

Investigation of the Anomalous Dry Berth Track Corrosion

Saud Aldajah^{#1}, Prakash Bhalchandra^{*2}, Arif Ustadi^{*3} and Zakarya AlJassmi^{*4}

^{#1}Mechanical Engineering Department, United Arab Emirates University, Al-Ain, UAE

Abstract— Severe corrosion rates were observed in a relatively new track rail system used in Dubai Maritime City. Similar track system in a nearby location, Gaddaf, with similar temperature and humidity profile did not exhibit similar results. The purpose of this research is to investigate the root cause for the abnormal corrosion behavior of DMC tracks and to study the differences between DMC and Gaddaf track materials in terms of microstructure, chemical composition, mechanical behavior and corrosion resistance characteristics.

Keywords— Corrosion, Tracks, Mechanical behavior.

I. INTRODUCTION

High carbon steels possessing a fully pearlitic microstructure, are used as rail steels in railway systems of several countries because of their superior mechanical properties. However, rail steels are adversely affected under severe corrosive environments, for example, near coastal areas. The economic implications of corrosion of rail steels are significant. It is extremely important for the integrity of the rail track system in Dubai Maritime City (DMC) to be conserved due in order to avoid any catastrophic accidents and to ensure daily operations. However, the life of the rails is reduced to nearly half the expected life due to corrosion. The corroded rails have to be replaced frequently, disturbing daily operations as well as resulting in economic loss. Moreover, sudden failure of rails is a major safety concern.

It is very well known that pearlite reduces the corrosion resistance of steels in chloride saturated environment [1]. This is because high carbon, and consequently high amount of cementite (Fe₃C) in steel, is detrimental to its corrosion performance [2, 3]. Chen et al. [2] reported that steels with complete ferrite microstructure showed lowest weight loss during the early stages of wet-dry test in a chloride environment, compared to steels with pearlite/ferrite microstructures. The corrosion resistance was related to the carbon content in steel [2, 4, 5].

Recently, severe corrosion rates were observed in a relatively new track rail system used in DMC. Similar track system in a nearby location, Gaddaf, did not exhibit similar results. The purpose of this research is to investigate the root cause for the abnormal corrosion behavior of DMC tracks and to study the differences between DMC and Gaddaf track materials in terms of microstructure, chemical composition, mechanical behavior and corrosion resistance characteristics.

II. EXPERIMENTAL METHODS

In order to fully investigate the mechanical and corrosion behavior of the DMC and Gaddaf rail steel; samples were collected from large rail segments provided by DMC and Gaddaf. Microstructure and chemical analysis were carried out in order to examine the microstructure and chemical composition of both materials. Tensile and Three-point bending Tests were carried out in order to reveal the mechanical characteristics of both rails steels. Galvanic corrosion tests were conducted to compare between the two materials.

III. RESULTS AND DISCUSSION

In order to fully investigate the mechanical and corrosion behavior of the DMC and Gaddaf rail steel; samples were collected from large rail segments provided by DMC and Gaddaf. Microstructure and chemical analysis were carried out in order to examine the microstructure and chemical composition of both materials. Tensile and Three-point bending Tests were carried out in order to reveal the mechanical characteristics of both rails steels. Galvanic corrosion tests were conducted to compare between the two materials.

A. Microstructure and Chemical Analysis

Large Segments from DMC and Gaddaf the in-service rail steel were collected from the users. Different size rectangular samples were prepared from these segments using the water jet cutting technology. The sizes of these samples were decided to fit the tensile, three point bending, corrosion, microstructure and hardness tests.

Small 2 cm x 2 cm x 1 cm rectangular samples were cut, polished and chemically etched with Nitol (98.5% Methanol, 1.5% Nitric acid). The samples were examined under the microscope at different magnifications in order to reveal their microstructural characteristics. Figure 1 shows the Optical Microscope images of the Gaddaf sample taken at 100x, 500x and 100x respectively. The images show that the Gaddaf sample is comprised of equiaxed pearlite matrix with dispersed ferrite grains. Proeutectoid ferrite, outlining the prior-austenite grain boundaries also observed throughout the sample. Figure 2 shows the Optical Microscope images of the DMC sample taken at 100x, 500x and 100x respectively. The images show that the DMC Sample is comprised of equiaxed pearlite matrix. A small number of proeutectoid ferrite grains, outlining the prior-austenite grain boundaries also observed

The chemical analysis of the Gaddaf and DMC samples is shown in tables 1 and 2 respectively.

