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Environmental variables in the concrete saturation degree modelling

Variáveis ambientais na modelagem do grau de saturação do concreto



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Abstract

Mathematical models that do not take into account local measurements were developed to make the calculation of the concrete saturation degree easier, which is assumed to be an important factor in the diffusion coefficient of chloride ions inside concrete. Many studies have already proven the influence of the saturation degree in the diffusion coefficient, and a proposed model enables the calculation of the ion diffusion coefficient, considering the variations of the saturation degree for each type of concrete. The models were developed based on a statistical analysis of the environmental variables affecting the variation of the saturation degree. As a conclusion of this study, fifteen models were developed based on the multiple linear regression, which estimate the seasonal average saturation degree of each type of concrete, leading to a maximum percentage error lower than 5%.

Keywords: diffusion coefficient, linear regression, models, maximum temperature.

Resumo

Com o objetivo de facilitar o cálculo do grau de saturação do concreto, visto que é um fator influente no coeficiente de difusão de íons cloreto no interior do concreto, foram elaborados modelos matemáticos que dispensam medições locais. Pesquisas concluídas comprovam a influência do grau de saturação no coeficiente de difusão, e um modelo proposto viabiliza o cálculo do coeficiente de difusão de íons, considerando as variações do grau de saturação para cada tipo de concreto. Os modelos foram elaborados através de análises estatísticas de variáveis ambientais que influenciam na variação do grau de saturação. Como conclusão da pesquisa elaborou-se quinze modelos obtidos pela regressão linear múltipla, que estimam o grau de saturação médio sazonal de cada tipo de concreto, gerando um erro percentual máximo, inferior a 5%.

Palavras-chave: coeficiente de difusão, regressão linear, modelos, temperatura máxima.

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1.Introduction

Many studies have been undertaken to improve the techniques and materials used in concrete buildings. Few centuries ago, it was believed that concrete would have an infinite service life, and that a concrete building would never fail or suffer from environmental influences. However, this idea ended when the first corrosion-related problems started to appear, which led to cracks and deterioration problems in need for repairs or even led to partial or total failure of large structures. Since then, engineers are engaged in understanding this concrete deterioration process.

Based on past researches, it is possible to calculate, based on a model derived from the Fick's second Law, Crank [2], the time at which the reinforcement of a concrete structure will start to be attacked by chloride ions and, hence, to be able to use prevention measures to make this attack more difficult.

This study dealt with concretes located in a mist region and, for this reason, they were considerably attacked by chloride ions present in the water droplets.

To obtain better results from the model described above, there is a need to measure the seasonal variations of the saturation degree (SD) to correlate them with the diffusion coefficient used in the model (Guimarães [3], Climent et al. [1], Nielsen e Geiker [10]).

Two previous works allowed these measurements and provided data that allowed the studies on the factors influencing the SD variation.

Guimarães [3] developed a method to measure the degree of saturation in concrete structures and Souza [11] determined, statistically, the minimum periodicity of the measurements.

SD is one of the most decisive factors in the intensity of the ingress of chloride ions in concrete structures.

Recent studies proved the importance of taking into account the SD influence on the chloride diffusion in concrete structures located in maritime environments.

According to Guimarães and Helene [6] and Guimarães [9], there is a large difference between the chloride ingress depth assumed by deterministic models and the real value found in structures located in the south of Brazil, when the SD was not accounted for.

Aiming to find models that allow obtaining approximations for the values of SD, without the need for periodical measurements, the influence of the environmental variables in the estimative of SD was studied and a group of mathematical models that allowed these approximations was obtained.

Hence, after Souza [11] conclusions, weekly measurements of SD had been carried out in the specimens used in his research for four more years, which led to the development of models capable of duplicating the SD values, with no need to measure them.

SD is a measurement related with the humidity degree of the concrete. This humidity starts in its outer layer, continuing towards its interior. As climate changes occur, the wet and dry process of the concrete starts. The aggressive agents that attack concrete (e.g. chlorides) penetrate through the outer layer of the concrete. Once inside the concrete, chlorides tend to dissipate until they reach and depassivate the steel bars. This triggers the deterioration process of the concrete.

