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Influence of Martensite on Oxidation Behavior of Mild Steel at Elevated Temperature

Suresh Chand, Madhusudhan D
Metallurgical and Materials Engineering
Rajiv Gandhi University of Knowledge Technologies
IIIT A P, Nuzvid, India

ABSTRACT:

The purpose of this work is to determine the corrosion rate of the 27 samples of mild steel at 500, 600, 650, 690, 720, 750, 790, 830 and 890 ^{o} C temperatures for 1.5, 3 and 4 hrs of heating time before quenching and after quenching. After the heat treatment, weight loss is measured and corrosion rate of the each sample is calculated at each temperature and time. In heat treatment process the corrosion rate of the mild steel increases with increasing temperature. Weight loss also increases with time and temperature. The highest corrosion rate occurs at 830 °C at 1.5, hrs. At 500 °C, the weight loss is 0.0013 gm by increasing the temperature upto 830 °C the weight loss also increases to 0.065 gm, but at 890 °C the weight loss decreases to 0.0025 gm, for1.5 hrs. After quenching, the corrosion rate of mild steel increases as compared to initial mild steel. It is found that the corrosion rate decreases with increasing temperature in the presence of marten site specimen. At 790 °C a least corrosion rates are found as compared to initial temperature. At initial temperature the weight loss is 0.644 gm, by increasing the temperature up to 890 °C the weight loss decreases to 0.043 gm for specimen after quenching.

KEYWORDS: Martensite, High temperature, Oxidation, Muffle furnace.

INTRODUCTION:

Steel has many practical applications in every aspects of life. The steel with favorable properties are the best among the other materials. The steel is being divided as low carbon steel, medium carbon steel and high carbon steel on the basis of carbon content. Mild steel has carbon content of up to 0.25 wt % [4]. Mild steel is the most common form of steel as it provides material properties that are acceptable for many applications. It is neither externally brittle nor ductile due to its low carbon content. It has lower tensile strength, good wear resistance and malleability. Steel with low carbon content has properties similar to iron. As the carbon content increases, the metal becomes harder and stronger but less ductile and more difficult to weld. Mild steel can be used in nut, bolts, screws, automobile body panels, tin plate, wire product, tubes, girders etc. The deterioration in metals is caused by oxidation or chemical reactions. Corrosion can be fast or slow. Oxidation is a special form of corrosion degradation of metals and alloys that occurs when the metals or alloys are exposed to air or oxygen. Oxidation can also take place in other environments, such as sulfur dioxide and carbon dioxide, which have relatively low oxidation potentials. Carbon steels have negligible oxidation in air up to temperatures of about 250–300 °C. Oxidation attack is less than about 20 mg/cm^2 up to 450 °C. Above this temperature, the oxidation rate increases rapidly, following linear kinetics, especially above 600 °C.

Habsah MdIshak et.al investigated oxidation kinetics of AISI304 coated with $MgCO_3$ for 24-120 hrs, oxidized at different temperatures of 900, 950 and 1000 °C. The results indicated that the oxidation rates were influenced by both time of exposure and temperature. The deposit caused the formation of oxide layer on the metal surface, and mass of steel are changed with the increasing temperature [2]. B.A. Baker et.al investigated high temperature oxidation behavior of a new Ni-Cr-Mo-Si Alloy. They evaluated the oxidation behavior of a new Ni-Cr-Mo-Si alloy from 1000 °C to 1200 °C in air plus 5 % water vapor and in oxygen at 1200 °C, under cyclic conditions. The Ni-Cr-Mo-Si material found to have excellent resistance to oxidation, provided by both a continuous chromium oxide scale, a discontinuous silicon oxide sub-scale, and rare- earth additions [3]. It is known that oxide films are ductile at high temperature and are often brittle at low temperature. Most of oxide films have different thermal expansion coefficients than those of the underlying metals from which they are formed. Hence, the oxide films formed at high temperatures may lose adherence to the underlying metals, when cooled to low temperature. These are main reasons for high oxidation rate and weight loss of the underlying metals [6-11].

MATERIALS AND METHOD:

27 mild steel samples were cut from the steel square bar of dimension 10 mm x 10 mm using hack-saw. To find out the corrosion rate at different high temperature, The samples were heated at each temperature for 3 different time of intervals in the muffle furnace in the presence of air. Three samples were heated for 3 different time of intervals at each temperature. All surfaces of samples are polished by different grades of emery papers followed cleaning of samples with water and acetone. The samples were dried. After drying the samples initial weights were measured using weighing machine, the dimensions of samples are also measured with help of the Vernier calipers. Three samples were placed in three different crucibles and were put in a muffle furnace at 500 °C. The dimensions of the samples are as under:

Table I: The details of mild steel specimens dimensions.