Based on the chemical and microstructure analysis, the main difference between the Gaddaf and the DMC samples is the carbon content; which is higher in the DMC case. The higher the carbon content in a carbon steel means that the steel will be stronger and less ductile.

B. Mechanical Testing

In order to assess the mechanical properties of the Gaddaf and DMC rail samples rectangular samples were prepared and three different types of testing were carried out namely tensile, three point bending and hardness tests

The main purpose of this test is to study the hardness characteristics of DMC and Gaddaf Rail samples.

Rockwell C hardness tests were conducted on both rail samples Table 5 shows the results of the tests.

The tensile testing program consisted from 4 tests of DMC samples and 4 tests of Gaddaf samples. A sample representation of these tests is shown in Figure 3, which shows stress strain curve. From the stress-strain curves, the maximum stress, ductility (represented by % elongation or strain at fracture), toughness and resilience can be estimated as shown in Table 6.

Three point bending tests were conducted in order to assess the flexure behavior of the DMC and Gaddaf rail steel samples. Figure 4 shows a comparison between the two samples, the peak load for the DMC sample was 3928 kN whereas for the Gaddaf sample it was 3167 kN.

C. Corrosion Tests

A standard galvanic corrosion test were carried out to compare the DMC and Gaddaf samples regarding their corrosive tendency in sea water. Both samples were tested against Standard Calomel Reference Electrode (SCRE). The test results showed that the DMC rail steel is slightly better than the Gaddaf steel in galvanic corrosion, Table 7.

D. XRF Analysis

X-ray fluorescence (XRF) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays. The XRF spectroscopy is widely used for the qualitative and quantitative elemental analysis of environmental, geological, biological, industrial and other samples. Table 8 shows the XFR analysis of six different samples collected from DMC, Gaddaf and Al-Ain locations.

IV. CONCLUSIONS

The microstructure and chemical analysis of DMC and Gaddaf Rail samples were carried out. The results obtained in this analysis are different than what reported in the draft report submitted to DMC by D. W. D. The main differences are in C, Si and Cr contents for the DMC rail steel and in C, Mn, Cr and Ni contents for Gaddaf samples.

The Mechanical testing included tensile, three point bending and hardness tests. The tensile tests showed that the average maximum strength of DMC samples is 1213 MPa and 822 MPa for the Gaddaf samples, which means that the DMC rail is 50% stronger than Gaddaf rail.

Hardness test results showed that the DMC rail samples had an average of 42 RC hardness number whereas the Gaddaf samples had an average of 28 RC hardness number. The DMC is 50% harder than the Gaddaf rail which is consistent with the strength. Both strength and hardness increase with the increased carbon content of the carbon steel.

Three point bending tests show the flexure behavior of the rail samples; the results showed that the maximum load carrying capacity is 3928 kN for DMC rail samples whereas for the Gaddaf sample it was 3167 kN.

Galvanic corrosion test was conducted in order to compare the two rail samples' corrosion potential. The DMC rail sample showed a slightly better corrosion performance compared to the Gaddaf rail samples.

The severe corrosion taking place in the DMC site has to be further analyzed. As a first step, sand samples were collected from the DMC site to be analyzed and then compared with a local (Al-Ain) sand sample. The results showed that the Cl⁻ concentration in the DMC sand was 5.23% compared to 0.13% in Al-Ain sand. It is very well known that the Cl⁻ accelerates corrosion. It is highly recommended to investigate the impact of the Cl⁻ concentration on the rail corrosion rate and to find an effective method of protecting the rail against it.

There are many effective corrosion protection methods such as the cathodic protection and application of resin coating which will reduce the corrosion rate and lengthen rail life. However, a further study should be carried out in order to assess which method is more effective for DMC rail tracks.