By definition, SD is the percentage of the pore solution volume by the total volume of pores. SD is defined by the percentage of the humidity degree of the specimen's mass in relation to the water absorption after immersion and boiling. (Guimarães [7])

Previous studies proved the direct influence of the concrete SD in the diffusion of chloride ions in the interior of the concrete. Some researchers that developed their studies on topics that contributed for the maintenance and durability of concrete, examining factors that stimulate the penetration of chloride ions into concrete and

Table 1 – Grading of fine aggregate

Sieves Number	Sieves Size (mm)	Mass (g)	% retained	% accumulated	NBR 7211 Ideal	NBR 7211 Acceptable
3/8"	9.5	-	0.00	0.00	-	-
4	4.8	1.90	0.19	0.19	3 - 5.	0 - 3
8	2.4	34.50	3.45	3.64	29 - 43	13 - 29
16	1.2	166.70	16.67	20.31	49 - 64	23 - 49
30	0.6	360.20	36.02	56.33	68 - 83	42 - 68
50	0.3	353.00	35.30	91.63	83 - 94	73 - 83
100	0.15	73.30	7.33	98.96	93 - 98	88 - 93
200	0.075	8.90	0.89	99.85	< 3%	< 5%
Residue	-	1,50	0.15	100.00	-	-
Sum	-	1000	100	271.06	-	-
			Fineness modulus	2.71		

Table 2 – Grading of coarse aggregate

Sieve size (mm)	Mass etained (g)	Percentage by mass	
		Retained	Retained accumulated
76.00	0	0.00	0.00
50.00	0	0.00	0.00
38.00	0	0.00	0.00
25.00	0	0.00	0.00
19.00	1064.4	10.64	10.64
9.50	7695.2	76.95	87.60
4.80	1045.1	10.45	98.05
2.40	0	0.00	98.05
1.20	0	0.00	98.05
0.60	0	0.00	98.05
0.30	0	0.00	98.05
0.15	0	0.00	98.05
residue	195.3	1.95	-
Total	10000	100.00	686.52
Apparent specific weight (kg/l)			1.25
Absolute specific weight (kg/l)			2.62
Maximum diameter (mm)			19
Fineness modulus			6.87

models to estimate the service life of reinforced concrete structures, taking into account the influence of SD in the chloride diffusion are: Climent et al. [1], Nielssen and Geiker [10], Vicente [13], Guimarães [3], Guimarães and Helene [5 and 6], Guimarães [7], Guimarães and Helene [8], Souza et al. [12], Souza [11], Guimarães [9].

A calculation methodology for the SD was developed by Guimarães [7], based on daily measurements of SD, undertaken throughout 2004. Souza et al. [12] concluded that only one weekly measurement of SD is enough to obtain the SD behaviour during a specific season and, thus, to be able to estimate the seasonal average. With the seasonal average of SD, the model proposed by Guimarães [3] can be used to obtain the mean values of the diffusion coefficient per season and, thus, the mean annual diffusion coefficient of SD, that is, the diffusion coefficient considering the seasonal variation of SD.

The methodology used to measure SD requires a large availability of personnel as well as costs for materials. The methodology depends on the casting and measurements of mass of concrete specimens and calculations to obtain SD. Aiming to make the SD calculations easier and faster, this study aimed to elaborate mathematical models to calculate SD of each type of concrete, through environmental variables influencing the SD.

Since SD calculations are difficult, the models that estimate the service life of concrete (Crank [2]) and that do not take into account the SD influence on the ion diffusion coefficient calculations, tend to lose their accuracy. This is another factor that this study aimed for: to be able to calculate with a better accuracy the service life of concrete structures or the cover depth necessary for a certain service life to be achieved for a specific structure.

2. Materials

The materials used in this study are presented as follows. The characterisation of the materials is shown in tables 1, 2, 3 and 4. These parameters were obtained from a previous study undertaken by Souza [11], where they were compared with the values of SD.

