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Comparative evaluation of the loss of mass, under the effect of corrosion, and the corrosion rate that initiates the cracking of asphalt concrete, steel bars for reinforced concrete used in constructions in Senegal

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ABSTRACT: This article presents the study of the behaviour of reinforced concrete steels, used in constructions in Senegal, under the effect of corrosion. The study is carried out on locally manufactured steels from three (03) companies located in Senegal and on control bars imported from France. Type 1 (E1), Type 2 (E2) and Type 3 (E3) steels are locally manufactured and Type 4 (E4) steels come from France. For each type of steel, samples with diameters of 8 mm, 10 mm and 12 mm were used. Mass losses were evaluated after immersion of these samples in a corrosive solution. For each type of steel and for all the diameters studied, the corrosion rate that initiates cracking of the asphalt concrete was evaluated from the actual diameter of the bars and the thickness of the nominal coating. From the mass lost over time, correlations between duration and mass loss were established for all diameters of the different types of steel. These relationships made it possible to calculate the time required to reach the corrosion rate that initiates concrete cracking. The results indicate that 66.67% of the steels studied, of local manufacture, have a corrosion time that initiates cracking of concrete lower than that of the control bars imported from France. Type E1 steels with a diameter of 8 mm have a duration to reach the corrosion rate that causes cracking of concrete, equal to 49.71% of the duration of type E4 steels. These results indicate that the steels used in construction in Senegal do not have the same behaviour vis-à-vis corrosion.

KEYWORDS: Local manufacturing, structure, quality of materials, reinforcement, durability.

1 INTRODUCTION

For the durability of reinforced concrete constructions, it is essential to use reinforcements with good corrosion resistance [1]. Indeed, corrosion of steels can have several consequences on reinforced concrete structural elements. Among the consequences, we can note a reduction in the section of the reinforcement in a state of corrosion, which can lead to a decrease in the resistant moment. This reduction of the resistant moment can go as far as the collapse of the structure. In Senegal, there are local companies that manufacture reinforcement for reinforced concrete. However, there is no independent body that certifies the quality of steels before they are used in constructions. The final report of a technical commission of May 2021 [2], following building collapses in Senegal, under the direction of the Ministry of Urban Planning, Housing and Public Hygiene, indicates that the poor quality of materials is one of the causes of building collapse in Senegal.

Reinforced concrete steels, used in construction in Senegal, are imported or manufactured by locally based companies. For the safety and durability of constructions, the choice of quality materials is necessary. Knowledge of the characteristics of materials by construction stakeholders is often lacking during construction, especially steel. At the time of construction, the actors have no information on the quality of the steels, to adapt their choice of materials according to the level of exposure of the structure.

Corrosion of steels in structures made of reinforced concrete often causes cracks on the asphalt concrete. In this case, the time it takes before the structure gives way depends essentially on the rate of loss of mass of the steels.

Research has shown that the loss of mass of steels caused by corrosion leads to a loss of adhesion between steel and concrete [3-7], at the level of reinforced concrete structures. Sulaiman et al. have shown, in the course of their work, that the shear stress decreases with increasing the degree of corrosion of steels [4]. For a fixed corrosion rate, the results indicate that the decrease in adhesion stress is more significant on larger diameter reinforcements.

These authors also showed that the high rate of corrosion leads to a loss of adhesion between steel and concrete. The results obtained through the results indicate the importance of having information on the sensitivity of locally manufactured steels to corrosion.

Knowledge of the rate of mass lost over time, at the level of steels, makes it possible to evaluate the rate of corrosion. The determination of the loss of mass, corroded steels, over time and the corrosion rate that initiates the cracking of concrete, make it possible to have a characterization of locally manufactured steels vis-à-vis their behavior in the face of corrosion. To date, no scientific study has evaluated, comparatively, the loss of mass, under the effect of corrosion and the corrosion rate that initiates the cracking of asphalt concrete, reinforced concrete steels used in the construction sector in Senegal.

The aim of this article is to study the behaviour of locally manufactured steel under the effect of corrosion compared to steels imported from France. Correlations between duration and loss of mass as well as the corrosion rate that initiates concrete cracking for each type of steel, for diameters 8 mm, 10 mm and 12 mm, are also presented.

2 MATERIALS AND METHODS

The steel bars used in our research were obtained directly from suppliers who sell to companies at the time of construction. Indeed, during the execution phase of the work, a large part of the companies buy the steels directly at the level of retail suppliers. Locally produced steels are sometimes identifiable by the initials of the producing company. For this study, three (03) types of locally manufactured steels and one type (01) of steel imported from France, which serves as a control material, are used. To ensure anonymity:

- locally manufactured steels are designated: type 1 (E1), type 2 (E2) and type 3 (E3);
- telltale steels from France are designated: type 4 (E4).

To avoid any confusion about the origin of the bars, only bars with the trademarks of the companies concerned are used. The study concerns steel bars with diameters of 8 mm, 10 mm and 12 mm, for each type.

The chemical composition of steel bar with a diameter of 10 mm, for all types studied (E1, E2, E3 and E4) is presented in Table (1) [8].

Table 1. Chemical compositions of 10 mm diameter steel bars [8]

Samples	Chemical elements - Contents (% mass)										
	C	S	P	N	Cu	Mn	V	Cr	Ni	Mo	Ceq
E1 (Loc.)	0.15	0.046	0.036	0.0088	0.22	0.544	0.0028	0.109	0.076	0.013	0.29
E2 (Loc.)	0.09	0.012	0.014	0.01	0.26	0.364	0.0012	0.101	0.125	0.017	0.2
E3 (Loc.)	**0.31**	0.041	0.028	0.0089	0.24	0.706	0.0037	0.181	0.094	0.018	0.49
E4 (Imp.)	0.22	0.03	0.022	0.001	0.45	0.626	0.0021	0.121	0.127	0.02	0.39

To assess the amount of mass lost, all types of steels are subjected to the same conditions of exposure to corrosion. For the conduct of the tests, a number of devices are required. An electronic balance was used for mass measurements, a pH meter (Figure 1) to indicate the pH (Hydrogen Potential) and temperature of the solution. Seawater, taken directly from the Atlantic Ocean in Dakar, was used as a corrosive solution.

