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An Experimental Study of Microbial Corrosion and Fatigue-Corrosion of HSLA Steel in Seawater

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Abstract: ***High strength low alloy steel known as HSLA is widely used in naval construction and ship building due to its capacity to resist to fatigue and corrosion which are considered to be complex phenomena. A study on microbial corrosion in seawater is held on steel plate and compared to specimen removed from a 27-meter naval unit subject to about 37 years of service. Both mechanical properties and microstructural behaviour were studied. The study showed a huge decrease in ductility of steel after exposure to microbial corrosion which is confirmed with Scanning Electron Microscopy (SEM) images. The steel serving for about 37 years showed less decrease in ductility but more in terms of elasticity and this was confirmed with SEM images showing a huge quantity of micro-cracks and corrosion sites. The steel submerged in calm sea water showed a form of pitting corrosion and less fractures.***

Keywords: HSLA steel, Microbial corrosion, Fatigue-corrosion, Mechanical properties, Microstructure investigation

1. Introduction

Corrosion is known to be one of the main causes leading to metal loss [1]. This phenomenon is very complex and needs to be well studied especially in maritime industry and naval construction .The high strength low alloy steel known as HSLA steel is widely used in maritime industry because it exhibits an excellent combination of mechanical performance, corrosion-fatigue resistance and weldability [2-3] Corrosion can occur under many forms and types [4]. Previous publications on the real corrosion behavior in seawater and after years of service of HSLA steel are limited.Most of studies are conducted in simulated marine atmosphere according to[5]. For example [6] revealed that under cyclic loading with peak stress close to or above the proof stress pitting corrosion can occur leading to the initiation of cracks .While [7] revealed that no stress corrosion cracking SCC was found in typical HSLA steels in both natural and simulated seawater environments. Lately, studies have shown that SCC can occur for HSLA steels in ocean conditions [8-9]. In most cases of study, interest goes to pitting corrosion, SCC corrosion and fatigue corrosion in simulated sea water and remains microbial corrosion less treated. According to [10] microbial-influenced corrosion usually occurs mainly in stagnant conditions of flow than can cause severe pitting and provide prone conditions for deposition and bacterial growth.

In this paper, a comparative study is held to investigate the effect of corrosion and fatigue on the HSLA steel after so many days and years of service in sea in the Northern coast of Tunisia. In fact, while corrosion and fatigue are time dependant phenomena, most of the researchers prefer using simulated conditions and in-laboratory experiments. But it still is necessary to compare with real conditions because interference between mechanical, chemical and physical laws complicate the understanding and estimation of each behaviour.

Microbial corrosion is highlighted after putting samples in sea water in harbour for about 220 days and fatigue corrosion is studied in the case of ship serving for about 37 years in the same region. All mechanical properties and microstructure behaviour are discussed.

2. Material and Methods

2.1 Materials

HSLA steel grade NV E32 is used in this study. For the first experiment, two specimens were extracted from two locations in the hull of a 27-meter ship as mentioned in **figure 1**. This naval unit is serving in the Mediterranean Sea for about 37 years and docks in the North of Tunisia, region of Bizerte. Samples were taken from both frontal and middle parts because of the difference in their fatigue behavior. For the second experiment specimen is cut from a plate of 0.1*0.5*0.05 m which has been emerging in harbor in calm seawater for about 220 days as shown in **figure 2**. The products were supplied by the naval academy of Tunisia.

Figure 1*:* Acquisition of samples of the 37-year-old ship; front and middle area (samples S1 and S2)