Table 3 – Mix proportions, slump test results and specific mass of fresh concrete

Concrete	Mix proportion (c : fa : ca : w/c)*	Slump (cm)	Specific mass of fressh concrete (kg/m^3)	Cement content (kg/m^3)
Mix 1 (1:5:0.54)	1 : 2.12 : 2.88 :0.54	11	2350	359
Mix 2 (1:4:0.45)	1 : 1.60 : 2.40 : 0.45	11	2285	419
Mix 3 (1:6:0.63)	1 : 2.64 : 3.36 : 0.63	11	2325	304
Mix 4 (1:4:0.54)	1 : 1.60 : 2.40 : 0.54	22	2275	411
Mix 5 (1:6:0.54)	1 : 2.64 : 3.36 : 0.54	1,2	2325	308

* c: cement, fa: fine aggregate, ca: coarse aggregate, w/c: water to cement ratio

Table 4 – Compressive strength (MPa)

Mix	Strength at 28 days	Mean strength at 28 days	Mean strength at 60 days
1	29.37 29.90	29.63	35.88
2	32.30 33.40	32.85	38.48
3	27.80 27.80	27.80	30.33
4	28.60 31.50	30.05	36.56
5	33.70 36.00*	33.70	39.16

* Not accounted due to the 60 days results

Cement – Type CP IV 32 from Votorantin
Fine aggregate – quartz origin sand with grading according to table 1

Figure 1 – Preparation of specimens: extraction and cutting of cylinders (Souza, (10))

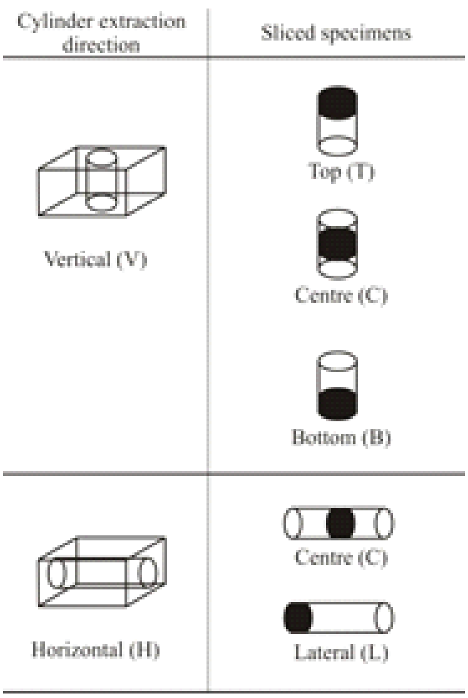
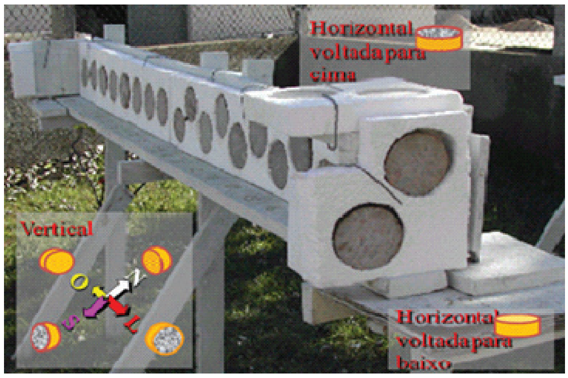


Figure 2 – Variation in the position of specimens exposed to natural environment (Souza, (10))



Coarse aggregate – granite origin crushed aggregate with grading according to table 2
Potable water

3. Methodology

With the material, five mix proportions were used: three mixes with same consistency and different w/c ratio; three mixes with the same w/c ratio and different consistencies, being one of the mixes common to both families of mixes. All mixes have the same mortar ratio of 52%. Table 3 shows the mix proportions, the slump test results and the specific mass of the fresh concrete. Table 4 presents the compressive strength at 28 and 60 days of the mixes.