ACKNOWLEDGMENT

This project was supported by Nakheel company.

REFERENCES

- [1] C. Zhang, D. Cai, B. Liao, T. Zhao, Y. Fan, A study on the dual-phase treatment of weathering steel 09CuPCrNi, Mater. Lett. 58 (2004) 1524–1529.
- [2] Y.Y. Chen, H.J. Tzeng, L.I. Wei, L.H. Wang, J.C. Oung, H.C. Shih, Corrosion resistance and mechanical properties of low-alloy steels under atmospheric conditions, Corros. Sci. 47 (2005) 1001–1021.
- [3] H.H. Uhlig, Corrosion and Corrosion Control, third ed., J. Wiley & Sons, New York, 1991.
- [4] T. Misawa, T. Kyuno, W. Suëtaka, S. Shimodaira, The mechanism of atmospheric rusting and the effect of Cu and P on the rust formation of low alloy steels, Corros. Sci. II (1971) 35–48.
- [5] T. Misawa, K. Asami, K. Hashimoto, S.R. C. Yu and S. M. Shahed, "Effect of Injection Timing and Exhaust Gas Recirculation on Emissions from a D.I. Diesel Engine," SAE Technical Paper # 811234, (1981).

Chemical Analysis for Gaddaf Rail Steel							
C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Mo [%]	Ni [%]
0.46	0.24	0.95	0.020	0.021	0.04	<0.01	0.02

Table 1 Chemical composition of Gaddaf rail steel

Chemical Analysis for DMC Rail Steel							
C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Mo [%]	Ni [%]
0.66	0.24	0.85	0.015	0.011	0.03	<0.01	0.01