S.No	Length (inch)	Breadth (inch)	Height (inch)	Area (inch^2)	S.No	Length (inch)	Breadth (inch)	Height (inch)	Area (inch^2)
1	0.521	0.331	0.3149	0.888128	15	0.479	0.343	0.3149	0.85551
2	0.516	0.33	0.3149	0.879444	16	0.517	0.343	0.3149	0.90765
3	0.537	0.33	0.3149	0.907164	17	0.517	0.344	0.3149	0.90972
4	0.623	0.348	0.3149	1.06554	18	0.397	0.343	0.3149	0.74301
5	0.668	0.331	0.3149	1.082756	19	0.537	0.346	0.3149	0.94153
6	0.669	0.334	0.3149	1.092108	20	0.563	0.346	0.3149	0.97752
7	0.516	0.342	0.3149	0.904212	21	0.666	0.344	0.3149	1.11474
8	0.55	0.341	0.3149	0.948524	22	0.568	0.344	0.3149	0.97989
9	0.524	0.347	0.3149	0.925636	23	0.575	0.345	0.3149	0.99182
10	0.598	0.342	0.3149	1.016388	24	0.582	0.345	0.3149	1.00148
11	0.56	0.342	0.3149	0.964404	25	0.565	0.343	0.3149	0.9735
12	0.5	0.345	0.3149	0.888324	26	0.552	0.343	0.3149	0.95567
13	0.471	0.344	0.3149	0.84642	27	0.503	0.343	0.3149	0.88844
14	0.486	0.342	0.3149	0.86317					

Table II: Process variables for high temperature oxidation.

Temperature (˚C)	500	600	650	690	720	750	790	830	890
Time (hrs)	1.5, 3 and 4 hrs								

After completion of heating the samples were taken out from the furnace and allowed to cool in air to room temperature. The Final weight of each sample was measured and the corrosion rates were calculated. In this way, the process continues for remaining 9 temperatures. After calculating corrosion rate of all the samples again the all surfaces of samples were polished. Austenzation was carried out at 880 °C followed by water quenching. The microstructure of the sample was observed and the hardness values were measured. The Rockwell hardness values are measured on C-scale applying minor and major loads 10 Kg & 150 Kg respectively. Next another 3 samples were polished followed by cleaning with water and acetone. Next we measured the initial weight and heat treatments were carried out at different temperature for different time of intervals. After heat treatment the final weights were measured and corrosion rates are calculated. Finally, the corrosion rates of the samples before quenching and after quenching are compared. The corrosion rate of the metal in that particular corrosive media can be determined by the following expression:

$$\text{Corrosion Rate (R)} = \frac{534\ \text{w}}{\text{DAt}}$$

Where, W is weight loss (mg), D is density of the sample (g/cc), A is Area of the sample (in^2), t time (hr) [1]

DISCUSSIONS/ANALYSIS:

The high temperature oxidation behavior of mild steel is analyzed at nine different temperatures (500,600, 650,690, 720,750,790,830 and 890 °C) with respect to three different times (1.5, 3 and 4 hrs). We observe that by increasing the temperature, the corrosion rate of mild steel increases. And the weight loss also increases with time and temperature.

The mild steel samples were heat treated at different temperature for different time of interval. The highest corrosion rate occurs at 830 °C at 1.5, hrs. At 500 °C, the weight loss is 0.0013 gm by increasing the temperature up to 830 °C the weight loss also increases to 0.065 gm, for, but at 890 °C the weight loss decreases to 0.0025 gm, for1.5 hrs. After quenching, the corrosion rate of mild steel increases as compared to initial mild steel. The weight losses for quenched specimen decreases from 0.6437 to 0.1895 from 500 °C to 720 °C, in this range of temperature the oxidation was found aggressive due to diffusing out carbon from martensite. It is found that the corrosion rate decreases with increasing temperature in the presence of martensite specimen. At 790 °C a least corrosion rate are found as compared to initial temperature. At initial temperature the weight loss is 0.644 gm, by increasing the temperature up to 890 °C the weight loss decreases to 0.043 gm.

The microstructure of as received mild steel has been shown in figure 1 (a) and quenched specimen in 1 (b). In figure 1 (a), reveals pearlite (dark) and ferrite (white).