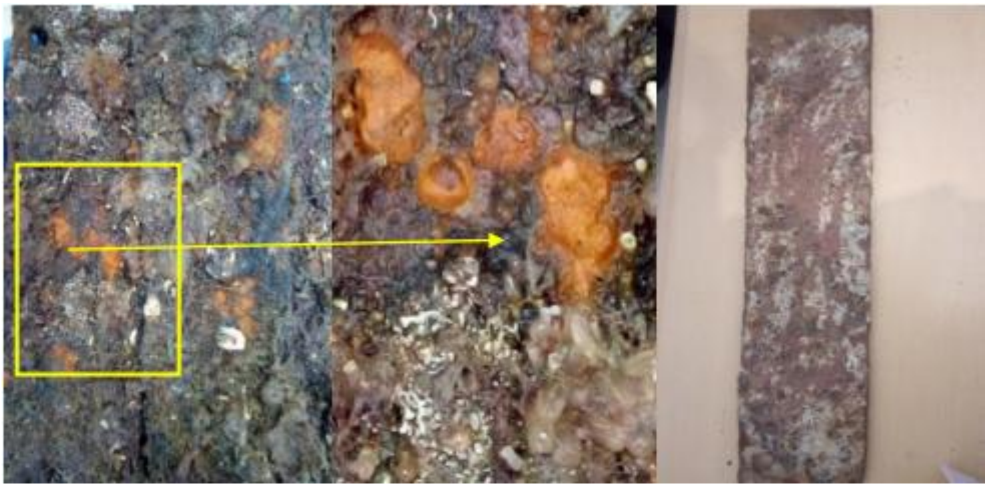


Figure 2: immersion of HSLA steel plate in harbour for 220 days (sample 3)

2.2 Experiment details

Technical parameters of the maritime atmosphere where the steel is serving, are given in Table 1.

Table 1: Atmospheric parameters of the Northern coast of Tunisia

Salinity Psu	Hypoxia Costs of Tunisia	Humidity %	Water temperature °C	Temperature °C
38.5	Medium	65-82	14-24	8-30

Three specimens of 0.5 cm*10 cm*1.5 cm were cut respectively, carefully cleaned then polished and etched with Nital solution (5% nitrate, 95 ethanol) for the SEM. They are conducted to a monotonous tensile test. The test was carried out with a universal ZWICK ROELL testing machine according to ASTM 1012 under room temperature. Chemical composition and mechanical properties are given respectively in **table 2**and **table 3**. Specimen taken from the front area of the hull is referred by S1, The second one cut from the middle area is referred by S2 and the third one is cut from the plate emerged in harbour in the northern coast of Tunisia for about 220 days and referred to by S3.

Table 2: Chemical Composition

Elements	C	Si	Mn	P	S	Cr	Ni	Cu	Mo
%	0.13	0.17	0.89	0.028	0.004	0.02	0.01	0.013	0.001

Table 3: Mechanical properties

Element	Elongation (%)	Yield strength (Mpa)	Tensile strength (Mpa)
Base metal	28	332	467

3. Results and Discussion

3.1 Mechanical properties

Table 4: Mechanical properties after the experiments

Specimen	S1 (Front area)	S2 (Middle area)	S3
Time exposure	37 years	37 years	220 days
Elongation	23.5	25.4	16
Tensile strength (Mpa)	316	321	387
Yield strength (Mpa)	255	267	280