Thirty concrete specimens were cast, leading to fifteen families of concrete with two specimens each. These specimens were cut (see figure 1) from 2 different cylinders of 10 cm in diameter. A disc saw was used to cut the specimens, which is usually found in concrete laboratories. The specimens were extracted from two directions (vertical and horizontal), of concrete blocks, as shown in figure 1. These slices originated thirty cylinders measuring 10 cm in diameter and 4 cm in height, which is approximately the same as the cover of steel bars. The specimens were covered with two layers of silicon, except in one of surfaces, according to the casting surface of the specimen. The dry mass of the specimens was measured prior and after to the application of the silicon layers. Once the exposure environment for the specimens was chosen, a frame made of timber and polystyrene was constructed aiming to hold the specimens, and allowing the non-covered surfaces to be partially exposed to the natural environment. The exposure surfaces were chosen by the researchers at the beginning of the study, and are shown in figure 2.

Each pair of specimens was installed together in the frame (made with timber to expose specimens), being one specimen with a humidity degree considerably low and the other considerably high. The SD measurements were only taken into account when both specimens had a similar SD value, in equilibrium with the environment.

From the thirty specimens, they were extracted in pairs from the same direction, to calculate their average variations of SD. In total, 15 families of specimens were examined, varying the extraction position, the mix proportion and the exposure in natural environ-

Table 5 – Identification of specimens

Specimen	Mix	Direction of cylinder extraction*	Exposed surface*	Position of the exposed surface	
				Direction	Position
1 and 2	1	V	C	V	S
3 and 4	2	V	C	V	S
5 and 6	3	V	C	V	S
7 and 8	4	V	C	V	S
9 and 10	5	V	C	V	S
11 and 12	1	V	T	V	S
13 and 14	1	V	B	V	S
15 and 16	1	H	L	V	S
17 and 18	1	H	C	V	S
19 and 20	1	V	C	H	UP
21 and 22	1	V	C	V	E
23 and 24	1	V	C	H	DOWN
25 and 26	1	V	C	V	N
27 and 28	1	V	C	V	W
29 and 30	1	V	C	V	LAB

Interpretation of the table. Extraction direction – vertical (V) and horizontal (H); Exposed surface – centre (C), top (T), bottom (B) and lateral (L); Position of exposed surface – direction – vertical (V) and horizontal (H); position of exposed surface – position – south (S), east (E), north (N), west (W) and interior (LAB).

ment. The measurements were carried out in pre-set dates and times, even in rainy days.
Table 5 summarizes the identification of specimens per family.
Once a week, the daily mass of each specimen was measured by a digital scale, as shown in figure 3. The dry initial mass of each specimen was also measured. Guimarães [7] established a methodology to measure SD of concrete, as shown in equations 1 and 2.

$$GS = \frac{A_d}{A_{\max}} \times 100 \quad (1)$$

$$A_d = \frac{M_d - M_{dry}}{M_{dry}} \times 100 \quad (2)$$

A_d = daily absorption
A_{max} = maximum absorption
M_d = daily mass
M_{dry} = dry mass

It is important to calculate SD due to the fact that it influences on the variation of the diffusion coefficient of chloride ions in the interior of the concrete. The diffusion coefficient of ions, however, is a variable in the equation that estimates the service life of concrete structures.

Crank [2] presents the following solution for the Fick's second Law, which estimates the service of concrete, for a constant diffusion coefficient.

$$C_{cl} = 2(z)\sqrt{D_{const.Cl^-} \times t} \quad (3)$$

C_{cl} = depth in mm
$D_{const.Cl^-}$ = effective coefficient of diffusion or diffusivity of concrete, in cm^2/year
t = service life, in years
z = Gaussian error function

The fact that the Crank [2] model does not take into account some factors influencing the diffusion coefficient, leads to an error in its result and to a lack of accuracy in the estimative. The SD factor is not commonly used in service life models. Since it is already known the importance of SD, this work aims to make easier its calculation for further consideration in the Crank's [2] model. For that, the diffusion coefficient proposed by Guimarães [3] is used, which considers the influence of the type of cement (**R_c**), mean temperature per season (**R_T**), saturation degree (**R_{SD}**) and the position of the attack surface in relation to the casting surface (**R_{CS}**) on the diffusion coefficient of the concrete.