Fig. 1. ***pH – Meter (Multi 350i/SET)***

After obtaining steels with diameters Ø8, Ø10 and Ø12, for each type, six (06) lengths of 10 cm were cut on the same bar. The specimens used are six (06) for each diameter of locally manufactured steels imported from France. Once the bars have been cut by 10 cm in length as shown in Figure (2), they are cleaned with sandpaper and then rinsed with distilled water and dried. The purpose of this step is to remove dirt and possible deposits on the surface of the steel bars used.

Fig. 2. ***Measurement of sample length for mass determination***

Each bar is placed in a container. For testing, seventy-two (72) containers, each containing 300 grams of corrosive solution, were used (Figure 3).

Fig. 3. Vessels used to assess the loss of mass of steels after immersion in a corrosive solution

The bars are then weighed using the electronic scale, to measure their initial mass (Mi), and placed in the containers.

After this step, the pH and temperature of the seawater are measured with the pH – meter. The average ambient temperature of the medium is 25 °C. The seawater is then poured into the containers containing the samples. Every thirty (30) days, the masses (Mj) are measured after cleaning the steel bars with distilled water and then brushed and dried. The pH of the solution also measured at this stage.

At each measurement, the lost mass is estimated from equation (1).

$$M = M_i - M_j \quad (1)$$

With:

M : Mass lost (in grams) during the period;

M_i : Initial mass of the bar (in grams);

M_j : Mass of the bar at the time of measurement (in grams).

For the rest of the test, the seawater used is changed after each measurement. After immersion for another thirty (30) days, the steps indicated above are repeated. The operation is performed for one hundred and eighty (180) days. The amount of mass lost is the average of the six (06) results of each diameter.

Excel was used for data processing, in particular for the calculation of the Standard Deviation and the correlations between the immersion time of the bars in the corrosive solution and the amount of mass lost for each type of bar studied for steels with diameters 8 mm, 10 mm and 12 mm.

Corrosion leads to an increase in the volume of steels. Thus, the pressure exerted on the asphalt concrete can cause cracking. The corrosion rate that initiates the cracking of concrete, steels used in constructions in Senegal with a coating of 20 mm, was evaluated on the basis of equation (2) obtained from the work of Thierry Vidal et al [9].

$$\%c=100\left[1-\left[1-\frac{\left[60.24+74.56\left({}^{e}/_{\emptyset_0}\right)\right].10^{-3}}{\emptyset_0}\right]^2\right] \quad (2)$$

With:

%c: corrosion rate that initiates cracking of concrete;
e : coating thickness (in mm);
ϕ_0 : diameter of the reinforcement (in mm).

The loss of mass at the level of the steels also impacts its characteristics, in particular the actual cross-section of the bar. For the determination of the residual section, after loss of mass, equation (3) was used [9].

$$A_s = \left(1 - \frac{\% c}{100}\right) A \qquad (3)$$

With:

A_s : residual section of the reinforcement (in cm^2);
$\% c$: corrosion rate that initiates cracking of concrete;
A : initial section of the reinforcement (in cm^2).

3 RESULTS AND DISCUSSION

In this section, the results obtained from the mass loss tests and the corrosion rates that cause cracking of the concrete as well as the residual sections of the steel bars studied are presented.

3.1 LOSS OF MASS OF STEEL BARS

The amount of mass lost of bars of diameter 8 mm, 10 mm and 12 mm, for each type (E1, E2, E3 and E4), as a function of the immersion time in the corrosive solution is shown in Table (2). The results were obtained from equation (1).

Table 2. Quantity of mass lost by steels with diameters 8 mm (a), 10 mm (b) and 12 mm (c) after immersion in a corrosive solution as a function of time, for each type (E1, E2, E3 and E4)

(a)

Duration (days)	Lost mass - Diameter 8 mm							
	E1		E2		E3		E4	
	Mass lost (grams)	Standard Deviation	Mass lost (grams)	Standard Deviation	Mass lost (grams)	Standard Deviation	Mass lost (grams)	Standard Deviation
30	0.112	0.019	0.157	0.012	0.098	0.015	0.120	0.024
60	0.442	0.125	0.320	0.040	0.200	0.052	0.272	0.050
90	0.768	0.117	0.483	0.041	0.298	0.042	0.418	0.044
120	1.100	0.133	0.653	0.040	0.408	0.042	0.562	0.056
150	1.315	0.093	0.757	0.044	0.512	0.032	0.673	0.050
180	1.475	0.079	0.873	0.021	0.623	0.032	0.798	0.041

(b)

Duration (days)	Lost mass - Diameter 10 mm							
	E1		E2		E3		E4	
	Mass lost (grams)	Standard Deviation	Mass lost (grams)	Standard Deviation	Mass lost (grams)	Standard Deviation	Mass lost (grams)	Standard Deviation
30	0.172	0.036	0.120	0.014	0.153	0.014	0.107	0.020
60	0.343	0.058	0.287	0.037	0.473	0.169	0.298	0.052
90	0.525	0.044	0.453	0.040	0.800	0.193	0.480	0.048
120	0.717	0.059	0.593	0.027	0.958	0.078	0.655	0.045
150	0.868	0.057	0.707	0.012	1.100	0.079	0.780	0.042
180	0.995	0.030	0.825	0.019	1.307	0.116	0.897	0.027

(c)

Duration (days)	Lost mass - Diameter 12 mm							
	E1		E2		E3		E4	
	Mass lost (grams)	Standard Deviation	Mass lost (grams)	Standard Deviation	Mass lost (grams)	Standard Deviation	Mass lost (grams)	Standard Deviation
30	0.208	0.022	0.230	0.024	0.152	0.020	0.143	0.023
60	0.565	0.108	0.445	0.067	0.345	0.051	0.330	0.041
90	0.873	0.211	0.653	0.032	0.517	0.042	0.493	0.038
120	0.987	0.022	0.862	0.046	0.680	0.053	0.635	0.015
150	1.117	0.054	1.012	0.058	0.818	0.057	0.797	0.064
180	1.315	0.019	1.150	0.034	0.965	0.064	0.915	0.036

Tables (2a, b and c) show that steels used in construction in Senegal do not behave in the same corrosive environment.