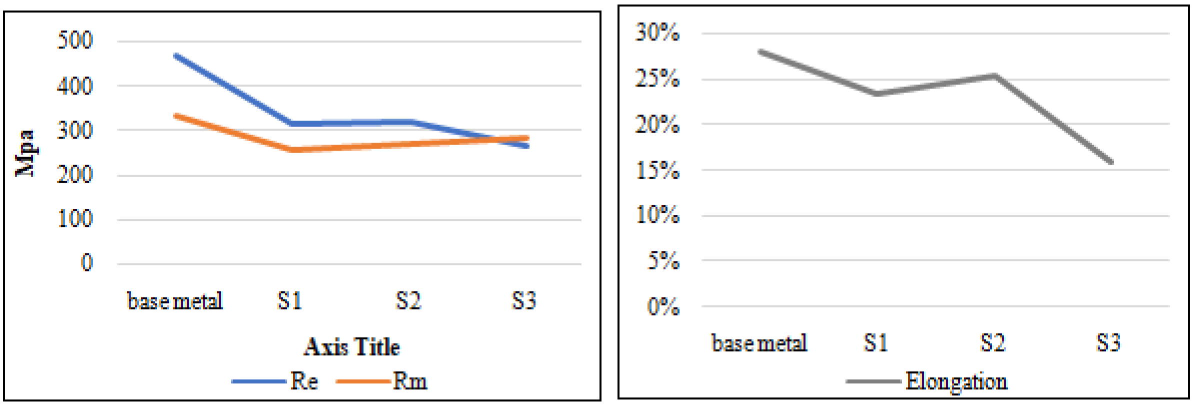


Figure 3: Mechanical properties: yield strength, tensile strength and Elongation

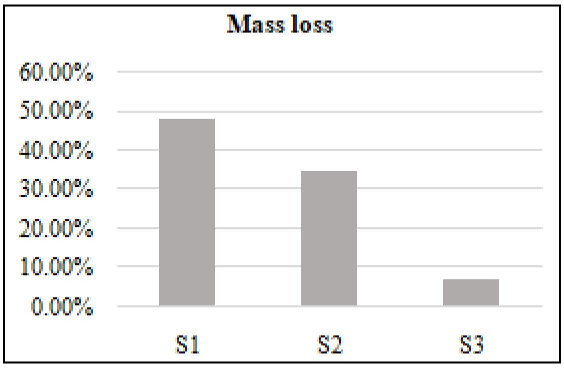


Figure 4: Mass loss of samples S1, S2, S3

As it is summarised in **table 4**, mechanical properties in both cases are affected. Infact, both yield and tensile strength values have dropped. The yield strength is the lowest in specimen S1 with about 255 Mpa as in **figure 3.** For this specimen taken from the front of the ship, the mass loss is about 48 %as shown **figure4**. The fatigue in this part of the hull is higher than in the middle part while the frequency of waves and hydrodynamic force is elevated. Fatigue associated with corrosion are combined in this case and led to a drop of ductility. The elongation of S1and S2 is still higher comparing to the specimen S3 put in harbour for 220 days. This is explained by the fact that the steel stayed in calm water conditions and wasn't subjected to cycling loading and wave force. Only corrosion is highlighted in this case and showed a direct impact on mechanical properties. **Figure 5** shows the percentage of mass loss in the considered steel. The highest value is observed in S1 enduring high loading fatigue cycles and corrosion for a very long period.

3.2 Microstructure behaviour

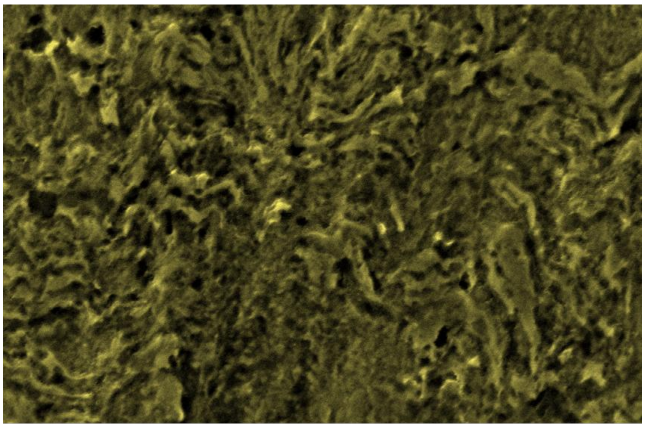
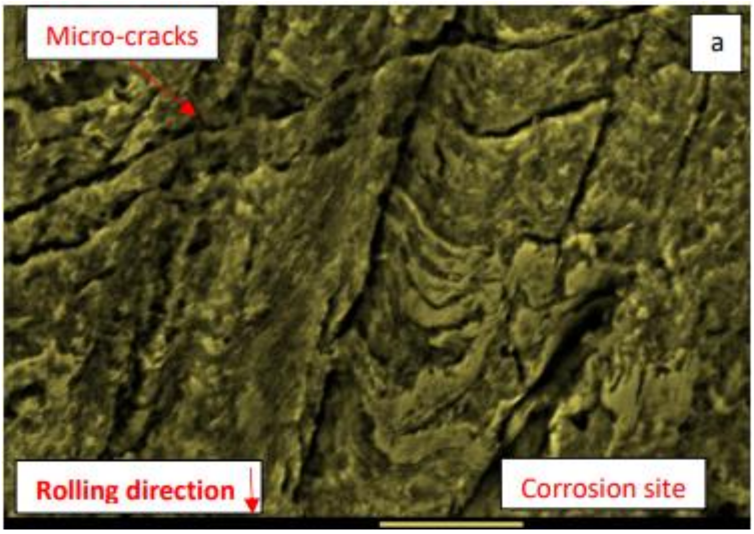


Figure 5: Microstructure of base metal (HSLAsteel)



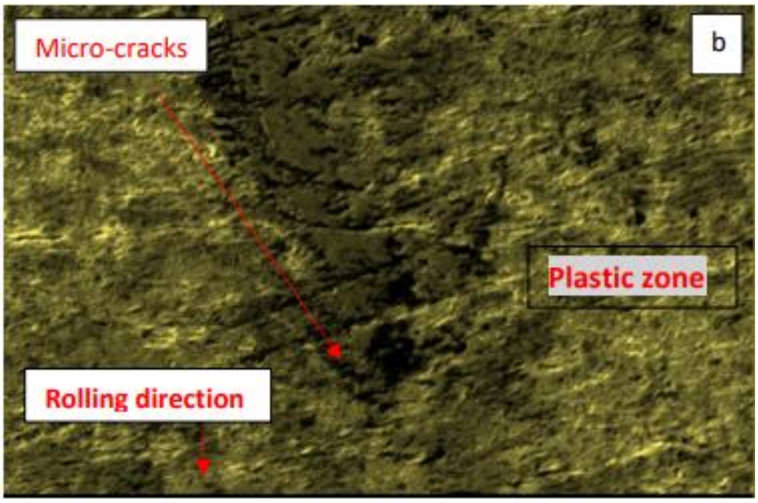


Figure 6: Microstructure evolution of sample S1 (a) and (b) sample S2 after 37years and 220 days of corrosion exposure