Figure 3 – Mass measurement of specimens (Souza, (10))

$$D_{const.Cl^-(est)} = D_{const.Cl^-(lab)} R_c R_T R_{SD} R_{CS} \quad (4)$$

$D_{const.Cl^-(est)}$ = diffusion coefficient considering the exposure conditions in the micro environment

$D_{const.Cl^-(lab)}$ = diffusion coefficient obtained in laboratory in saturated concrete condition (SD = 100%)

The objective of this study is to investigate SD through environmental variables. For that, it was considered as a hypothesis that each environmental variable influences in a more or less significant way the SD of concrete. Aiming to not take into account the less significant variables, a statistical study was undertaken by measuring the linear correlation coefficients between the analysed variables and the SD. The analysed variables were: atmospheric pressure, dry air temperature, maximum temperature, minimum temperature, relative humidity, precipitation rate, internal evaporation rate (Piché), humid air temperature, insolation hours, cloudiness, visibility and external evaporation rate.

In the first statistical analysis, it could be verified that the variable showing the highest correlation was the maximum temperature (MT), except for the family 2122 (family of specimens 21 and 22), even though MT was the second highest correlation. Table 6 shows the results for this analysis for all families of concrete.

A seasonal average of SD for each family of concrete is considered in the model proposed by Guimarães [3] to calculate the diffusion coefficient of chloride ions. Therefore, since the linear correlation is high for the MT variable, simple linear regression models were developed for all these families, as a function of the average MT for each season. The model returns the average seasonal SD for each family of concrete.

Table 7 presents the models developed by simple linear regressions and their correlation coefficients (R).

To investigate the behaviour of the model regarding the SD response, it was examined the measurements of a new sample of SD (seasonal average of measurements) with the values obtained in the models.

For the research to continue, it was investigated the significance of other environmental variables for the development of models obtained through multiple linear regression. It is important to note that a variable is taken as significant in the model if the p value (significance test) is lower than 5% (0.05).

The modelling was elaborated by mathematical computational programmes that calculate the coefficients of the independent variables, the intercept coefficient and the significances of the used variables in relation to SD. The results are matrix models including sum and multiplication of matrixes.

4. Results and discussions

The highest absolute error found in the simple linear regression model was 2.73 units, which corresponds to a percentage error of 4.24% in relation to the local measurement, for the family 1920 (family of specimens 19 and 20).

The results of a second analysis with the multiple linear regression model indicate that a second variable, in the majority of the cases the relative humidity – RH, increases the correlation coefficient of the models, helping to explain the SD values obtained in the models.

Table 8 shows the models obtained by the multiple linear regression, the values of the correlation coefficient (R) and the results of the significance test (p) for each variable used in the model.

It is important to note that, for the family 1516 (family of specimens 15 and 16), the independent variables used were MT and internal evaporation rate (IER), for the family 2930 (family of specimens 29 and 30) were MT and the humid air temperature (HAT) and for the other families were MT and RH.

The same analysis of the model behaviour undertaken for the simple linear regression was carried out for the models of multiple linear regression analysis. The highest calculated absolute error was of 2.47 units, which corresponds to a percentage error of 3.83% for the family 1920 (family of specimens 19 and 20).

The fact that a second variable have increased the correlation coefficient of the model, what can be observed by comparing tables 7 and 8, indicates that the multiple linear regression is better adjusted to the proposed objective, leading to a maximum percentage error lower than 5%.

The lowest correlation coefficients calculated are referent to the specimens with the surface turned up, lateral or down or to the specimens exposed to laboratory conditions. Notwithstanding, the multiple linear regression model generated better results.

To develop the models, it was investigated a possible time shift of SD in response to the environmental variables. Once verified that there was not a shift higher than 24 hours, it was not necessary to adjust time in the models.

Since the multiple linear regression model adjusted better to the proposed objective, this model was utilised as a standard for a guide that can be consulted in the design of SD for each type of concrete structure. Table 9 shows this guide.

