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Investigations on Atmospheric Corrosion of Low carbon Steel in Mauritius through Mass Loss and 2D

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Abstract

Losses due to corrosion have been found to make a significant impact on the economy of many countries. Worldwide, studies have shown that the overall cost of corrosion amounts to at least 4-5% of the gross national product, and the major contributor to this cost is atmospheric corrosion. Determining the corrosivity of the atmosphere in any country is essential as it would enormously facilitate the task of selecting materials, protection systems, maintenance intervals, and corrosion allowance for metallic structures exposed outdoors.

Mauritius, being a tropical country, has an atmosphere which promotes atmospheric corrosion. This paper attempts to investigate the corrosion behaviour of the Mauritian atmosphere on low carbon steel through mass loss and 2D surface analysis. Outdoor atmospheric corrosion experiments were conducted at one test site in Mauritius. It was found to fall in category C3 as per ISO 9223.

2D surface roughness analysis, using R_a, R_q, and R_{dq} and R_{sm}, were used to model the corrosion process at the chosen site. Studies being conducted at the other sites will help formulate a generic corrosivity model for Mauritius.

Keywords: Atmospheric corrosion, mass loss, corrosivity, surface roughness.

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1. INTRODUCTION

Losses due to corrosion have been found to make a significant impact on the economy of many countries. In India, for example, corrosion damage is estimated to be responsible for losses to the national economy amounting to around £2.5 billion per year (Bhaskar *et al.* 2004). Worldwide, studies have shown that the overall cost of corrosion amounts to at least 4-5% of the gross national product, and the major contributor to this cost is atmospheric corrosion (Morcillo *et al.* 1993).

Atmospheric corrosion has a very detrimental effect on steel structures. Understanding the corrosion behaviour, proper materials selection to suit specific atmospheres, choosing effective protection systems, and performing regular maintenance can reduce the effects of atmospheric corrosion.

Mauritius, being a tropical country, consists of an atmosphere which promotes atmospheric corrosion. Steel is being commonly used in the fabrication of structures and construction of buildings. The import of iron and steel into Mauritius has constantly increased in recent years (Central Statistics Office, 2008). Hence, investigating and modelling the atmospheric corrosion behaviour of low carbon steel has become a necessity especially for designers, practitioners, and researchers.

Several studies have been performed worldwide to investigate the effect of atmospheric corrosion on carbon steels. Veleva & Maldonado (1998) investigated the effect of time of wetness, sulphur dioxide and chloride contaminant concentrations, and exposure angle on the corrosion rate of carbon steel in the tropical humid climate of the Yucatan Peninsula, Mexico. Four test sites were chosen: one rural and three marine-coastal. It was found that the mass loss of the carbon steel can be described by the equation:

$$C = At^{B} \qquad \text{equation (1)}$$

where C is the mass loss, t is the time of wetness corresponding to each exposure period, A is the annual mass loss and B is the exponent. The corrosivity at the sites was also classified according to ISO 9223.

Natesan *et al.*(2005) studied the atmospheric corrosion behaviour of engineering materials, among which was mild steel, at 40 exposure stations throughout India. It was observed that the corrosion rate of mild steel varied widely, ranging from 0.01 mmpy to 1.6 mmpy. The corrosion, however, is area specific and not region specific. For example, along the east as well as the west coasts, different corrosion rates could be observed, indicating that corrosion can be either in the lowest or in the highest range even though the location is on the coastline. Five stations were in the highest range (extremely severe corrosivity) with an annual corrosion rate of greater than 200 μm/year. The high corrosion rate at these sites was attributed to either high airborne salinity level or high level of sulphur dioxide, and high relative humidity.

The atmospheric corrosion behaviour of carbon steel at four sites in the tropical climate of south of Vietnam was investigated in terms of the environmental factors by Lan *et al.* (2006). It was observed that the mass loss could be expressed by the equation:

$$M = At^b. \qquad \text{equation (2)}$$

Where M is the mass loss in g/m^2, t is the time of exposure in years, and A and b are constants, where the power b can be considered as a measure of a growth law of the corrosion products (parabolic or linear).