Figure (4) shows the status of the solution at the time of measurements. This change can be explained by the presence of corrosion products.

Fig. 4. Colour change of corrosive solution at measurement time

The pH values of the solutions measured during tests are given in Table (3).

Table 3. pH measured at solution level for steels with diameters 8 mm (a), 10 mm (b) and 12 mm (c)

(a)

Duration (days)	**pH of solutions - Diameter 8 mm**			
	E1	**E2**	**E3**	**E4**
Initial (to)	8.74	8.74	8.74	8.74
30	7.98	8.10	8.15	8.05
60	7.71	7.88	7.95	8.10
90	7.99	7.85	7.88	7.89
120	7.87	7.59	7.67	7.59
150	7.78	7.89	7.75	7.75
180	7.98	8.05	7.94	7.97

(b)

Duration (days)	**pH of solutions - Diameter 10 mm**			
	E1	**E2**	**E3**	**E4**
Initial (to)	8.74	8.74	8.74	8.74
30	8.26	7.36	8.10	7.61
60	8.05	4.49	7.65	7.55
90	7.85	7.80	7.49	7.51
120	8.10	7.52	7.55	7.55
150	7.95	7.59	7.66	7.72
180	7.97	7.81	7.91	7.85

(c)

	pH of solutions - Diameter 12 mm			
Duration (days)	E1	E2	E3	E4
Initial (to)	8.74	8.74	8.74	8.74
30	8.26	7.42	8.38	7.51
60	7.13	7.41	7.50	7.49
90	7.89	7.40	7.48	7.47
120	7.57	7.41	7.46	7.52
150	7.80	7.56	7.56	7.54
180	7.90	7.85	7.89	7.82

Tables (3 a, b and c) indicate a decrease in the pH value, after thirty (30) days of immersion, for all types of bar studied. This decrease is due to a decrease in OH- ions or acidification of the medium. Indeed, in the presence of chloride, corrosion begins by pitting phenomenon after the formation of micro-batteries. According to Sandberg [10] and Bodian [11], these chloride ions act:

- By the formation of $FeCl_3$ or $FeCl_2$ ions, from reactions:

$$F_e \rightarrow F_e^{2+} + 2e^- \quad (4)$$

$$F_e + 3Cl^- \rightarrow FeCl_3^- + 2e^- \quad (5)$$

$$Fe^{2+} + 2Cl^- \rightarrow FeCl_2 \quad (6)$$

- Then, the ions formed consume the hydroxides present, according to the reactions:

$$FeCl_3^- + 2OH^- \rightarrow Fe\,(OH)_2 + 3Cl^- \quad (7)$$

and in the absence of oxygen in sufficient quantity:

$$FeCl_2 + 2OH^- \rightarrow Fe(OH)_2 + 2Cl^- \quad (8)$$

or in the presence of oxygen in sufficient quantity:

$$4FeCl_2 + 2O_2 + 6H_2O \rightarrow 4FeO.OH + 8HCl \quad (9)$$

These reactions show on the one hand that chloride ions are permanently "recycled", and on the other hand that the consumption of OH- ions (Equations (7) and (8)) leads to a decrease in the pH of the medium. In the presence of oxygen, which is in our case, equation (9) shows an acidification of the medium which explains the decrease in the pH of the medium with the immersion time of the steels in the corrosive solution.

The variation in pH values, depending on the type of steel, could be explained by the difference in the nature of the materials lost at the bar level over time.

In Table (4), the types of reinforcement studied are classified according to their level of sensitivity to corrosion, for the same diameter. A type classified "1" being less sensitive and a type classified "4" being the most sensitive.

Table 4. Classification of the 8 mm, 10 mm and 12 mm bars studied according to their level of corrosion resistance after immersion in seawater

Samples	Classification of steel bars			
	E1	E2	E3	E4
Diameter 8 mm	4	3	1	2
Diameter 10 mm	3	1	4	2
Diameter 12 mm	4	3	2	1

The results obtained show that locally produced steels do not have the same level of sensitivity to a corrosive environment. It was also noted that the behaviour of locally produced steels depends on their diameter. Indeed, the classification of bars according to their susceptibility to corrosion is not the same according to the diameters.

These observations can be explained by a difference in the raw material used by companies for the manufacture of bars. Rebar is made from ferrous waste (scrap metal as raw material), but also from imported billets. There is also the lack of certification of steels used in construction in Senegal, to guarantee the quality of materials. The chemical composition of 10 mm steel bar (E1, E2, E3 and E4), presented in Table (1), will be used to analyze their level of corrosion susceptibility. The results show that locally produced steels do not have the same chemical composition. Since carbon can play a harmful role in relation to the corrosion of steels [12], its low rate, with a value of 0.09%, at the level of type E2 steels may justify the fact that they are less sensitive to corrosion. The 0.31% carbon content of type E3 steels could justify the amount of mass lost compared to other types. The carbon content of type E3 steels is also higher than the limit value of 0.24% for the weldability of reinforced concrete steels according to standard NF EN 10080 [13].

In addition, although type E4 steels have a higher carbon content value (0.22%), they have a better behavior than type E1 steels. This result can be explained by the rate of 0.45% copper at type E4 bars, while E1 has a copper rate of 0.26%. Indeed, copper increases the resistance of the bar to corrosion [14].