It was not possible to compare the results obtained with other studies, since it was not found references of models for the calculation of SD through environmental variables. New mod-

Table 6 – Correlations of concrete families with environmental variables

Variable/SD	Mean correlations of 2004-2007							
	SD 12	SD 34	SD 56	SD 78	SD 910	SD 1112	SD 1314	SD 1516
Atmospheric pressure	0.44	0.44	0.43	0.42	0.40	0.40	0.41	0,39
Dry air temperature	-0.70	-0.67	-0.68	-0.67	-0.66	-0.65	-0.60	-0,63
Maximum temperature	-0.74	-0.70	-0.73	-0.72	-0.72	-0.70	-0.62	-0,68
Minimum temperature	-0.64	-0.61	-0.61	-0.61	-0.59	-0.58	-0.54	-0,57
RH	0.52	0.51	0.42	0.38	0.43	0.41	0.58	0,35
Precipitation rate	0.33	0.24	0.27	0.28	0.28	0.29	0.17	0,25
Evaporation rate	-0.68	-0.66	-0.67	-0.67	-0.69	-0.69	-0.57	-0,64
Humid air temperature	-0.65	-0.62	-0.65	-0.65	-0.62	-0.62	-0.52	-0,61
Insolation	-0.48	-0.44	-0.45	-0.45	-0.50	-0.50	-0.40	-0,44
Cloudiness	0.33	0.28	0.32	0.32	0.35	0.36	0.25	0,31
Visibility	-0.28	-0.26	-0.29	-0.29	-0.36	-0.34	-0.21	-0,30
External evaporation rate	-0.38	-0.41	-0.38	-0.37	-0.39	-0.38	-0.39	-0,36

Variable/SD	Mean correlations of 2004-2007						
	SD 1718	SD 1920	SD 2122	SD 2324	SD 2526	SD 2728	SD 2930
Atmospheric pressure	0.43	0.41	0.36	0.27	0.33	0.46	0.12
Dry air temperature	-0.65	-0.60	-0.53	-0.42	-0.57	-0.66	-0.23
Maximum temperature	-0.69	-0.63	-0.55	-0.47	-0.63	-0.70	-0.30
Minimum temperature	-0.59	-0.53	-0.49	-0.36	-0.50	-0.60	-0.18
RH	0.46	0.57	0.62	0.44	0.40	0.47	0.18
Precipitation rate	0.25	0.27	0.15	0.09	0.28	0.23	0.03
Evaporation rate	-0.64	-0.63	-0.51	-0.45	-0.57	-0.63	-0.27
Humid air temperature	-0.61	-0.54	-0.45	-0.35	-0.53	-0.62	-0.20
Insolation	-0.43	-0.54	-0.38	-0.31	-0.41	-0.40	-0.14
Cloudiness	0.29	0.40	0.23	0.22	0.31	0.27	0.13
Visibility	-0.25	-0.10	-0.29	-0.25	-0.32	-0.28	-0.18
External evaporation rate	-0.37	-0.38	-0.39	-0.32	-0.29	-0.36	-0.18

els are being studied for high initial strength concretes, thus allowing a future comparison of results.

5. Conclusions

The main conclusion of this research was the possibility to adjust two models, one originated from a simple linear regression and another from a multiple linear regression, to obtain with good accuracy the values of mean SD in the seasonal periods, for concrete with pozzolanic cement for structures located in maritime zone, in the south of Brazil.

There is an indication that the use of the models may reduce personnel and material costs spent for the local measurements of SD. Once defined the type of concrete used in a structure as well as its position in relation to the exposure surface, the most appropriate model to calculate the mean SD for the four seasons can be chosen. After this calculation is performed, the result obtained from the model proposed by Guimarães [3] is used to determine the corresponding diffusion coefficient. This coefficient as well as the values of other variables are input data for Crank's [2] model based on the second Fick's Law to estimate the service life of concrete structures. Moreover, it can be concluded that there is no time shift higher than 24 hours in the response of SD to the maximum temperature, relative humidity, internal evaporation rate and humid air temperature.

Finally, table 9 can be used as a guide of models that can be consulted for the calculation of SD in each type of concrete structure, in the analysed region.
This study has its limits in the South of Brazil, in a mist zone, ensuring local results only, and a new study is necessary to use the models in other regions.