The corrosivity at three of the four sites fell in category C3 according to ISO 9223. Two of the sites consisted of chloride-dominated environments while the third one was sulphur-dominated. The fourth site consisted of a sulphur-dominated environment and its corrosivity fell in category C4.

The surface texture of a metal is identified as an important factor affecting its corrosion resistance (Petropopulos & Pandazaras, 2003; Burakowski & Werzchon, 1998); the lower the roughness the higher the resistance. A rise in surface roughness intensifies corrosion process by development of real surface contact of the element subjected to corrosion, creating possibilities for accumulation of surface contaminants. The greatest influence on the extent of corrosive wear is connected with asperity height, spacing parameters, as well as the radius of recess in the roughness profile (Burakowski & Werzchon, 1998).

Reddy *et al.*(2005) performed a detailed experimental study and analysis of the effect of residual stresses in medium carbon steel (0.48 % carbon content) in a corrosive environment on ground components. The average roughness, R_a, was used describe the surface texture of the ground surfaces. It was concluded that grinding parameters have profound influence on the residual stress and microstrain induced which, on their side, affect the corrosion behaviour in a material.

Hassiotis & Petropopulos (2006) have, on their side, investigated the influence of surface roughness on the corrosion resistance of turned carbon steel parts. The surfaces, as machined and after the application of an accelerated alternate immersion corrosion test, were examined stereoscopically and studied using a multiparameter roughness analysis. It was revealed that the samples exhibited different corrosion behaviour according to the machining conditions and the type of steel considered. Close correlation between corrosion resistance and surface roughness parameters was evident, also allowing the introduction of a roughness index which is directly related to the weight loss due to corrosion. The corrosion index, however, used the profile real length, R_{lo}, as one of its roughness parameters which is rarely used and which is not included in the new ISO 4287 (1997). R_{lo} is a hybrid parameter which characterises the profile openness and gives an indication of the true surface area.

This paper attempts to investigate the corrosion behaviour of the Mauritian atmosphere on low carbon steel through mass loss and 2D surface analysis using a variety of 2D roughness parameters.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

Low carbon steel specimens of size 150 mm×100 mm×3mm were used in this study. All the specimens were cut from the same sheet. Each of them were subsequently weighed to the nearest 0.001g and preserved. The specimens were then exposed outdoors at Reduit (Mauritius) according to BS EN ISO 8565.

The percentage composition of the main alloying elements in the low carbon steel used is as shown in Table 1.

Carbon	Sulphur	Manganese	Phosphorus	Silicon	Nickel	Chromium	Copper
0.246	0.027	0.238	-	0.004	0.024	0.026	0.033

Table 1 – Percentage composition of the main alloying elements in low carbon steel

After the times of exposure of approximately 3, 7, 13, and 19 months, the specimens were removed in sample size of 4. They were cleaned, according to BS 7545 and, consequently, their mass loss and their corrosion rate were determined.

After cleaning the samples, it was observed that the surfaces of the base metal of the specimens were very rough and this roughness increased with exposure time. The roughness was produced due to the porosity of the rust layer and analysing the roughness of the base metal would consequently indicate the progress of the atmospheric corrosion process. Therefore to further investigate the effect of corrosion in modifying the surface, the surface roughness of the base metal of the corroded specimens, after cleaning, was measured. Hence, in addition to the mass loss analysis, the surface roughness of the base metal of the corroded specimens was measured. The following parameters were selected for analysis (Whitehouse,1994):

- R_a- It refers to the average roughness of the surface.
- R_q – It is the root mean square deviation.
- R_{dq} – The root mean square slope. It is same to slope measurement of the profile as R_q is for the amplitude.
- R_{sm}- It is the average distance between positive crossings of the profile with mean line.