3.2 CORROSION RATE THAT INITIATES CRACKING AND RESIDUAL SECTION

For each type (E1, E2, E3 and E4), the corrosion rate that initiates cracking was determined from equation (2). This rate, which depends on the thickness of the coating of the steels and the diameter of the bar, makes it possible to evaluate the behaviour of steels used in constructions in Senegal.

The corrosion rate that initiates cracking was calculated for each type of steel, for diameters 8 mm, 10 mm and 12 mm. The results are presented in Table (5).

Table 5. Corrosion rate that initiates cracking of steels of types E1 (a), E2 (b), E3 (c) and E4 (d) for diameters 8mm, 10mm and 12 mm

(a)

Type steels - E1			
Reinforcement type	**Actual diameter (mm)**	**C: Cover (mm)**	**%C**
Ø8	7,81	20	6,322
Ø10	9,54	20	4,489
Ø12	11,55	20	3,254

(b)

Type steels – E2			
Reinforcement type	**Actual diameter (mm)**	**C: Cover (mm)**	**%C**
Ø8	7,82	20	6,315
Ø10	9,68	20	4,376
Ø12	11,64	20	3,212

(c)

Type steels – E3			
Reinforcement type	**Actual diameter (mm)**	**C: Cover (mm)**	**%C**
Ø8	7.76	20	6.405
Ø10	9.50	20	4.523
Ø12	11.64	20	3.212

(d)

Type steels – E4			
Reinforcement type	**Actual diameter (mm)**	**C: Cover (mm)**	**%C**
Ø8	7.85	20	6.268
Ø10	9.92	20	4.200
Ø12	11.90	20	3.096

Equation (2) and the results presented in Table (5) show that the corrosion rate that initiates cracking decreases with increasing the diameter of the bar.

Since the resistant moment of reinforced concrete structures depends on the steel section, it is essential to evaluate the steel bar section at the time of cracking. The residual section, at the corrosion rate that initiates cracking, was evaluated from equation (3). Table (6) shows the residual section values for each type of bar for nominal diameters of 8mm, 10mm and 12mm.

Table 6. Residual sections according to the corrosion rate that initiates cracking steels of types E1, E2, E3 and E4 for diameters 8 mm, 10 mm and 12 mm – Cnom = 20 mm

(a)

	E1		
	Ø8	Ø10	Ø12
%C	6.322	4.489	3.254
Dr (mm)	7.815	9.540	11.545
A (mm^2)	47.962	71.476	104.688
As (mm^2)	44.929	68.267	101.281

(b)

	E2		
	Ø8	Ø10	Ø12
%C	6.315	4.376	3.212
Dr (mm)	7.820	9.683	11.636
A (mm^2)	48.025	73.644	106.331
As (mm^2)	44.993	70.422	102.916

(c)

	E3		
	Ø8	Ø10	Ø12
%C	6.405	4.523	11.636
Dr (mm)	7.756	9.497	11.636
A (mm^2)	47.248	70.839	106.344
As (mm^2)	44.222	67.635	93.970

(d)

	E3		
	Ø8	Ø10	Ø12
%C	6.268	4.200	3.096
Dr (mm)	7.854	9.920	11.896
A (mm^2)	48.445	77.284	111.146
As (mm^2)	45.409	74.038	107.706

With:

Dr: Actual diameter (mm)
A: Actual section (mm^2)
As: Residual section (mm^2)

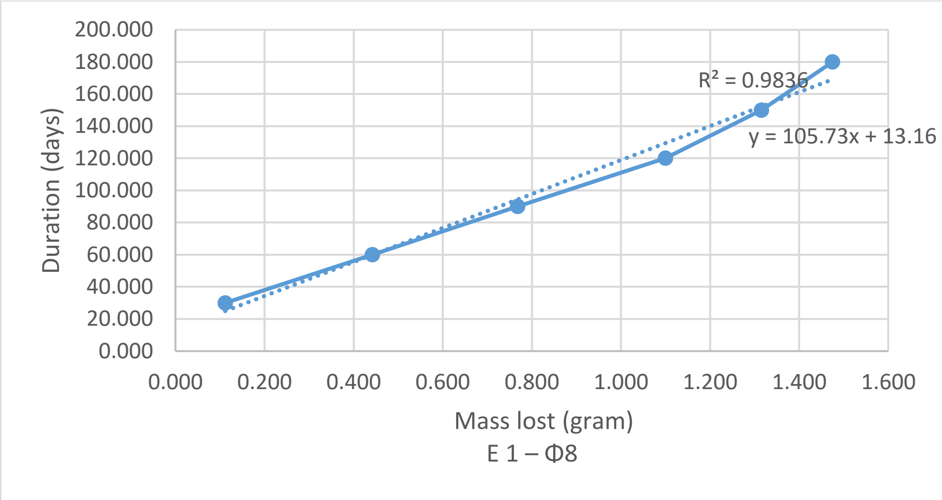
The results show that at the time of cracking, the cross-section of the steels decreases significantly. This reduction in section leads to a decrease in the strength of the structural elements.