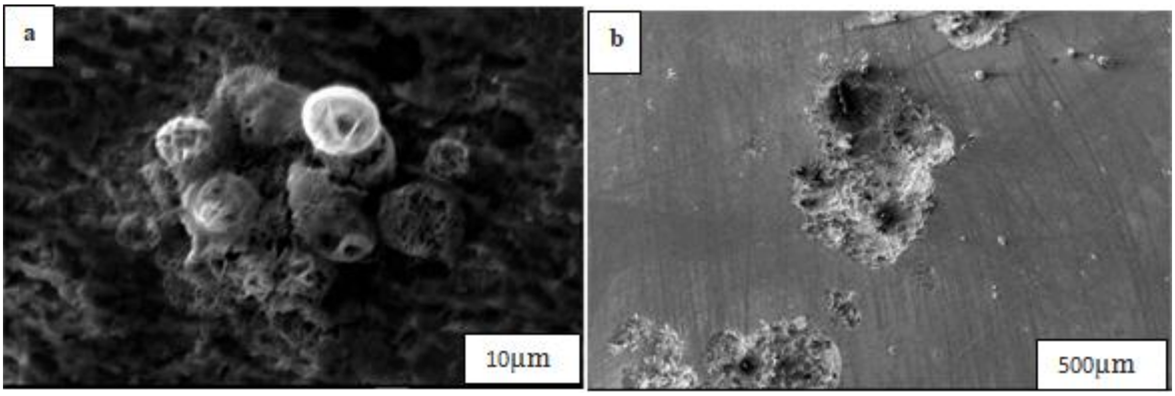


Figure 7 (a, b): Microstructure evolution of sample S3 (a)

All of the three samples were carefully cleaned, polished and etched with Nital solution (5% nitrate, 95 ethanol) for the SEM. The microstructure of base metal is shown in **figure 5.** It presents a homogeneous structure of ferrite and pear lite with numerous precipitations of alloy carbides. **Figure 6** shows the microstructure evolution of S1.The presence of microcracks is very clear. A significant amount of microcracks is revealed with a perpendicular direction compared to the one of rolling. The cracks spacing is estimated to about 1.3 µm in S1 and about 2.2 µm in S2. Thus, S1 is more solicitated than S2. Plastic zones are relevant by SEM images which is the region beyond the rupture zone and host aspects of both effect of cycling loading and fatigue indicators such as the beach marks well expressed in the surface with presence of multiple striation and second of crack propagation and closure phenomena. It is more obvious in sample 1 than 2, so it is considered to be an important parameter in fatigue crack growth.

Figure 7 shows the presence of microbial culture on the surface of the sample which had a great atmosphere for their proliferation. This form of attack led to the pitting corrosion phenomena which is obvious by microscopy investigation **.**in fact the presence of those active species induce a difference on the electrochemical potential on the surface of the steel and leads to breakdown of the passive film initially formed to protect from the reduction process .Bacteriological presence causes the propagation of pits to a scale of 500µm. Thus microbial-influenced corrosion occurs in stagnant conditions of flow which enhance the deposition and bacteriological growth.

4. Conclusion

In this paper, a comparative study was carried out between a microbial corrosion and fatigue corrosion on HSLA steel in realistic maritime atmosphere. Even though corrosion is a time-dependent phenomenon, it is necessary to not only rely on in -laboratory experiments. The study investigates both mechanical properties and microstructure evolution. The main conclusions are as follows:

a) Yield strength, tensile strength and elasticity decreased in both cases but is more relevant in the case of specimen enduring microbial corrosion in harbor
b) Microstructure investigation showed many micro-cracks initiated from the corrosion sites when the HSLA was subjected to long-term fatigue in the seawater environment.
c) Microbial culture is observed on the surface of the steel submerged in a harbor for 220 days. It is enhanced by the stagnant flow of sea water and presence of algae and seaweed. it led to a considerable decrease in mechanical properties of the steel especially in terms of ductility.

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