For each removal, one cleaned sample was selected randomly and used for the determination of the 2D surface roughness of the base metal. Measurements were performed on the surface which was exposed skyward. The surface roughness measurements were performed on the central surface area using the Talysurf series 2 from Taylor and Hobson.

Five measurements were taken per specimen. The traverse length was set at 50 mm basically to observe the profile of the surface. For determining the roughness parameters, the cut-off length was set to 2.5 mm, due to fact that large pits were easily observed by visual inspection, and the robust Gaussian filter was used. Roughness parameters R_a, R_q, R_{dq}, and R_{sm} were then determined from the profiles obtained.

3. RESULTS

The results of average mass loss against days of exposure of the samples are shown in Table 2 and fig. 1.

Removal	Days after exposure	Average mass loss (g)	Average corrosion loss (μm/year)
1	78.9	3.023	57.7
2	213.1	8.360	59.0
3	391.9	11.203	43.0
4	596.0	13.046	33.0

Table 2- Results of the average mass loss of the specimens

In fig. 1, a trendcurve of the form $M = \mathrm{A}t^{0.5}$ has been fitted from the average mass loss data, which represents a corrosion process which is diffusion controlled as described by Graedel & Leygraf (2000).

The profiles of the surfaces of the base metal of the exposed specimens, after cleaning, are shown in figures 2(a) to 2(d). The roughness parameters measured are shown in Table 3.