Table 2 Chemical Composition of DMC rail steel

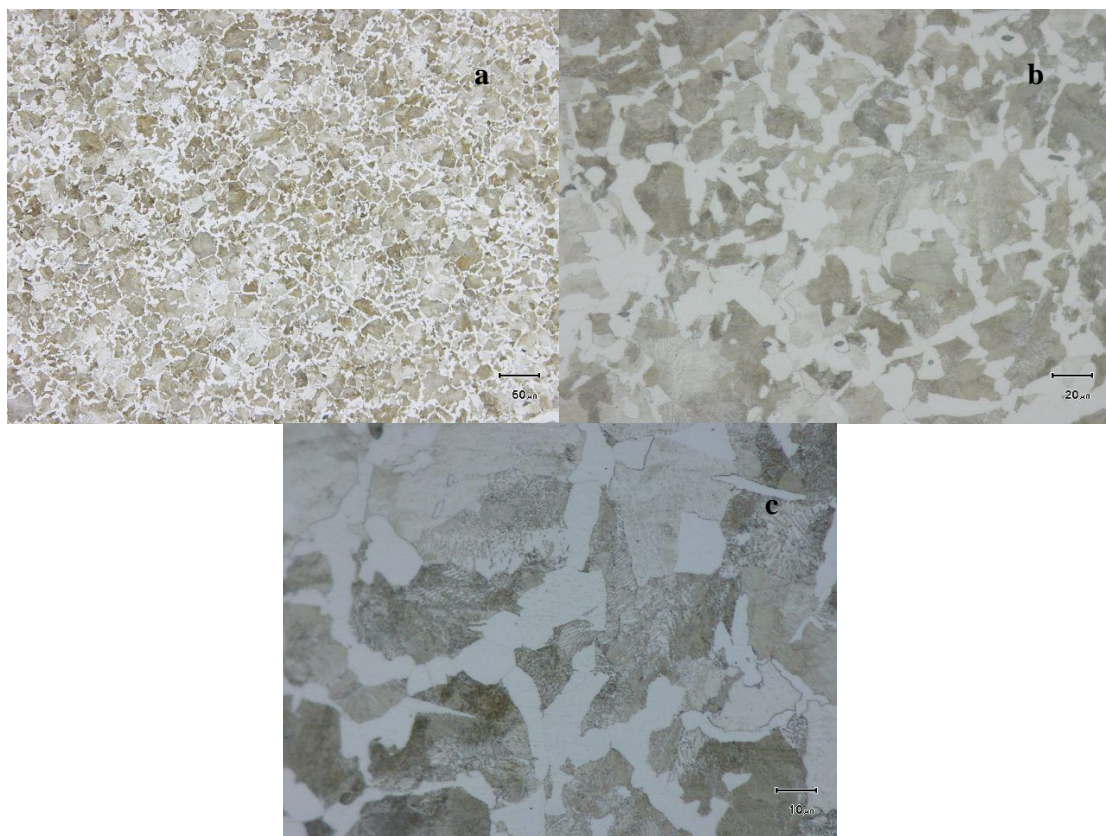


Figure 1: Micro photograph of Gaddaf sample taken at magnifications of a.100X Micrograph b. 500x c. 1000x

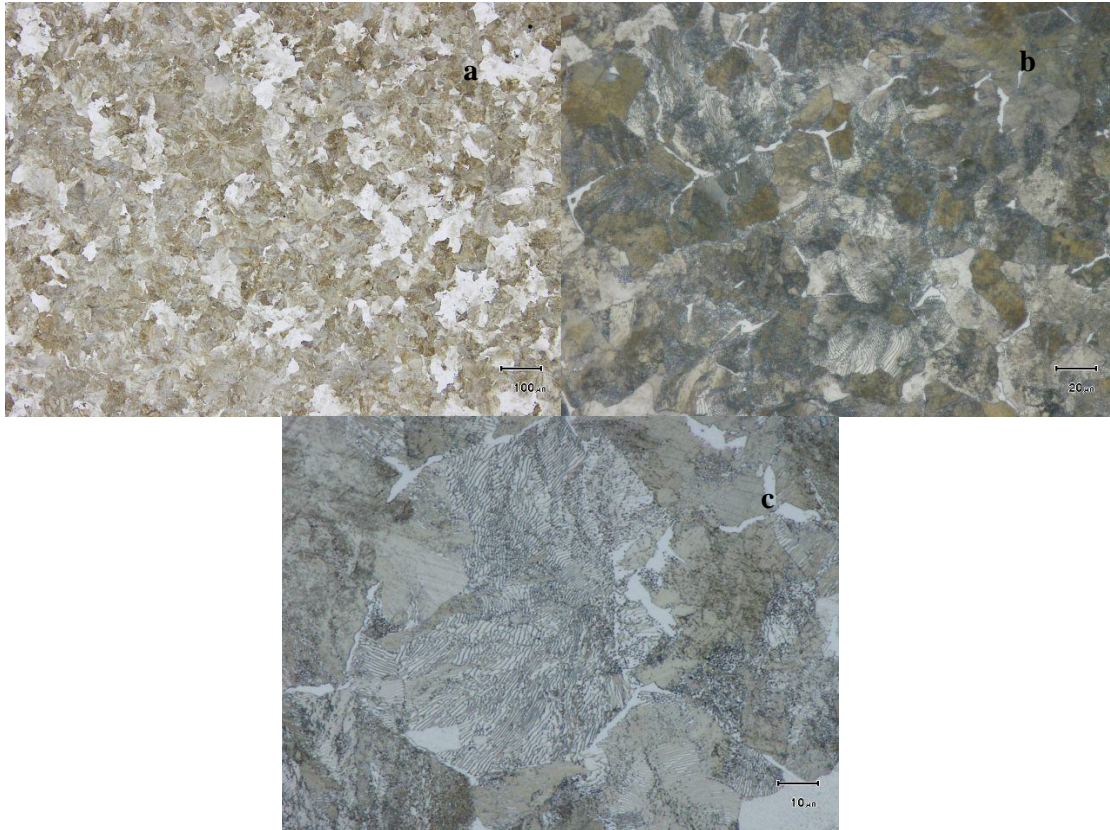


Figure 2: Micro photograph of DMC sample taken at magnifications of a.100X Micrograph b. 500x c. 1000x

Chemical Analysis for 10 month old Rail - DMC Rail Steel as reported by D. W. D.								
C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Mo [%]	Ni [%]	
0.781	0.447	0.91	0.0155	0.0217	0.385	0.015	0.013	

Table 3. Chemical Analysis for 10 month old Rail - DMC Rail Steel as reported by D. W. D.

