Corrosion Behaviour of Heat Treated Rolled Medium Carbon Steel in Marine Environment

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ABSTRACT

Investigation were carried out to study the corrosion behaviour of heat treated rolled medium carbon steel and as-rolled medium carbon steel in sodium chloride medium. The as-rolled medium carbon steel was heated to a temperature of 830° C to completely austenize it and water quenched; it was reheated to the ferrite-austenite dual phase region at a temperature of 745° C below the effective Ac₃ point. The steel was then rapidly quenched in water and tempered at a temperature of 480° C. The corrosion behaviour of the steel in marine medium (NaCl) was studied by weight loss measurement. The weight loss is between 0.02g-0.11g for the as-rolled steel and 0.01g - 0.013g for the heat treated steel. The results obtained showed that the as-rolled medium carbon steel is more susceptible to corrosion than the heat treated rolled medium carbon steel.

Keywords: Corrosion, Medium carbon steel, sodium chloride.

1. INTRODUCTION

Corrosion is the destruction of a metal by its reaction with the environment; this reaction is an electrochemical oxidation process that usually produces rust or other metal oxide [1].

Structural steel is used in most metal water front structures because it is strong, readily available, easily fabricated and not excessively costly. The steel is normally used for such accessories as bitts, bollards, cleats, and chocks [2]. There are many types of marine corrosion that can occur to steel water front structure (e.g. galvanic corrosion, stray current, differential environment,

erosion corrosion, and biological corrosion) and many methods for corrosion control. Heat treatment of structural steel is one of the way of improving its resistance to corrosion. Heat treatment involves the application of heat to a material to obtain desired material properties (e.g. Mechanical, corrosion, electrical, magnetic e-t-c) [3]. During the heat treatment process, the material usually undergoes phase microstructural and crystallographic changes and this has effect on the corrosion, mechanical and electrical properties of the steel [4].

Rolled medium carbon steel products are produced through a forming process called rolling. The process is carried out in a rolling mill which consist of a complex machine for deforming metal in rotary rolls and performing auxiliary operations such as transportation of stock to rolls, disposal after rolling, cutting, cooling, piling or coiling e-t-c [5]. To study the corrosion behaviour of heat treated rolled medium carbon steel and the as-rolled steel in marine medium (NaCl); 24 specimens were prepared from the as-rolled medium carbon steel sample; 12 out of the specimens were heat-treated. The corrosion susceptibility of the heat treated specimens and as-rolled specimens were investigated.

The objective of this work is to investigate the effects of heat treatment on the corrosion susceptibility of rolled medium carbon steel.

2. MATERIALS AND METHODS

The material used in this study was 12mm diameter rolled medium carbon steel. The spectrometric analysis of the steel was carried out; The Chemical compositions from the analysis are shown in Table 1. Twenty four specimens were prepared from this material using lathe machine; Twelve out of these specimens were heat treated. The corrosion test and metallographic examination of the as-rolled and heat treated specimens were carried out.

2.1.Determination of Operating Temperature

The lower critical temperature (AC_1) and upper critical temperature (AC_3) were determined by Grange empirical formula [6] as presented here.

 $AC_1(^{\circ}C) = (1333 - 25Mn + 40Si + 42Cr - 26Ni) - (32)5/9 -----1.1$ $AC_3(^{\circ}C) = (1570 - 323C - 25Mn + 80Si - 3Cr - 32Ni) - (32)5/9 -----1.2$

С	Si	Mn	Р	S	Cr	Мо	Ni	Al	Со	Cu	Nb	Ti
0.353	0.290	0.987	0.050	0.057	0.071	0.005	0.11	0.025	0.015	0.185	0.005	0.0037
V	W	Pb	Sn	Zn	Fe							
0.0057	0.010	0.005	0.026	0.0076	97.805							

Table 1. Chemical Composition of As – Rolled Medium Carbon Steel

2.2. Heat Treatment Processes

Representative samples of as-rolled medium carbon steel were subjected to heat treatment processes

2.2.1. Quenching + Quenching + Lamelarizing + Tempering (Q+Q+L+T)

The steel specimens were heated to the austerizing temperature of 830°C, soaked for 20 minutes and quenched in water, this process was repeated again before the specimens were thereafter heated to the dual phase region at a temperature of 745°C, soaked for 20 minutes again and quenched in water. The specimens were finally tempered at a temperature of 480°C for 30 minutes.