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Table 7 – Models obtained by simple linear regression

$SD_{12} = -0.7122MT + 76.138$ $R = 0.7351$	$SD_{1718} = -0.6432MT + 78.270$ $R = 0.6867$
$SD_{34} = -0.6124MT + 74.50$ $R = 0.7039$	$SD_{1920} = -0.6104MT + 73.579$ $R = 0.6337$
$SD_{56} = -0.7861MT + 78.906$ $R = 0.7262$	$SD_{2021} = -0.6190MT + 73.655$ $R = 0.5531$
$SD_{78} = -0.7461MT + 81.244$ $R = 0.7178$	$SD_{2324} = -0.2236MT + 52.195$ $R = 0.4747$
$SD_{910} = -0.6623MT + 70.901$ $R = 0.7171$	$SD_{2526} = -0.5519MT + 73.595$ $R = 0.6331$
$SD_{1112} = -0.6736MT + 71.899$ $R = 0.7048$	$SD_{2728} = -0.7793MT + 74.031$ $R = 0.7039$
$SD_{1314} = -0.3999MT + 61.701$ $R = 0.6220$	$SD_{2930} = -0.1126MT + 46.664$ $R = 0.2970$
$SD_{1516} = -0.7536MT + 78.466$ $R = 06761$	

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Table 8 – Models obtained by multiple linear regression

$M_{12} = [59.648] + [MT \;\; RH] \times \begin{bmatrix} -0.60695 \\ 0.17501 \end{bmatrix}$ R=0.7797; p_{MT}=2.75E-26; p_{RH}=6.9E-08	$M_{1718} = [65.29077] + [MT \;\; RH] \times \begin{bmatrix} -0.56039 \\ 0.13775 \end{bmatrix}$ R=0.7188; p_{MT}=3.47E-21; p_{RH}=5.643-05
$M_{34} = [59.794] + [MT \;\; RH] \times \begin{bmatrix} -0.51848 \\ 0.15607 \end{bmatrix}$ R=0.7499; p_{MT}=1.21E-22; p_{RH}=3.52E-07	$M_{1920} = [51.659] + [MT \;\; RH] \times \begin{bmatrix} -0.47042 \\ 0.23264 \end{bmatrix}$ R=0.7231; p_{MT}=8.47E-16; p_{RH}=1.3E-10
$M_{56} = [68.207] + [MT \;\; RH] \times \begin{bmatrix} -0.71778 \\ 0.11355 \end{bmatrix}$ R=0.7417; p_{MT}=7.49E-26; p_{RH}=0.0026	$M_{2122} = [41.01789] + [MT \;\; RH] \times \begin{bmatrix} -0.41065 \\ 0.34638 \end{bmatrix}$ R=0.7104; p_{MT}=7.1E-10; p_{RH}=4.18E-15
$M_{78} = [73.47328] + [MT \;\; RH] \times \begin{bmatrix} -0.69650 \\ 0.08247 \end{bmatrix}$ R=0.7269; p_{MT}=2.23E-25; p_{RH}=0.025	$M_{2324} = [43.45735] + [MT \;\; RH] \times \begin{bmatrix} -0.16777 \\ 0.092734 \end{bmatrix}$ R=0.5529; p_{MT}=2.78E-07; p_{RH}=7.67E-06
$M_{910} = [60.82999] + [MT \;\; RH] \times \begin{bmatrix} -0.59804 \\ 0.10689 \end{bmatrix}$ R=0.7363; p_{MT}=1.09E-24; p_{RH}=0.001	$M_{2526} = [63.78509] + [MT \;\; RH] \times \begin{bmatrix} -0.48927 \\ 0.10411 \end{bmatrix}$ R=0.6560; p_{MT}=4.76E-17; p_{RH}=0.002
$M_{1112} = [62.71975] + [MT \;\; RH] \times \begin{bmatrix} -0.61501 \\ 0.09742 \end{bmatrix}$ R=0.7198; p_{MT}=1.36E-23; p_{RH}=0.0047	$M_{2728} = [58.42597] + [MT \;\; RH] \times \begin{bmatrix} -0.67968 \\ 0.16561 \end{bmatrix}$ R=0.7362; p_{MT}=7.18E-2; p_{RH}=2.67E-05
$M_{1314} = [46.10837] + [MT \;\; RH] \times \begin{bmatrix} -0.30037 \\ 0.16548 \end{bmatrix}$ R=0.7242; p_{MT}=8.46E-15; p_{RH}=9.72E-12	$M_{2930} = [47.74959] + [MT \;\; HAT] \times \begin{bmatrix} -0.46501 \\ 0.42559 \end{bmatrix}$ R=0.4086; p_{MT}=4.13E-07; p_{HAT}=4.91E-05
$M_{1516} = [76.05208] + [MT \;\; IER] \times \begin{bmatrix} -0.49714 \\ -0.99674 \end{bmatrix}$ R=0.7098; p_{MT}=2.07E-08; p_{IER}=5.09E-05	