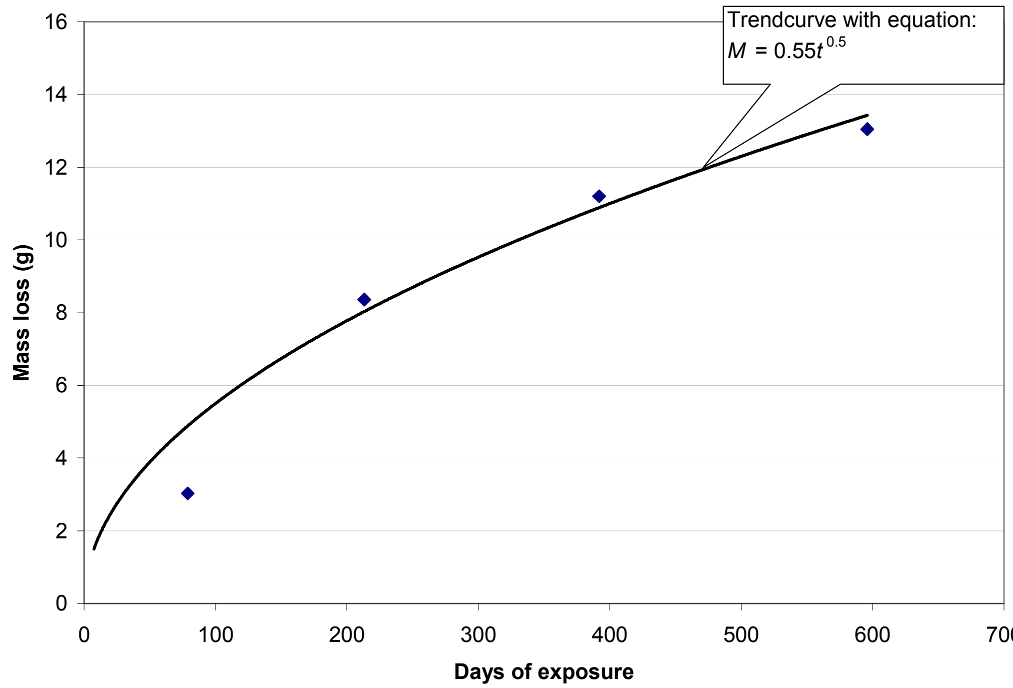

Fig. 1- Graph of average mass loss (sample size of 4) against days of exposure

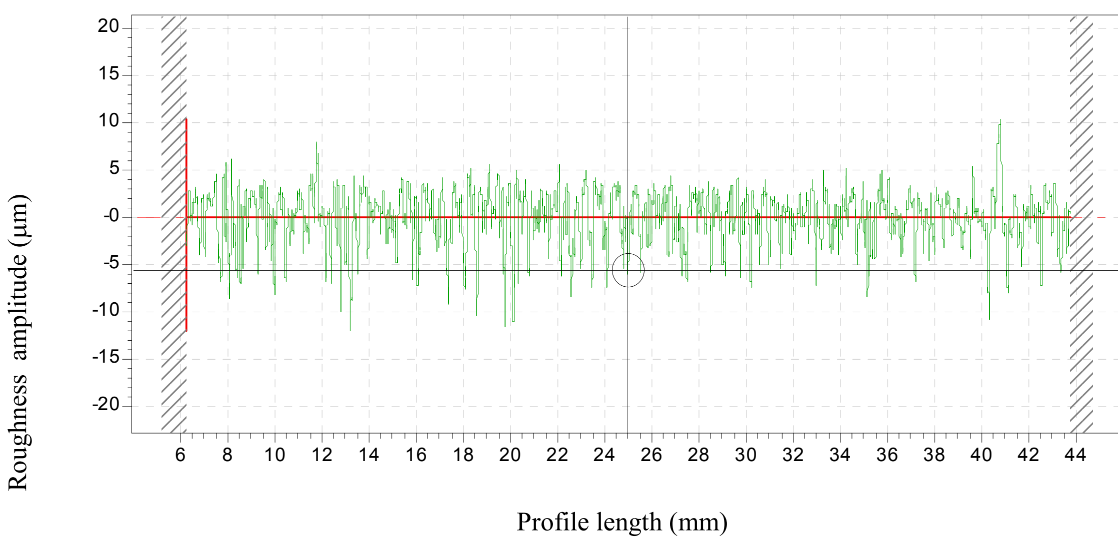

Fig. 2 (a)- Roughness amplitude against profile length for 1st removal

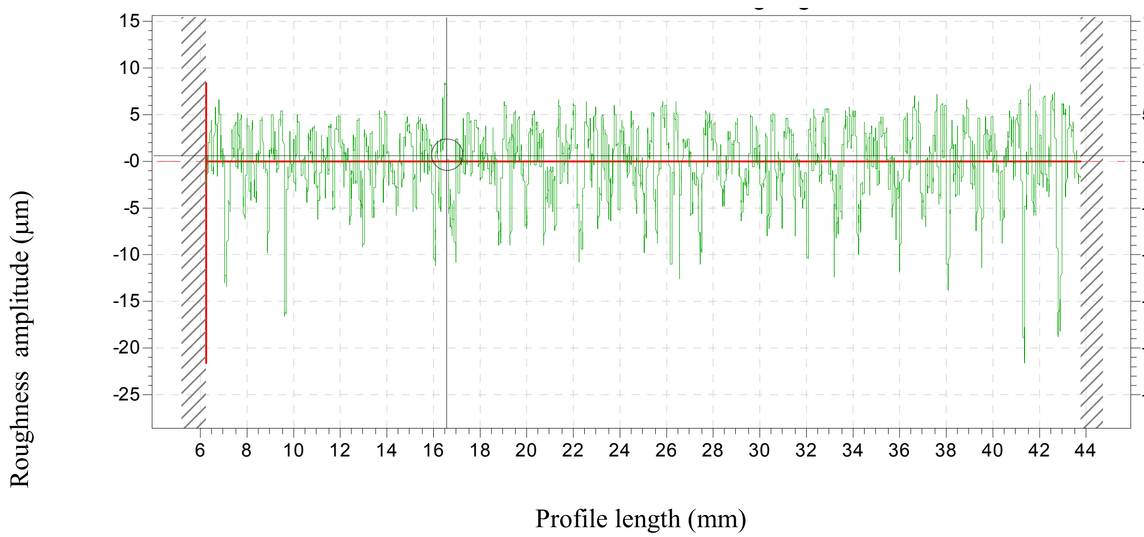

Fig. 2 (b) - Roughness amplitude against profile length for 2nd removal

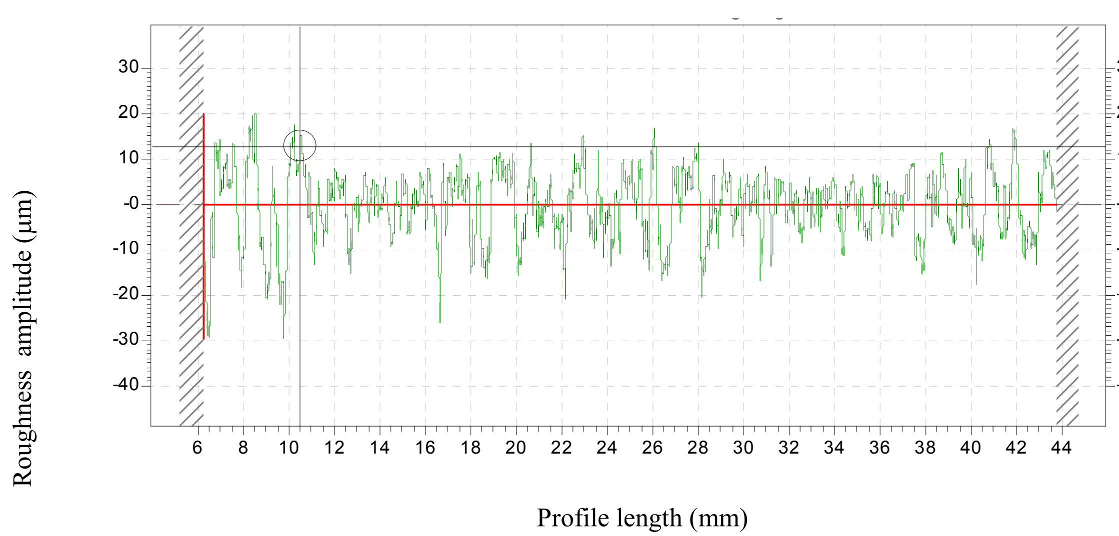

Fig. 2(c)- Roughness amplitude against profile length for 3rd removal

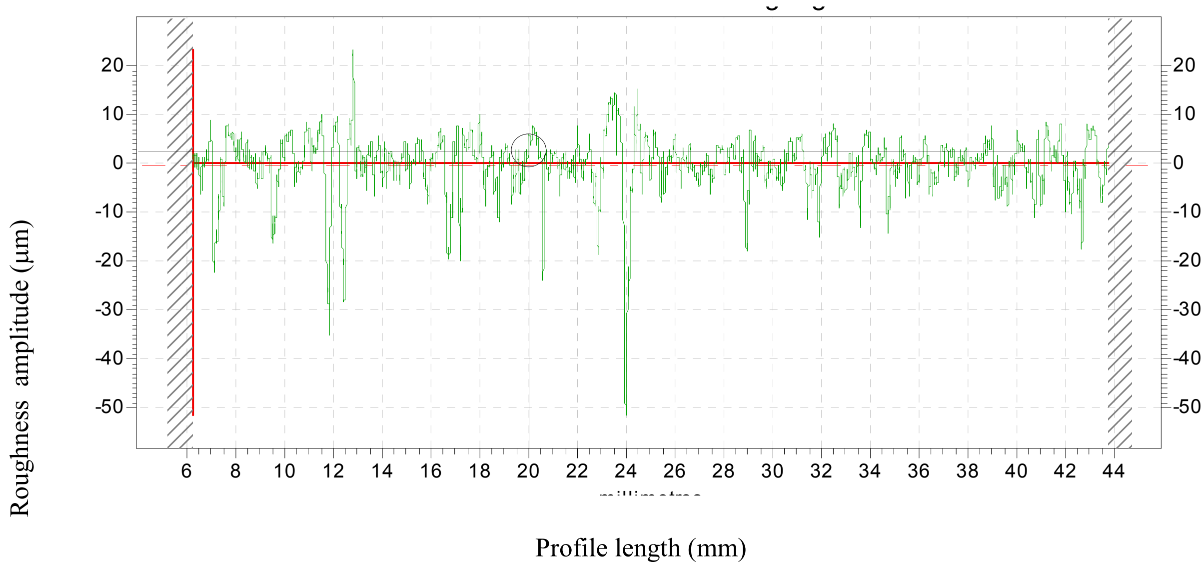

Fig. 2 (d) - Roughness amplitude against profile length for 4th removal

Days after removal	**Mass loss(g)**	**R_a(µm)**	**R_q(µm)**	**R_{dq} (µm)**	**R_{sm}(µm)**
78.9	2.87	2.528	4.046	5.931	413.19
213.1	8.226	3.1919	4.144	6.671	455.5
391.9	12.113	6.082	7.757	8.538	669.93
596	15.224	4.124	6.536	7.968	825.94

Table 3- Surface roughness parameters

4. DISCUSSION