2.2.2 Quenching + Lamelarizing + Tempering (Q + L + T)

The steel specimens were heated to 830°C, soaked for 20 minutes and quenched in water, the specimens were reheated to the dual phase region at a temperature of 745°C, soaked for 20 minutes and quenched in water. The specimens were tempered at temperature of 480°C for 30minutes.

2.2.3 Lamerlarizing + Tempering (L + T)

The specimens were heated to the dual phase region at a temperature of 745°C, soaked for 20 minutes, quenched in water and tempered at 480°C for 30 minutes.



Time (minutes)

Figure 1: Temperature- Time Graph involving Quenching, Quenching, Lamelarizing and Tempering (Q + Q + L + T)



Figure 2: Temperature – Time Graph involving Quenching, Lamelarzing and tempering (Q + L + T)



Figure 3: Temperature – Time Graph involving Lamelarzing and Tempering (L+T)

2.3 Corrosion Test

The corrosion rates of as-rolled specimen and heat treat treated specimens were measured by immersing these specimens in a solution of sodium chloride (NaCl). The cross-sectional area of

each of the specimens was calculated; each of the specimens was also weighed on a chemical balance and the weight recorded. The PH and the electrode potential of the corrosive medium were measured and recorded. After every 3 days interval (72 hours); specimens were retrieved, washed properly in water, dried and

weighed on a weighing balance to determine the weight loss during exposure. The laboratory simulation experiments were carried out in NaCl (O.5M and 1.OM) medium.. Finally, the corrosion rate was calculated using

 $mpy = \frac{3.45 \times 106W}{ATD}$ where W = weight loss in g D = density of specimen in g/cm³ A = Area in cm² T = Exposure Time in hour

2.4 Metallographic Examination

Samples of as-rolled and heat – treated specimen were mounted in hot phenolic powder and were ground on a water lubricated hand grinding set-up of abrasive papers, progressing through from the coarsest to the finest grit sizes. The 240, 320, 400 and 600 grades were used in that order. Polishing was carried out on a rotating disc of a synthetic velvet polishing cloth impregnated with micron alumna paste. Final polishing was carried out with diamond paste. The specimens were then etched with the standard 2% Nital so as to reveal the ferrite grain boundaries.

The optical microscopic examinations were carried out on a metallurgical microscope at a magnification of 400X. The specimens were illuminated with 100 kilowatts detachable quartz iodine lamp.

3. RESULTS AND DISCUSSION

3.1 Corrosion Properties

The results of the corrosion rate of the heat treated specimens and as-rolled specimen is shown in Tables 2–8. The corrosion rates of the heat treated specimens in marine medium (NaCl) is low when compared to the as-rolled steel, as shown in Figures 4-9, this is because the as-rolled steel consist of mainly pearlite in which each crystal consist of alternate layers of ferrite and cementite, it was understood that ferrite is anodic to cementite and this corrode with moisture as the electrolyte [7]. This was confirmed from the microstructure of the as-rolled steel shown in Plates 1–7. In the NaCl environment, the corrosion rate of the as-rolled steel was very high within the first 2 days and after this, the corrosion decreases with increase in exposure time; this is because the FeCl₂ formed during the process is insoluble and forms a protective film on the corroding surface of the steel which effectively prevent corrosive medium from coming into

contact with the steel and greatly reduces the corrosion rate[8]. After 20 days of exposure, the corrosion rate becomes uniform, this is because the steel is in the thermodynamically stable phase, the surface of the steel becomes immuned and no corrosion occurs as shown in

Figures 5 – 16. It could be seen that the same trend of corrosion rate hold for all the specimens but the steel developed by Q + L + T process have the least corrosion rate followed by L + T process and Q + Q + L + T process.