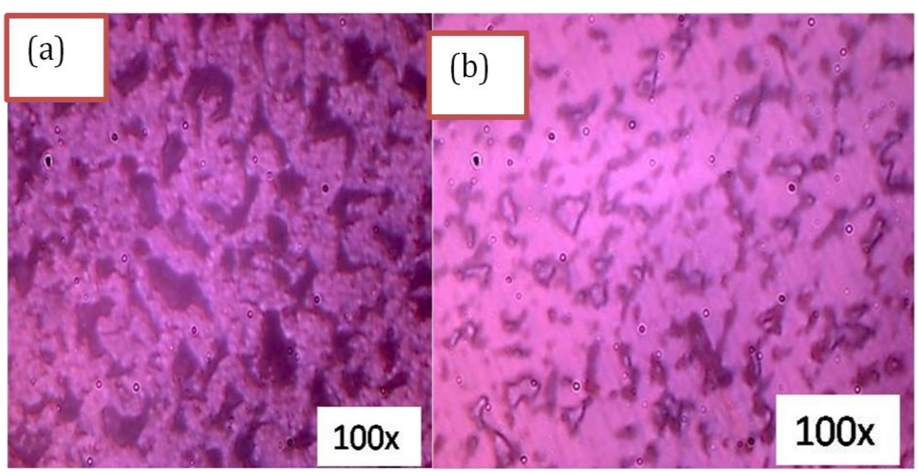

Fig.1: Optical microstructures of mild steel, (a) As received, at 100X, (b) Quenched, at 100X.

Table III. Details of weight loss and corrosion rate for as received specimen

Temperature (°C)	Time (hrs)	Total area ($inch^2$)	Initial wt (gm)	Final wt (gm)	Weight loss (ΔW) (gm)	Corrosion rate (mpy)
500	1.5	0.888128	7.0549	7.0562	0.0013	6.63817E-05
	3	0.879444	7.0815	7.0833	0.0018	4.64103E-05
	4	0.907164	8.8489	8.8514	0.0025	4.68669E-05
600	1.5	1.06554	8.8489	8.8514	0.0025	0.000106402
	3	1.082756	9.3019	9.3118	0.0099	0.000207327
	4	1.092108	9.1818	9.1863	0.0045	7.00743E-05
650	1.5	0.948524	8.1036	8.1039	0.0003	1.43434E-05
	3	0.916524	8.3816	8.3821	0.0005	1.23702E-05
	4	0.925636	7.1355	7.1802	0.0447	0.000821257
690	1.5	1.016388	7.1603	7.1732	0.0129	0.000575586
	3	0.964404	7.5665	7.5799	0.0134	0.000315062
	4	0.888324	7.2541	7.2673	0.0132	0.000252705
720	1.5	0.84642	8.0134	8.0233	0.0099	0.000530432
	3	0.863172	7.6484	7.6552	0.0068	0.000178633
	4	0.855512	6.8835	6.9056	0.0221	0.000439317
750	1.5	0.907648	6.9693	6.991	0.0217	0.001084233
	3	0.909716	6.5714	6.5725	0.0011	2.74181E-05
	4	0.743008	6.4253	6.4404	0.0151	0.000345617
790	1.5	0.941532	8.0057	8.0277	0.022	0.001059663
	3	0.977516	7.9384	7.9925	0.0541	0.001254942
	4	1.11474	8.1262	8.1953	0.0691	0.001054183
830	1.5	0.979892	6.6362	6.7008	0.0646	0.002989748
	3	0.991824	7.1501	7.2237	0.0736	0.001682649
	4	1.001484	5.4634	5.4672	0.0038	6.45284E-05
890	1.5	0.973504	7.5087	7.5637	0.055	0.002562154
	3	0.955668	7.8382	7.9075	0.0693	0.001644283
	4	0.88844	9.2795	9.3291	0.0496	0.000949435

Table IV. Details of weight losses and corrosion rates after quenching the specimen