3.3 Relationship between immersion time and corrosion rate

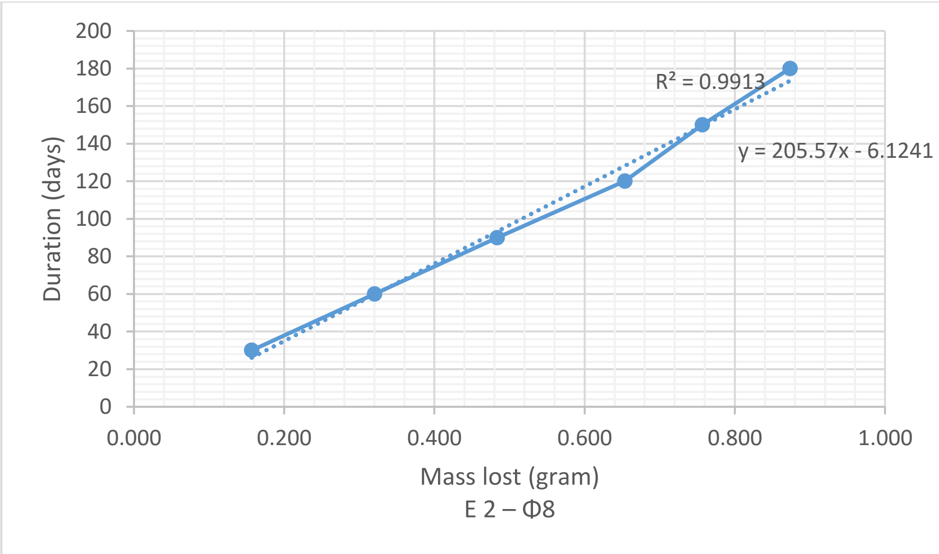
From the results of tests on the loss of mass of steels, correlations between the immersion time of the steels in a corrosive solution and the quantity of mass lost were established. These correlations concern all the diameters studied (8 mm, 10 mm and 12 mm) for each type (E1, E2, E3 and E4).

Figures (5, 6 and 7) show the experimental diagrams of the time required for the loss of a quantity of steel mass, for bars of nominal diameters 8 mm, 10 mm and 12 mm for types E1 (a), E2 (b), E3 (c) and E4 (d). The equations of the linear regression line and the coefficients of determination (R2) are also shown in the diagrams.

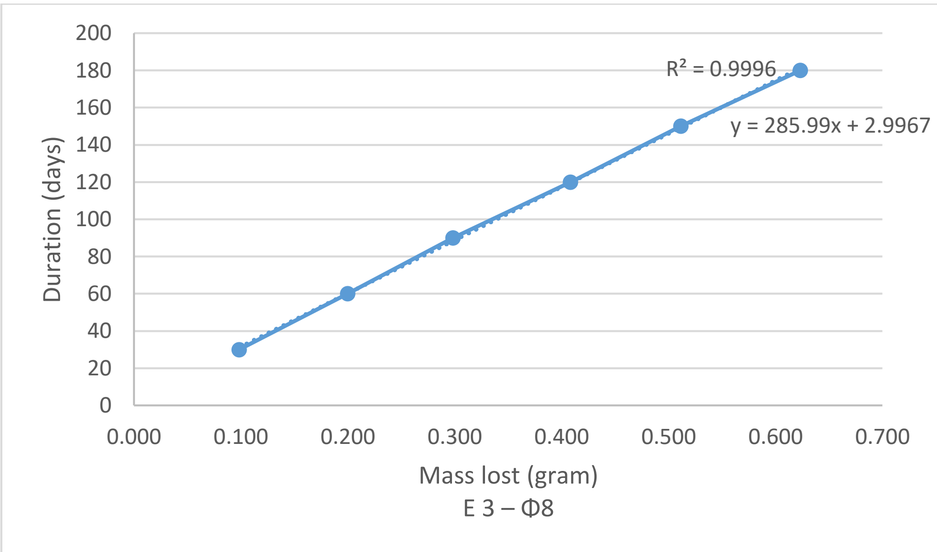
In the equations in figures (5, 6 and 7), "x" and "y" correspond respectively to the amount of mass lost and the duration of immersion in the corrosive solution.


200.000
180.000
160.000
140.000
120.000
100.000
80.000
60.000
40.000
20.000
0.000
Duration (days)
R^2 = 0.9836
y = 105.73x + 13.16
0.000
0.200
0.400
0.600
0.800
1.000
1.200
1.400
1.600
Mass lost (gram)
E 1 – Φ8

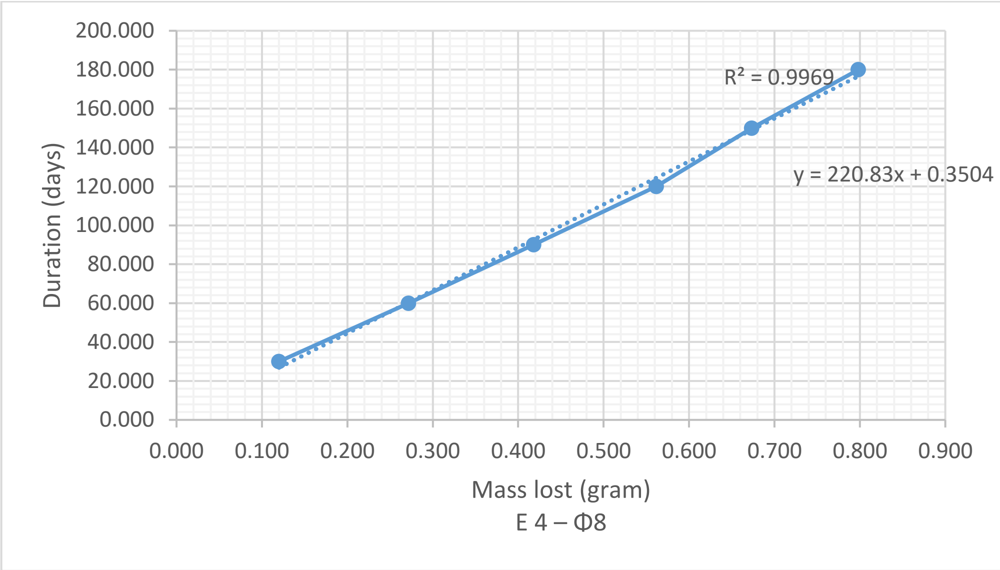
(a)


200
180
160
140
120
100
80
60
40
20
0
Duration (days)
R^2 = 0.9913
y = 205.57x - 6.1241
0.000
0.200
0.400
0.600
0.800
1.000
Mass lost (gram)
E 2 – Φ8

