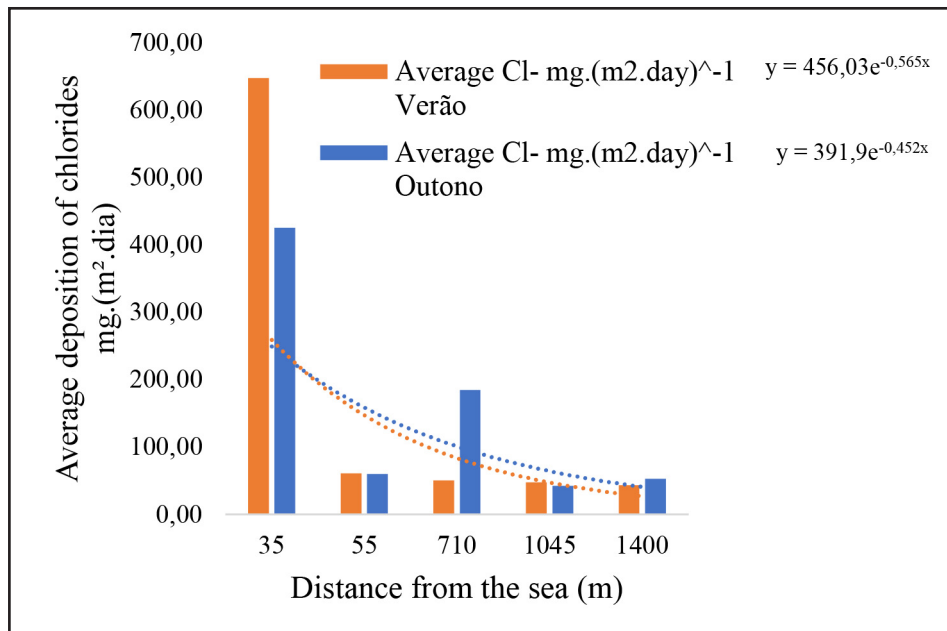
Table 3 - Chloride deposition during autumn

Sample	Distance [m]	Volume [l]	Conductivity [μS/cm]	Chloride content [g/l]	Chloride deposition mg.(m ² .day) ⁻¹
P1.1	35,0	0,295	1740,000	0,616	404,070
P1.2	35,0	0,430	1642,000	0,583	557,000
P1.3	35,0	0,365	1075,000	0,389	315,740
P2.1	55,0	0,345	147,200	0,072	55,500
P2.2	55,0	0,360	154,700	0,075	59,960
P2.3	55,0	0,335	187,200	0,086	64,060
P3.1	710,0	0,319	725,000	0,270	191,210
P3.2	710,0	0,305	657,000	0,247	167,070
P3.3	710,0	0,355	662,000	0,248	195,810
P4.1	1045,0	0,365	112,300	0,060	49,050
P4.2	1045,0	0,345	85,100	0,051	39,240
P4.3	1045,0	0,267	124,800	0,065	38,410
P5.1	1400,0	0,357	143,300	0,071	56,370
P5.2	1400,0	0,350	128,400	0,066	51,310
P5.3	1400,0	0,371	116,000	0,062	50,900

Source: Organized by the authors (2022)

Additionally, the averages obtained at each analysis point are presented in Figure 4.

Figure 4 - Chloride deposition at different distances and seasons of the year



Source: Organized by the authors (2022)

It can be observed that the deposition of chlorides in the first 35 m from the sea exceeded the average of $600 \text{ mg.}(\text{m}^2.\text{day})^{-1}$, reaching a maximum value of $912.77 \text{ mg.}(\text{m}^2.\text{day})^{-1}$ and a minimum of $506.72 \text{ mg.}(\text{m}^2.\text{day})^{-1}$ during the summer period. In the autumn, the average deposition was $425 \text{ mg.}(\text{m}^2.\text{day})^{-1}$, with a maximum value of $557 \text{ mg.}(\text{m}^2.\text{day})^{-1}$ and a minimum of $315.74 \text{ mg.}(\text{m}^2.\text{day})^{-1}$.

It is possible to observe a disparity between the results obtained at distances of 35 and 55 meters from the sea. Both points were allocated in the first houses facing Praia do Foguete in the city of Cabo Frio. However, station P2 was sheltered due to the circulation of vehicles in the area. Therefore, the importance of considering microenvironments within the same (in this case, marine) environment is reiterated. Although the difference between stations P1 and P2 (= 20 m) is small in the context of the marine environment, the difference between the mean chloride deposition values is quite significant (= $476 \text{ mg.}(\text{m}^2.\text{day})^{-1}$) and may be a consequence of the protection

provided to station P2. Additionally, it is noted that between the range of 1 km and 1.4 km, the results find equilibrium at an average of approximately $50 \text{ mg} \cdot (\text{m}^2 \cdot \text{day})^{-1}$.