Exposure	New Weight	Weight	Corrosion	pН	p.d (v)
Time (Hrs)	(g)	Loss (g)	Rate (mpy)		
0	8.940	0.00	0	8.030	0.776
72	8.920	0.020	18.820	8.250	0.765
144	8.905	0.030	16.470	8.290	0.795
216	8.890	0.040	15.680	8.460	0.801
288	8.880	0.050	14.110	8.470	0.803
360	8.870	0.060	13.170	8.180	0.813
432	8.860	0.070	12.540	8.250	0.814
504	8.850	0.080	12.090	8.360	0.816
576	8.840	0.090	11.760	8.410	0.866
648	8.840	0.0100	10.460	8.470	0.869
720	8.840	0.0100	9.410	8.490	0.876
792	8.830	0.0110	9.410	8.520	0.899

Table 2: As – Rolled Steel in NaCl (0.5M). Initial Weight = 8.940g

Table 3: Heat Treated Specimen A2 in NaCl (0.5M)	Initial Weight $= 7.540$	Jg
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Exposure	New Weight	Weight	Corrosion	pН	p.d (v)
Time (Hrs)	(g)	Loss (g)	Rate (mpy)		
0	7.540	0	0	8.030	0.776
72	7.530	0.010	10.780	8.250	0.765
144	7.528	0.012	6.740	8.290	0.795
216	7.528	0.012	4.314	8.460	0.801
288	7.528	0.012	2.235	8.470	0.803
360	7.528	0.012	2.588	8.180	0.813
432	7.528	0.012	2.157	8.250	0.814
504	7.528	0.012	1.849	8.360	0.816
576	7.528	0.013	1.753	8.410	0.866
648	7.527	0.013	1.558	8.470	0.869
720	7.526	0.014	1.509	8.490	0.876
792	7.525	0.015	1.471	8.520	0.899

Exposure	New Weight	Weight	Corrosion	pН	p.d (v)
Time (Hrs)	(g)	Loss (g)	Rate (mpy)		
0	8.120	0.00	0	8.030	0.776
72	8.110	0.010	9.89	8.250	0.765
144	8.108	0.012	5.936	8.290	0.795
216	8.107	0.013	4.287	8.460	0.801
288	8.106	0.014	2.463	8.470	0.803
360	8.106	0.014	2.770	8.180	0.813
432	8.106	0.014	1.308	8.250	0.814
504	8.106	0.014	1.979	8.360	0.816
576	8.106	0.014	1.731	8.410	0.866
648	8.106	0.014	1.539	8.470	0.869
720	8.105	0.015	1.484	8.490	0.876
792	8.105	0.015	1.349	8.520	0.899

Table 4: Heat Treated Specimen B2 in NaCl (0.5M). Initial Weight = 8.120g

Table 5: Heat Treated Specimen C2 in NaCl (0.5M). Initial Weight = 7.750g

Exposure	New Weight	Weight	Corrosion	pН	p.d (v)
Time (Hrs)	(g)	Loss (g)	Rate (mpy)		
0	7.750	0	0	8.030	0.776
72	7.750	0.0	0	8.250	0.765
144	7.750	0.0	0	8.290	0.795
216	7.740	0.010	3.423	8.460	0.801
288	7.740	0.010	2.567	8.470	0.803
360	7.740	0.010	2.054	8.180	0.813
432	7.740	0.010	2.712	8.250	0.814
504	7.739	0.011	1.614	8.360	0.816
576	7.739	0.011	1.412	8.410	0.866
648	7.739	0.011	1.522	8.470	0.869
720	7.738	0.012	1.232	8.490	0.876
792	7.737	0.013	1.213	8.520	0.899