(b)


200
180
160
140
120
100
80
60
40
20
0
Duration (days)
R^2 = 0.9996
y = 285.99x + 2.9967
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Mass lost (gram)
E 3 – Φ8

(c)

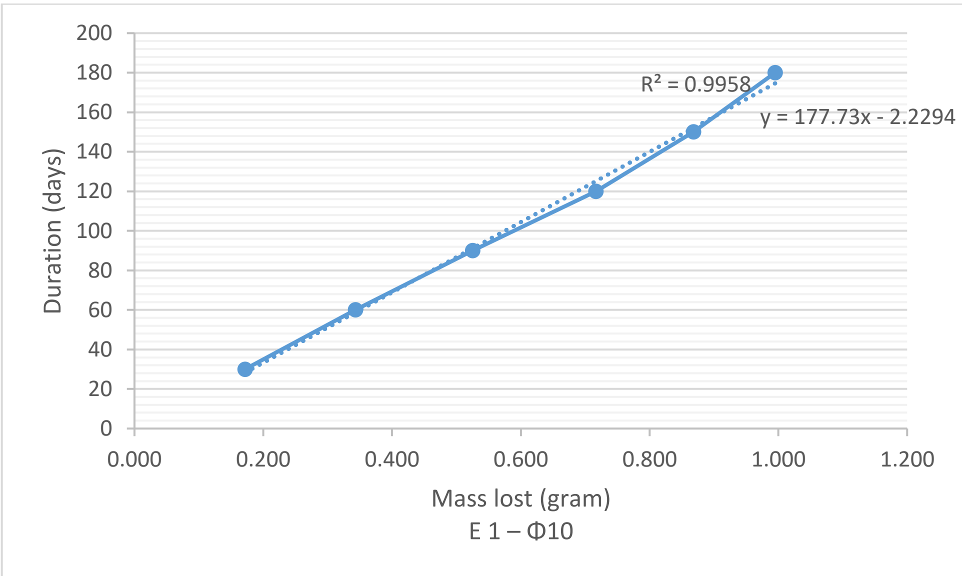


(d)

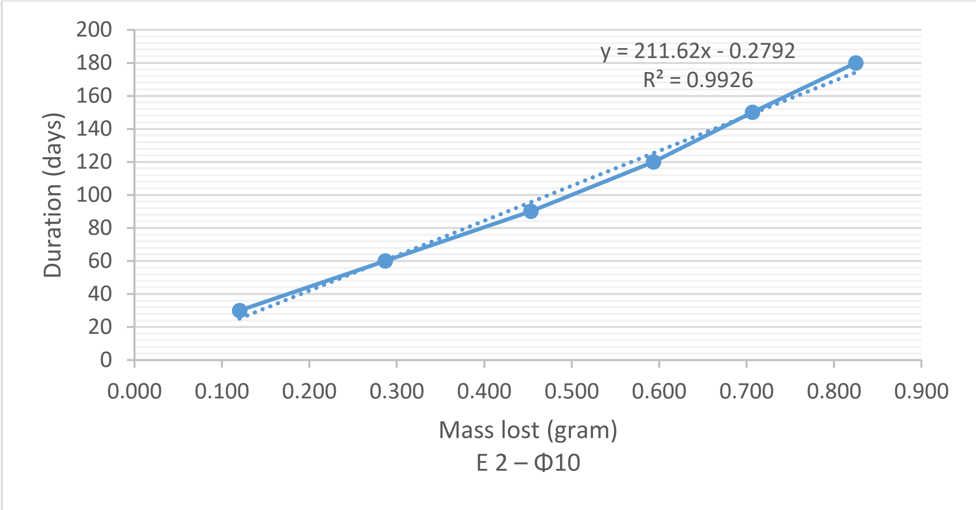
Experimental curve;

Linear regression line.

Fig. 5. Evolution of the immersion time as a function of the quantity of mass lost - Steels of types E1 (a), E2 (b), E3 (c) and E4 (d) for diameters 8mm

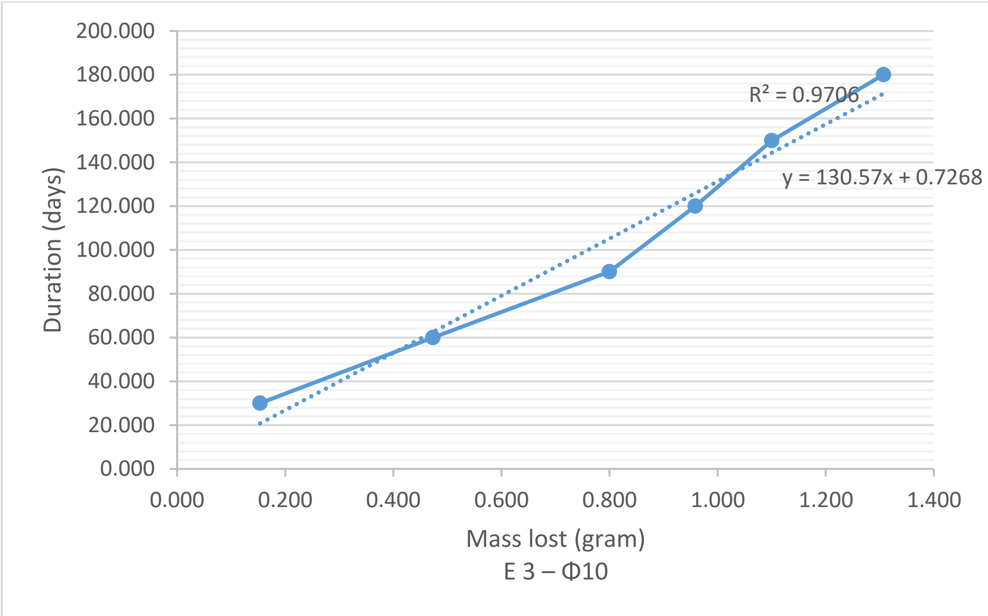


(a)