Temperature (°C)	Time (hr)	Area (inch2)	Initial wt (g)	Final Wt (g)	Weight loss (□W)	Corrosion rate (mpy)
500	1.5	0.88813	6.6266	7.2703	0.6437	0.032869135
	3	0.87944	6.8294	7.144	0.3146	0.008111494
	4	0.90716	6.7578	7.054	0.2962	0.005552785
600	1.5	1.06554	8.5634	8.9091	0.3457	0.014713295
	3	1.08276	8.3042	8.6238	0.3196	0.006693088
	4	1.09211	8.0396	8.6744	0.6348	0.009885142
630	1.5	0.94852	7.0907	7.2485	0.1578	0.007544648
	3	0.91652	6.9712	7.1365	0.1653	0.004089586
	4	0.90421	6.859	7.0242	0.1652	0.003107072
650	1.5	0.90421	7.0443	7.5128	0.4685	0.023497392
	3	0.94852	7.1534	7.4664	0.313	0.007482494
	4	0.92564	7.5805	7.8763	0.2958	0.005434624
690	1.5	1.01639	6.4662	6.9785	0.5123	0.022858365
	3	0.9644	6.4187	6.7688	0.3501	0.008231585
	4	0.88832	6.7094	7.073	0.3636	0.006960879
720	1.5	0.84642	6.904	7.0765	0.1725	0.009242373
	3	0.86317	6.6174	6.7925	0.1751	0.004599802
	4	0.85551	6.5541	6.7436	0.1895	0.003766992
750	1.5	0.90765	5.894	5.9335	0.0395	0.001973604
	3	0.90972	6.8214	6.9203	0.0989	0.002465135
	4	0.74301	8.6667	8.7532	0.0865	0.001979859
790	1.5	0.94153	5.9672	6.0009	0.0337	0.001623212
	3	0.97752	6.1041	6.153	0.0489	0.001134319
	4	1.11474	4.9149	4.9615	0.0466	0.000710925
830	1.5	0.97989	7.4221	7.4783	0.0562	0.002600989
	3	0.99182	7.7782	7.7809	0.0027	6.17276E-05
	4	1.00148	7.3843	7.8116	0.4273	0.007256054
890	1.5	0.9735	7.9173	7.9599	0.0426	0.001984505
	3	0.95567	6.9002	6.9815	0.0813	0.001929007
	4	0.88844	7.4014	7.5478	0.1464	0.002802364

Fig. 2 represents the weight loss vs time plot for as received mild steel specimen. It is observed that weight loss increases with increasing time of span at all temperatures from 500 ˚C to 890 ˚C. Since the longer exposure time and higher temperature, both parameters are favoring. the higher oxidation that is why the higher weight loss is recorded. As temperature increases the weight vs. time plots are shifting upward direction. Fig. 3 represents the weight loss vs. time plot for mild steel specimen austenitized at 880 ˚C and quenched into water. Here, this is

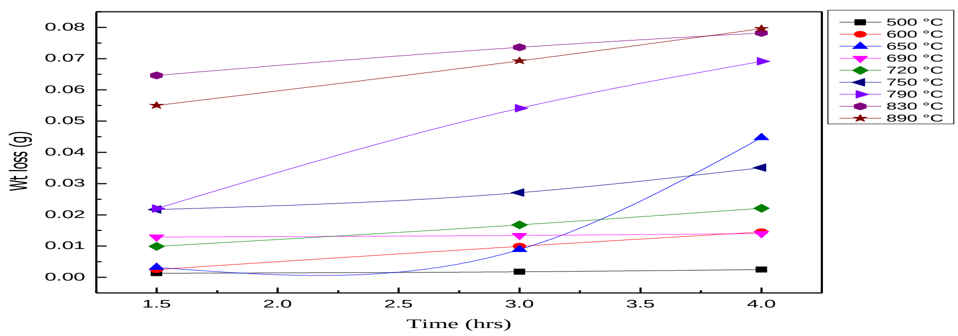

Fig.2: Weight loss vs. time plots as received.

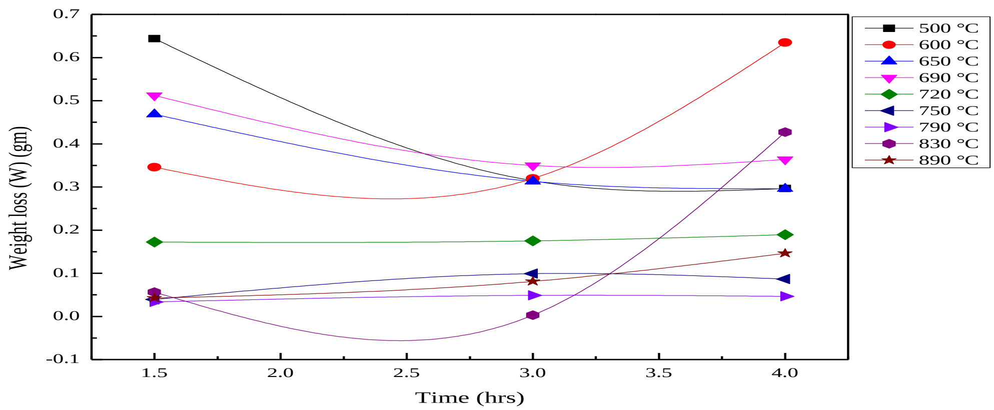

Fig.3: Weight loss vs. time plots after quenching into water

observed that weight loss decreases with increases in time for all temperature up to 3 hours of exposure time. After 3 hour the weight losses at 600 ˚C and 830 ˚C are found increased. Due to presence of marten site higher weight losses are observed. Here weight loss vs. time plots are shifting to downwards which is just opposite to the oxidation behavior of as received specimen.