Exposure	New Weight	Weight	Corrosion	pН	p.d (v)
Time (Hrs)	(g)	Loss (g)	Rate (mpy)		
0	6.980	0.00	0	8.030	0.776
72	6.970	0.010	11.275	8.250	0.765
144	6.970	0.010	5.637	8.290	0.795
216	6.970	0.010	3.758	8.460	0.801
288	6.969	0.011	3.101	8.470	0.803
360	6.969	0.011	2.481	8.180	0.813
432	6.969	0.011	2.057	8.250	0.814
504	6.969	0.011	1.771	8.360	0.816
576	6.968	0.012	1.691	8.410	0.866
648	6.968	0.012	1.503	8.470	0.869
720	6.967	0.013	1.353	8.490	0.876
792	6.967	0.013	1.333	8.520	0.899

Table 6: Heat Treated Specimen A1 in NaCl (0.5M). Initial Weight = 6.890g

 Table 7: Heat Treated Specimen B1 in NaCl (0.5M). Initial Weight = 9.200g

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Exposure	New weight	weight	Corrosion	рн	p.a (v)
Time (Hrs)	(g)	Loss (g)	Rate (mpy)		
0	9.200	0.00	0	8.030	0.776
72	9.190	0.010	9.409	8.250	0.765
144	6.190	0.010	4.705	8.290	0.795
216	9.189	0.011	3.450	8.460	0.801
288	9.188	0.012	2.832	8.470	0.803
360	9.188	0.012	2.258	8.180	0.813
432	9.187	0.013	2.839	8.250	0.814
504	9.187	0.013	1.748	8.360	0.816
576	9.187	0.013	1.529	8.410	0.866
648	9.187	0.013	1.359	8.470	0.869
720	9.187	0.013	1.223	8.490	0.876
792	9.186	0.014	1.198	8.520	0.899

Exposure	New Weight	Weight	Corrosion	pH	p.d (v)
Time (Hrs)	(g)	Loss (g)	Rate (mpy)	•	
0	6.680	0.000	0	8.030	0.776
72	6.680	0.000	0	8.250	0.765
144	6.680	0.000	0	8.290	0.795
216	6.670	0.010	3.492	8.460	0.801
288	6.670	0.010	2.619	8.470	0.803
360	6.670	0.010	2.095	8.180	0.813
432	6.669	0.011	2.920	8.250	0.814
504	6.669	0.011	1.646	8.360	0.816
576	6.668	0.012	1.571	8.410	0.866
648	6.668	0.012	1.397	8.470	0.869
720	6.668	0.012	1.257	8.490	0.876
792	6.668	0.012	1.143	8.520	0.899

Table 8: Heat Treated Specimen C1 in NaCl (0.5M). Initial Weight = 6.680g



Fig. 4: Corrosion Rate of Heat-Treated Specimen A2(Q+Q+L+T) and As-Rolled Steel in 0.5M NaCl Environment



Fig.5: Corrosion Rate of Heat-Treated Specimen B2(Q+L+T) and As-Rolled Steel in 0.5M NaCl Environment



Fig.6: Corrosion Rate of Heat-Treated Specimen C2(L+T) and As-Rolled Steel in 0.5M NaCl Environment



Fig. 7: Corrosion Rate of Heat-Treated Specimen A1(Q+Q+L+T) and As-Rolled Steel in 0.5M NaCl Environment



Fig. 8: Corrosion Rate of Heat-Treated Specimen B1(Q+L+T) and As-Rolled Steel in 0.5M NaCl Environment



Fig. 9: Corrosion Rate of Heat-Treated Specimen C1(L+T) and As- Rolled Steel in 0.5M NaCl Environment

3.2 Microstructure

The microstructures obtained are shown in Plates 1-7. The microstructure produced by the asrolled steel consist of pearlite while the microstructure produced by Q + Q + L + T, Q + L + Tand L + T processes consist of a duplex ferrite martensite but may contain bainite and retained austenite [9].