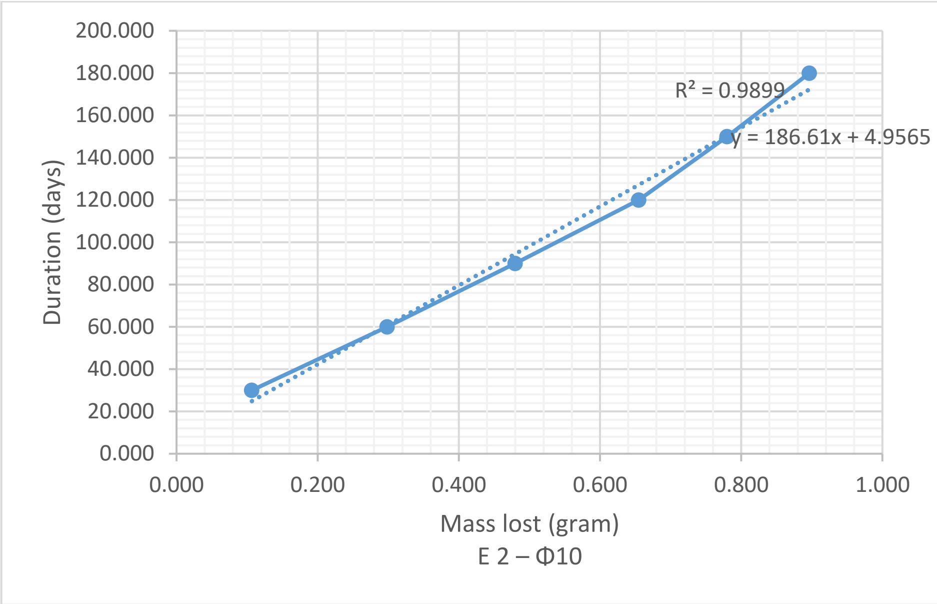
y = 211.62x - 0.2792
R² = 0.9926
Duration (days)
Mass lost (gram)
E 2 – Φ10

(b)



R² = 0.9706
y = 130.57x + 0.7268
Duration (days)
Mass lost (gram)
E 3 – Φ10

(c)

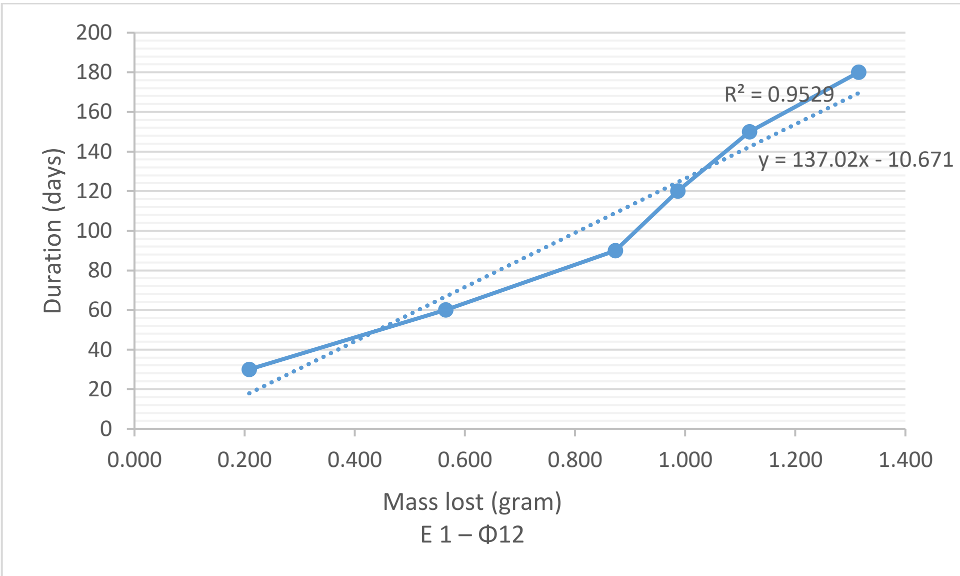


(d)

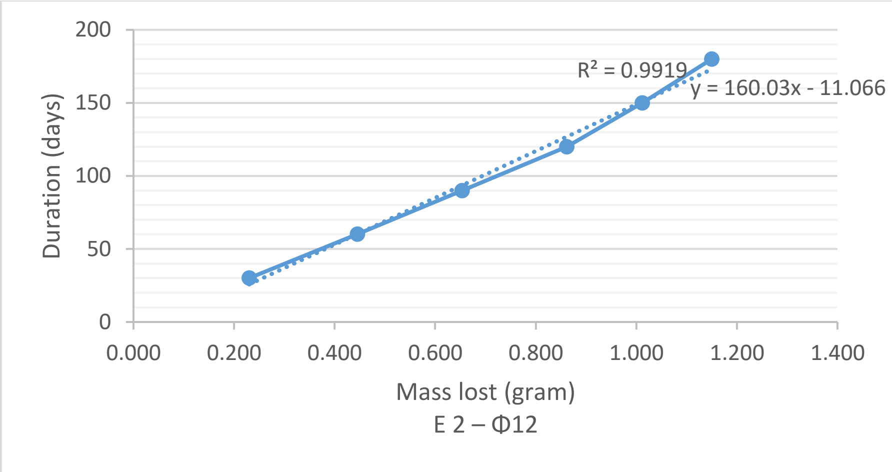
Experimental curve;

Linear regression line.