As described in fig. 1, the atmospheric corrosion process is found to be diffusion controlled. This implies that the rust layer acts as a protective barrier thus forcing the ions from the corroding metal to diffuse through the film, react, precipitate, and increase the film thickness further (Feng-I-Wei,1991; Graedel & Leygraf, 2000; Morcillo *et al.* 1994).

From the trendcurve, the mass loss after one year of exposure was calculated and which is given by 10.5g. This represents an average corrosion rate of 333 gm^{-2}/year. According to ISO 9223, the atmosphere at Reduit can therefore be classified into category C3, which refers to an atmosphere with medium corrosivity.

The corrosion behaviour prior to the first removal appears to drift away from the trendcurve obtained. This is explained by the fact that the rust layer was still thin, implying that it can not protect the base metal and therefore the corrosion process is general and not diffusion controlled. This can be supported by the small values of R_a, R_q, and R_{dq} and R_{sm} as recorded in Table 3 and the surface profile obtained as shown in fig. 2(a).

With time the rust layer becomes thicker, more compact, and more protective. The corrosion attack proceeds through available pores in the rust layer, more localised on a microscopic scale, as shown in fig. 3 (Hoerle *et al.*, 2004). This causes the formation of pits on the surface of the metal which, on its side, causes a slight increase in the amplitude, spacing and hybrid parameters as shown by their values for the second and third removal. This can also be confirmed from Table 3 and the surface profile of figures 2(b) and 2(c).

For the fourth removal, as the corrosion attack continues to proceed through pores, the pits become even larger and the peaks tend to flatten. Thus the value for R_a, R_q, and R_{dq} shows a decrease, while that for R_{sm} continues to increase as shown in Table 3.

The whole corrosion process is described in fig. 4.