The corrosion rates of the heat treated specimens in marine medium (NaCl) is low when compared to that of as-rolled steel. This is because the as-rolled steel which consist of mainly alternate layers of ferrite and cementite, ferrite is anodic to cementite and this corrode with moisture as electrolyte [9-10].



Plate 1: Microstructure of As – Rolled 5SP Steel etched in 2% Nital (400X) (Pearlitic Structure)



Plate 2: Microstructure of Heat Treated Specimen A2 (Q+Q+L+T) (400X) (Duplex Ferrite – Martensite Microstructure)



Plate 3: Microstructure of Heat Treated Specimen B2 (Q+L+T) (400X) (Duplex ferrite – Martensite Microstructure)



Plate 4: Microstructure of Heat Treated Specimen C2 (L+T) (400X) (Duplex ferrite – Martensite Microstructure)



Plate 5: Microstructure of Heat Treated Specimen A1 (Q+Q+L+T) (400X) (Duplex ferrite – Martensite Microstructure)



Plate 6: Microstructure of Heat Treated Specimen B1 (Q+L+T) (400X) (Duplex ferrite – Martensite Microstructure)



Plate 7: Microstructure of Heat Treated Specimen C1 (L+T) (400X) (Duplex ferrite – Martensite Microstructure)

4. CONCLUSION

From the findings, the heat treated medium carbon steel have better corrosion properties than the as-rolled medium carbon steel. The steel developed by Quenching + Lamelarizing + Tempering

(Q+L+T) process has the best corrosion properties followed by Lamelarizing + Tempering (L+T) process and Quenching + Quenching + Lamelarzing + Tempering (Q+Q+L+T) process. **REFERENCES**

- 1. Scully, J.C. (1990). The Fundamental of Corrosion. Maxwell Macmillan Perganman Publishing Corporation, Oxford.
- Mamoru, O. Yukito, T; Hitoshi, K. and Yuji, F. (1990). Development of New Steel Plates for building Structural use, Nippon Steel Technical Report, No44 pp. 8 – 15.
- 3. Rajan, T.V; Sharma, C.P. and Sharma, A. (1989). Heat Treatment Principles and Techniques, Prentice Hall of India Private Limited, New Delhi. pp. 36 58.
- 4. O.O. Daramola, B.O. Adewuyi and I.O. Oladele (2010), Effects of Heat Treatment on the Mechanical Properties of Rolled Medium Carbon Steel, Journal of Minerals and Materials Characterization and Engineering; Vol. 9, No. 8, pp. 693 708.
- 5. Thomas, G., Ahn, J.H. and Kin, N.J. (1986) Controlled Rolling Process for Dual-Phase Steel and Shapes. The Metal Society, London, Book 285, pp. 121 124.
- 6. Gorni, A.A. (2004). Steel Forming and Heat-Treating Hand Book; Vol. 2, Saova Center, Brazil, p. 4.
- 7. Faleke, E.O. (1987). Metallurgical Investigation of a Corroded Peugeot Car Body. Unpublished Thesis, Federal University of Technology, Akure
- 8. Baboian and Turcotte, (1985). Corrosion Sceince. Elservier Science Limited, Great Britain. Volume 25, No 13, pp. 958 1009.
- 9 Davies, D.J. and Harold, W. (1971). Practical Microcopical Metallography, Chapman and Hall Limited, London.
- 10. Davis, D.J. and Oelman, L.A. (1983). The Structure, Properties, and Heat Treatment of Metals, London, Pitman Books, pp. 44 52.
- Smith, W.F. and Hashemi, J. (2006). Foundations of Materials Science and Engineering, 4th Edition; Mcgraws – Hill Book. pp. 28 – 36.
- 12. Dieter, G.E (2000). Mechanical Metallurgy, 5th Edition. Singapore, Mcgraw Hill Book, pp. 186 195