Finally, Table 4 presents a comparison of the results obtained in this study with other studies conducted on the Brazilian coast.

Table 4 - Chloride deposition in different Brazilian states

Cabo Frio, RJ (Present study)		João Pessoa, PB (Meira <i>et al.</i>, 2006)		Florianópolis, SC (Garcia <i>et al.</i>, 2007)		Vitória, ES (Borba Jr., 2011)	
Dist [m]	Cl ⁻ mg.(m ² .day) ⁻¹	Dist [m]	Cl ⁻ mg.(m ² .day) ⁻¹	Dist [m]	Cl ⁻ mg.(m ² .day) ⁻¹	Dist [m]	Cl ⁻ mg.(m ² .day) ⁻¹
35	536,6	10	480,3	10	1095	10	502,08
55	60,4	100	117,6	100	11,5	65	62,16
710	117,4	200	19	200	21,1	120	116,65
1045	44,8	500	13,8	400	15	240	32,6
1400	48,2	-	-	600	6,5	520	9,4
-	-	-	-	1000	23,7	-	-

Fonte: Aatoria (2022)

Indication: Organized by the authors (2022)

In this way, when comparing the data shown in the Table 4, it can be observed that there is similarity and some relationship in the behavior of salinity at certain distances. However, it is also possible to observe a variation in concentration values in the area closest to the sea depending on the region. While in the Northeast, the initial concentration reaches approximately $500 \text{ mg} \cdot (\text{m}^2 \cdot \text{day})^{-1}$, in the South region this value is around $1,000 \text{ mg} \cdot (\text{m}^2 \cdot \text{day})^{-1}$. Despite the high variability inherent in environmental parameters, these averages can provide a good understanding of how these values may differ according to the environment.

4 CONCLUSIONS

The results obtained from the first two exposures indicate a region of high concentrations of aggressive ions in the first 1045 meters from the beach, with a balance found in regions of lower concentrations, that is, from 1045 m away from

the sea. There is also a greater difference in the decrease of chloride deposition from summer to autumn, which may be related to weather conditions and, mainly, wind predominance. These differences may become more evident with the contribution of the next exposures throughout the year.

In addition to the differences attributed to the chloride concentration due to the weather conditions of each season, it was also possible to observe the influence of micro-regions, a fact evidenced by the differences in the results obtained among the monitoring points.

Therefore, when observing the trend between the average depositions, the present data suggest a classification of high aggressiveness in the first 35 m, extending to distances of approximately 900 m; moderate aggressiveness between 900 and 1300 m, and minimum aggressiveness at distances above 1300 m. Thus, the importance of building a framework of data on the aggressiveness of marine environments is reiterated, contributing to the understanding of the mechanisms to which concrete will be subject during its service life and enabling improvements in normative texts that deal with the durability design of reinforced concrete structures.

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Authorship contributions

1 – Renata Cristina Fernandes Barbosa

Universidade Federal do Rio Grande, Engenharia Civil

<https://orcid.org/0000-0001-8678-7358> • re.crisfernandesb@gmail.com

Contribution: Conceptualization, Funding acquisition, Investigation, Methodology, Resources, Writing - original draft.

2 – Rodrigo César Fernandes Barbosa

Universidade Federal Rural do Rio de Janeiro, Mestrado em Química

<https://orcid.org/0000-0001-9848-4258> • rodrigocfbarbosa@gmail.com

Contribution: Data curation, Formal analysis, Funding analysis, Investigation, Resources, Methodology, Writing - review & editing

3 – Rafael Carlos Fernandes Barbosa

Universidade Estácio de Sá, Engenheiro Civil

<https://orcid.org/0000-0001-6808-0842> • rafaelcfc@gmail.com

Contribution: Funding acquisition, Investigation, Resources Writing – review & editing

4 – Carolina de Medeiros Strunkis

Universidade Federal do Rio de Janeiro, Mestre em Química

<https://orcid.org/0000-0003-1167-0096> • cmstrunkis@gmail.com

Contribution: Methodology, Writing – review & editing

5 – Evelton Alves Casartelli

Universidade Federal Rural do Rio de Janeiro, Doutorado em Química

<https://orcid.org/0000-0001-8463-1501> • eveltonc@yahoo.com.br

Contribution: Methodology, Resources, Supervision, Writing – review & editing

6 – Gustavo Bosel Wally

Universidade Federal do Rio Grande do Sul, Mestrado em Engenharia Oceânica

<https://orcid.org/0000-0003-3008-3815> • gustavo.wally@gmail.com

Contribution: Formal Analysis, Writing – review & editing

7 – Fábio Costa Magalhães

Universidade Federal do Rio Grande, Doutorado em Engenharia Civil

<https://orcid.org/0000-0001-8463-1501> • fabiocmagalhaes@gmail.com

Contribution: Conceptualization, Formal Analysis, Project administration, Supervision, Writing – review & editing

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