Chemical Analysis for 10 year old Rail - Gaddaf Rail Steel as reported by D. W. D.								
C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Mo [%]	Ni [%]	
0.645	0.238	0.659	0.0176	0.0159	0.021	0.04	0.004	

Table 4. Chemical Analysis for 10 year old Rail - Gaddaf Rail Steel as reported by D. W. D.

Sample	RC Hardness Value
DMC	42
Gaddaf	28

Table 5. Rockwell C hardness test results.

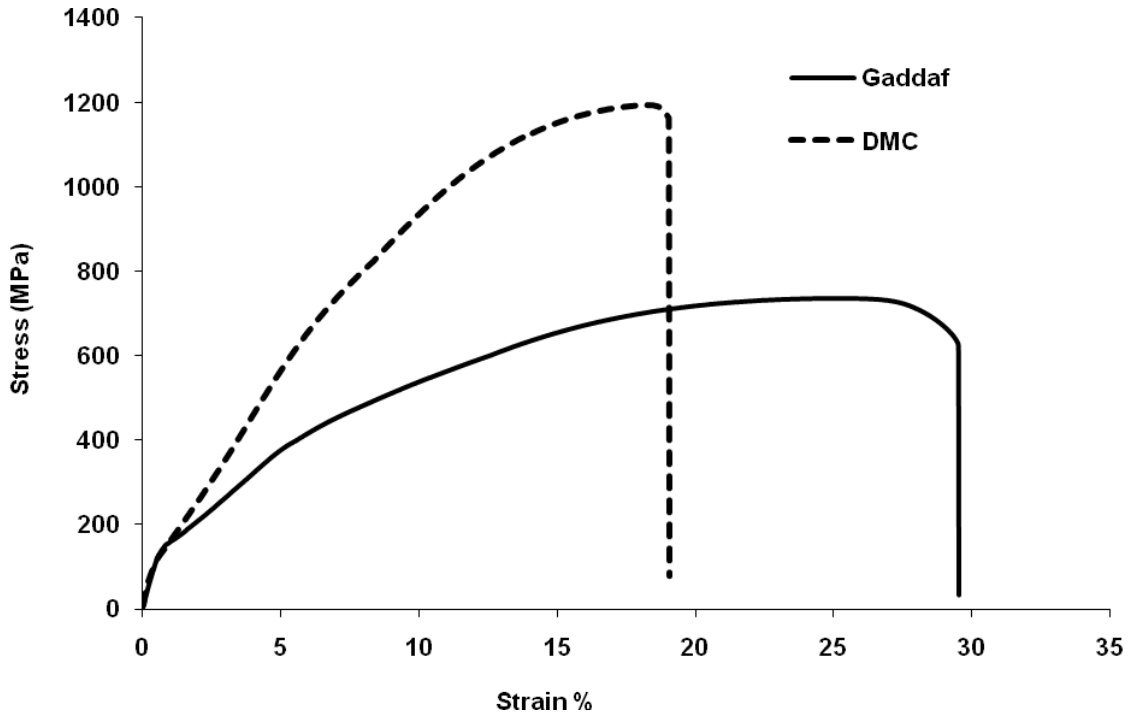


Figure 3 Stress- strain curves for DMC and Gaddaf samples – one test is shown per sample type.

Sample	Maximum Stress (MPa) *	% Elongation*	Toughness (N/mm ²)*	Resilience (N/mm ²)*
DMC	1213	24	135	46
Gaddaf	822	20	160	35