Cement and Concrete Research, 2003; p. 133-138.
[11] SOUZA, K. N. Estudo experimental e probabilístico da vida útil de estruturas de concreto armado situadas em ambiente marítimo: influência do grau de saturação do concreto sobre a difusividade de cloretos. Dissertação (Mestrado em Engenharia Oceânica). FURG - Universidade Federal do Rio Grande, Rio Grande, 2005. In Portuguese.
[12] SOUZA, K. N., GUIMARÃES A. T. C., ALMEIDA, T. L. and HELENE, P. R. L. Um método de medição do grau de saturação em estruturas de concreto. *In:* Teoria e Prática na Engenharia Civil, 2005, p. 53-57. In Portuguese.

Table 9 – Guide of appropriate models for each type of concrete

Structures	Type of concrete (Pozzolanic)	Model
Subjected to weather	Mix 1, with surface exposed to south and w/c 0.54	$M_{12} = [59.648] + [MT \;\; RH] \times \begin{bmatrix} -0.60695 \\ 0.17501 \end{bmatrix}$
	Mix 2, with surface exposed to south and w/c 0.45	$M_{34} = [59.794] + [MT \;\; RH] \times \begin{bmatrix} -0.51848 \\ 0.15607 \end{bmatrix}$
	Mix 3, with surface exposed to south and w/c 0.63	$M_{56} = [68.207] + [MT \;\; RH] \times \begin{bmatrix} -0.71778 \\ 0.11355 \end{bmatrix}$
	Mix 4, with surface exposed to south and w/c 0.54	$M_{78} = [73.47328] + [MT \;\; RH] \times \begin{bmatrix} -0.69650 \\ 0.08247 \end{bmatrix}$
	Mix 5, with surface exposed to south and w/c 0.54	$M_{910} = [60.82999] + [MT \;\; RH] \times \begin{bmatrix} -0.59804 \\ 0.10689 \end{bmatrix}$
	Mix 1, with up surface exposed and w/c 0.54	$M_{1920} = [51.659] + [MT \;\; RH] \times \begin{bmatrix} -0.47042 \\ 0.23264 \end{bmatrix}$
	Mix 1, with surface exposed to east and w/c 0.54	$M_{2122} = [41.01789] + [MT \;\; RH] \times \begin{bmatrix} -0.41065 \\ 0.34638 \end{bmatrix}$
	Mix 1, with surface exposed to north and w/c 0.54	$M_{2526} = [63.78509] + [MT \;\; RH] \times \begin{bmatrix} -0.48927 \\ 0.10411 \end{bmatrix}$
	Mix 1, with surface exposed to west and w/c 0.54	$M_{2728} = [58.42597] + [MT \;\; RH] \times \begin{bmatrix} -0.67968 \\ 0.16561 \end{bmatrix}$
Covered and open	Mix 1, with down surface exposed and w/c 0.54	$M_{2324} = [43.45735] + [MT \;\; RH] \times \begin{bmatrix} -0.16777 \\ 0.092734 \end{bmatrix}$
Dry interiors	Mix 1 and w/c 0.54	$M_{2930} = [47.74959] + [MT \;\; HAT] \times \begin{bmatrix} -0.46501 \\ 0.42559 \end{bmatrix}$