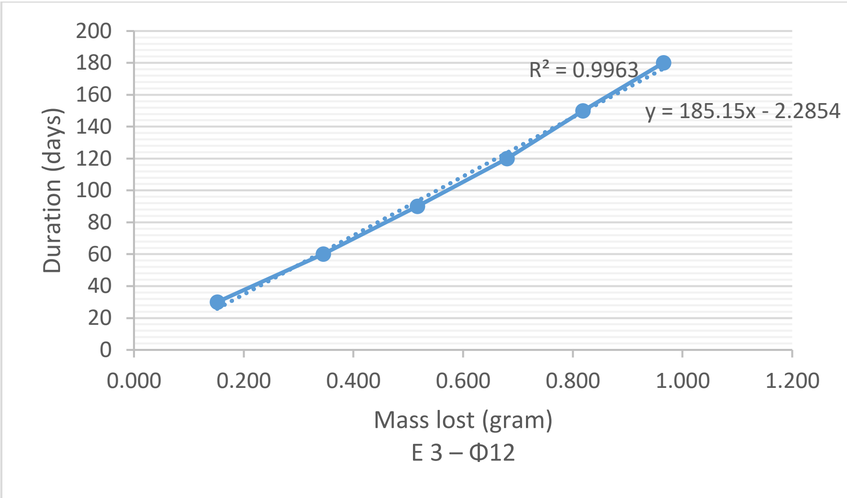
Fig. 6. ***Evolution of the immersion time as a function of the quantity of mass lost - Steels of types E1 (a), E2 (b), E3 (c) and E4 (d) for diameters 10mm***



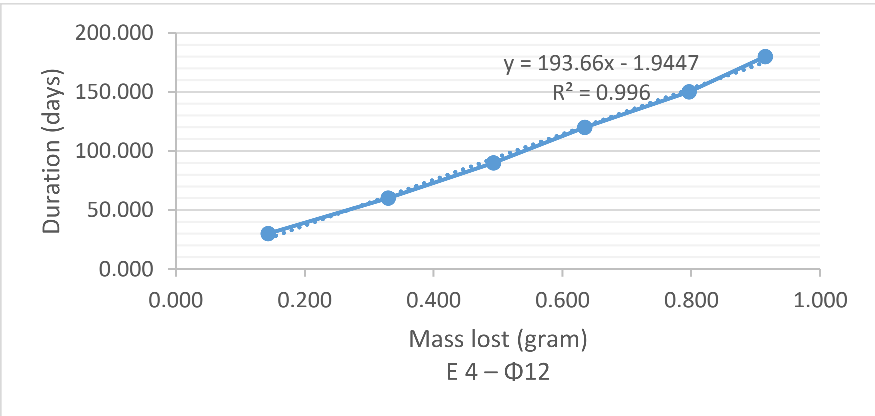
(a)



(b)



(c)



(d)

Experimental curve;

Linear regression line.

Fig. 7. ***Evolution of the immersion time as a function of the quantity of mass lost - Steels of types E1 (a), E2 (b), E3 (c) and E4 (d) for diameters 12mm***

The results show that locally produced steels do not have the same corrosion behaviour. The relationships obtained from the linear regression lines, with good values of determination coefficients, make it possible to determine the time required to have a given quantity of mass loss.

Table (7) shows the useful time to achieve the loss of mass which initiates cracking for each type of steel studied, respectively for diameters 8mm, 10mm and 12mm.

Table 7. Time required to reach the corrosion rate of steels that causes cracking of asphalt concrete - Steels of types E1, E2, E3 and E4 for diameters 8 mm (a), 10 mm (b) and 12 mm (c) – Cnom = 20 mm

(a)

	Ø8			
	E1	**E2**	**E3**	**E4**
Initial mass (gram)	37.65	37.70	37.09	38.03
%C	6.322	6.315	6.405	6.268
Mass lost (gram)	2.381	2.381	2.376	2.384
Duration (days)	265	483	682	527

(b)

	Ø10			
	E1	**E2**	**E3**	**E4**
Initial mass (gram)	56.10	57.80	55.60	60.70
%C	4.489	4.376	4.523	4.200
Mass lost (gram)	2.518	2.529	2.515	2.550
Duration (days)	330	447	532	481

(c)

	Ø12			
	E1	**E2**	**E3**	**E4**
Initial mass (gram)	82,18	83,47	83,48	87,25
%C	3,254	3,212	3,753	3,096
Mass lost (gram)	2,674	2,681	3,133	2,701
Duration (days)	356	419	578	521

The results presented in Table (7) indicate that steels do not have the same duration to reach the corrosion rate that initiates cracking of asphalt concrete. This difference can be explained by the nature of the raw materials used in the manufacture of the products and the lack of independent control of the quality of the basic products. In addition, only locally manufactured steels type E3, for all diameters (8 mm, 10 mm and 12 mm), have a necessary duration that initiates the cracking of concrete longer than the duration of type E4 steels (control bars).

4 CONCLUSION

For the durability of constructions, it is essential to use quality materials. All the parameters that can go in the direction of the safety of the constructions must be taken into account. In the final report of May 2021 of a technical commission [2], following collapses, it is indicated that the poor quality of materials is one of the causes of building collapse observed in Senegal. In most cases, it is found that the steels are at a very advanced level of degradation. The results obtained in the context of our work make it possible to realize that the steels used in constructions do not have the same behavior in the face of corrosion. Thus, it will be essential to integrate this parameter for the certification of locally manufactured reinforcements. This will allow the actors of the construction to choose suitable bars according to the class of exposure of the structure. The results indicate that 66.67% of the locally manufactured steels studied (for bars of diameter 8 mm, 10 mm and 12 mm) have a corrosion time that initiates cracking of the asphalt concrete lower than that of the control bars imported from France. For type E1 steels with a diameter of 8 mm, the time to reach the corrosion rate that initiates cracking is almost half the duration of steels imported from France (Type E4).

These results may constitute basic elements for the classification of reinforced concrete steels used in constructions in Senegal. Knowledge of the behaviour of locally manufactured steels vis-à-vis corrosion also makes it possible to have elements for the study of the effectiveness of corrosion inhibitors. Electrochemical tests can be carried out in addition to evaluate the corrosion kinetics of the different types of steels studied.

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