* These values are the average of four tests

Table 6. Mechanical properties of Gaddaf and DMC samples

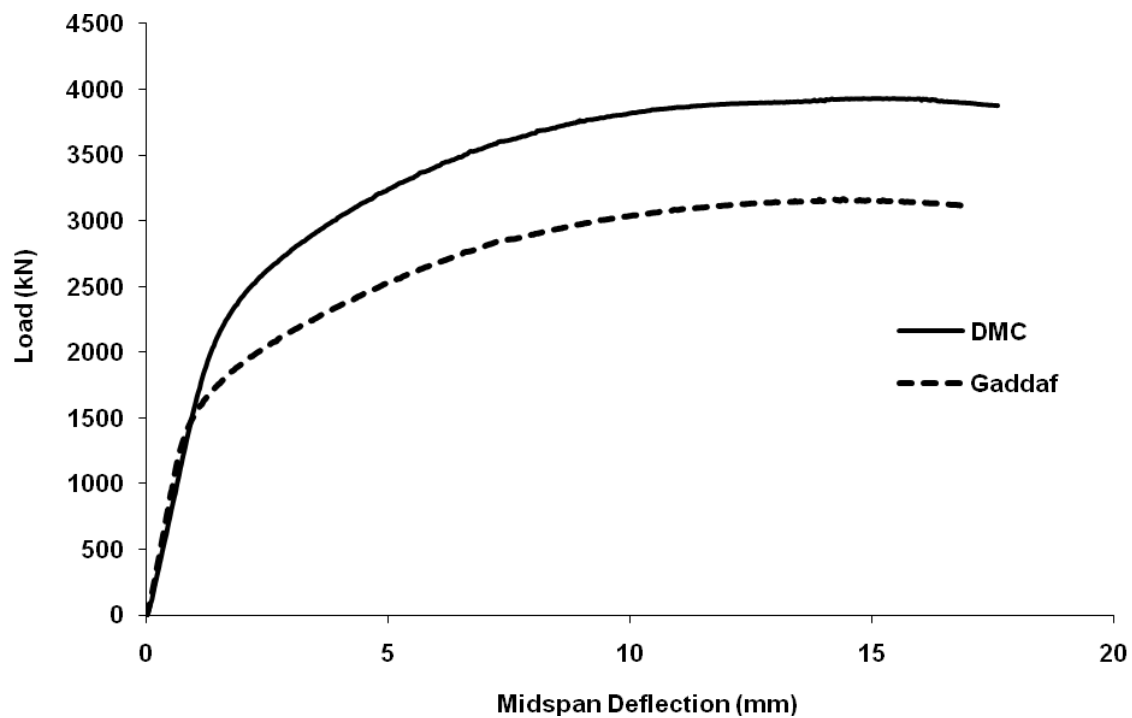


Figure 4. Load – Midspan deflection curve for three point bending test results for DMC and Gaddaf samples - one test is shown per sample type.

Sample	ΔV
DMC	-0.455
Gaddaf	-0.475

Table 7. Voltage difference of the Galvanic series

Sample .No.	Na ₂ O %	MgO %	Al ₂ O ₃ %	SiO ₂ %	P ₂ O ₅ %	SO ₃ %	Cl %	K ₂ O %	CaO %	Cr ₂ O ₃ %	MnO %	Fe ₂ O ₃ %	NiO %	CuO %	BaO %	SrO %
DMC : STC System /Transfer Bit " Rust "	0.000	1.730	0.451	2.590	0.082	0.563	0.525	0.152	19.000	0.240	0.737	73.700	0.000	0.000	0.000	0.210
DMC : STC System /Transfer Bit " Sand "	0.000	4.550	2.450	14.200	0.138	0.490	0.185	0.414	49.600	0.000	0.326	27.000	0.000	0.165	0.000	0.450
DMC : Ship Lift (Sea Water) " Rust Only "	0.000	5.680	2.000	4.180	0.000	2.050	2.010	0.200	1.630	0.215	0.898	77.900	0.000	0.412	2.710	0.103
DMC Sand	0.000	25.700	2.410	26.600	0.077	0.924	5.230	0.343	30.100	0.000	0.177	8.040	0.248	0.058	0.000	0.090
GADDAF : Ship Lift /Black foam " Rust Only "	0.000	5.600	0.666	3.440	0.122	0.843	1.200	0.225	5.710	0.000	0.690	81.200	0.000	0.214	0.000	0.072
Al-Ain Sand Sample	0.783	13.100	3.660	56.000	0.000	0.909	0.130	1.220	21.100	0.000	0.000	3.690	0.087	0.000	0.000	0.078

Table 8. XFR result of six different samples collected from DMC, Gaddaf and Al-Ain