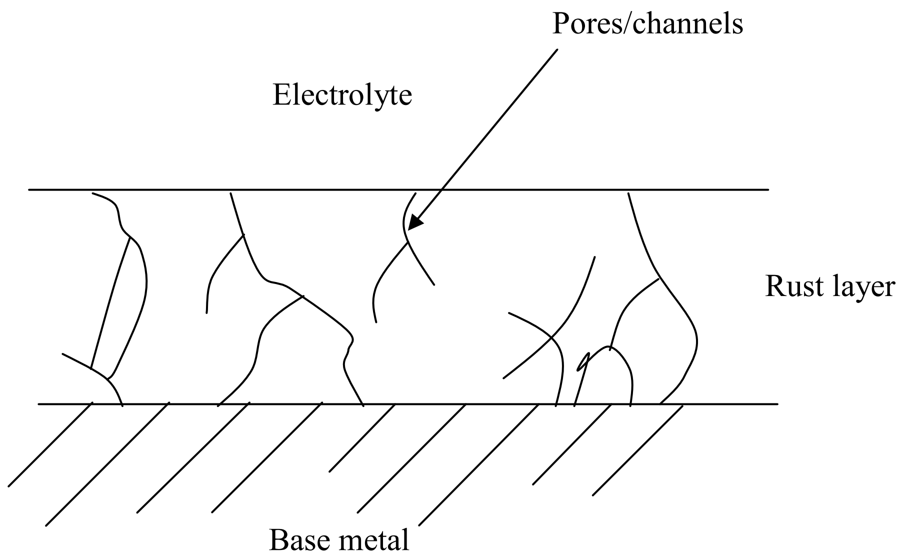

Fig. 3 – The rust layer

This description of atmospheric corrosion behaviour can explain the trend in mass loss of the low carbon steel.

When the mass loss was correlated with the roughness parameters R_q, R_{dq}, and R_{sm}, the following equation was obtained with an R value of 1:

$$\text{Mass loss} = -30.2 - 3.42R_q + 6.69R_{dq} + 0.0175R_{sm}$$

equation (3)

It should be noted that R_a was not used because it is an amplitude parameter which is less reliable that R_q.

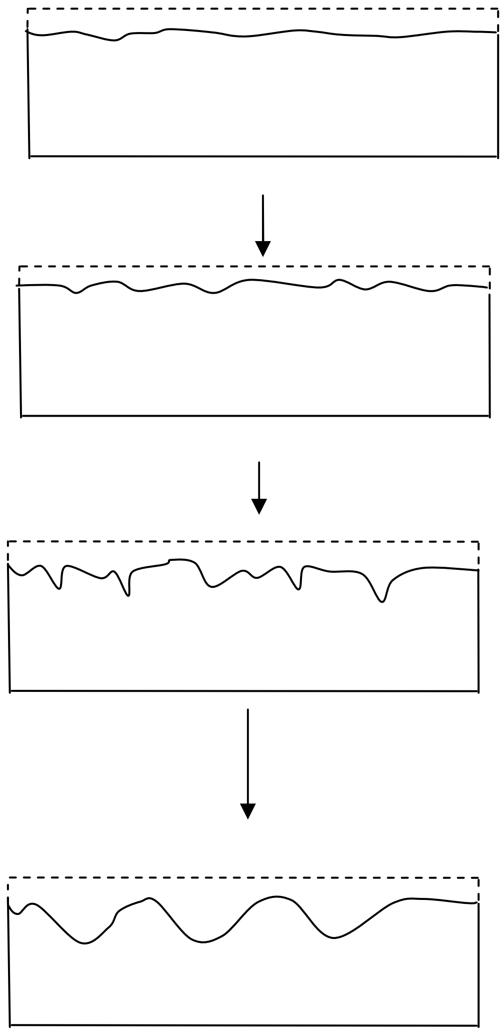

Fig. 4 – Description of the corrosion process

5. CONCLUSION

From the outdoor exposure of low carbon steel, based on the mass loss studies, it has been observed that the corrosivity of the atmosphere at Reduit, in Mauritius, falls in the C3 category which refers to an atmosphere of medium corrosivity. Measurements at other sites are, however, necessary to understand the corrosion behaviour of the entire Mauritius.

The surface roughness parameters used in combination could explain the atmospheric corrosion process of the low carbon steel at Reduit. The equation relating mass loss and roughness parameters thus obtained is:

$$\text{Mass loss} = -30.2 - 3.42R_q + 6.69R_{dq} + 0.0175R_{sm}$$

It should be noted that this study is part of an ongoing research work and 3D analysis is being performed in order to better understand the corrosion process. In this context, atmospheric conditions are also being analysed.

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