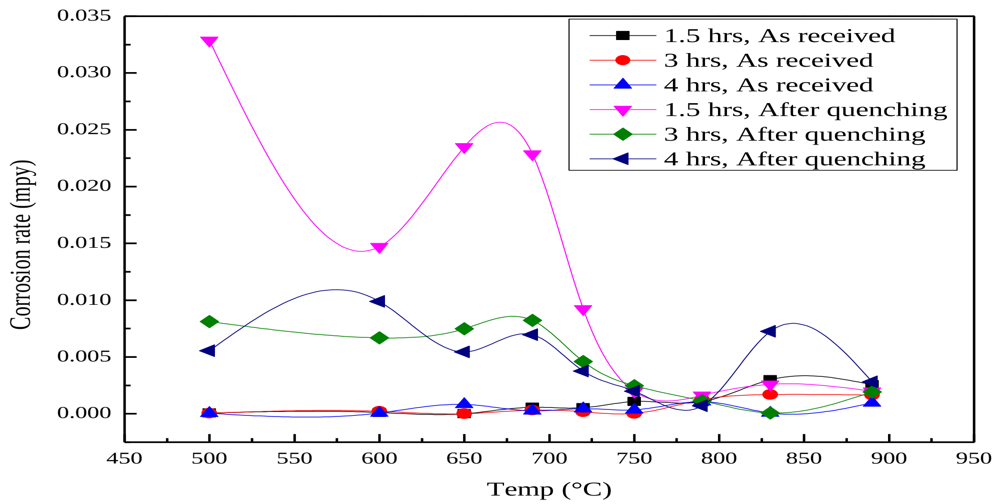

Fig. 4: Corrosion rate vs temperature plots for before and after quenching specimens

The corrosion rate vs. temperature has been shown in Fig. 4 for as received and quenched specimen. It is observed from the Fig. 4 that the corrosion values are found higher for the quenched specimen for all three time of intervals. The corrosion rates are lowered for longer time of exposure. The corrosion rate vs. temperature plots are shifting downwards for longer exposure of time and temperature. So, it is clear that the presence of marten site enhances the high temperature oxidation. As carbon diffuses out from the marten site, the rates of corrosion are found to be lowered. In presence of marten site, longer the time of exposure and higher the temperature, lower the rate of corrosion. The corrosion rate vs. time has been shown in the Fig. 5 for as received specimen. The rate of corrosion are increasing with increase in temperature and decreasing for longer time of exposure for as received specimen. Here, corrosion rate vs. time plots are shifting towards upward with increase in temperature. Fig. 6 represents the corrosion rate vs. time for quenched specimen. Here, the corrosion rates are found higher at 1.5 hrs of exposure for all temperatures. For longer exposure time, the rates are found to be lower. In this Fig. 6, plots are shifting downwards with increasing the temperature of exposure.

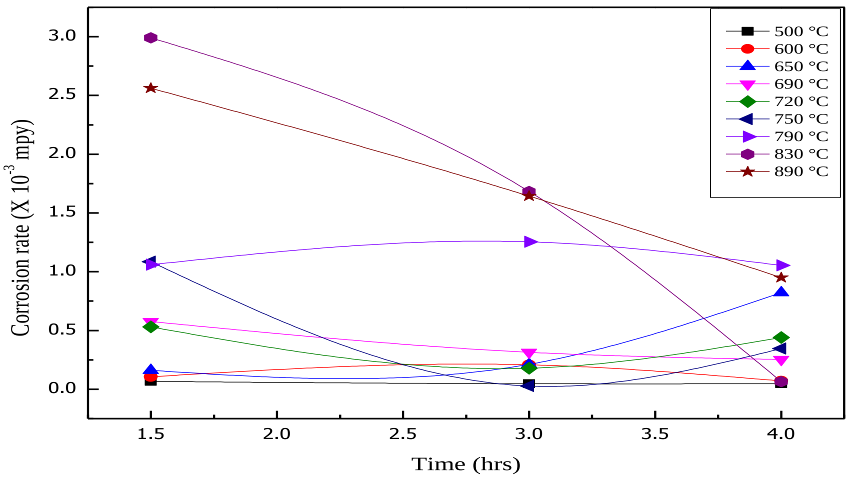

Fig. 5: Corrosion rate vs temperature plots for as received specimen.

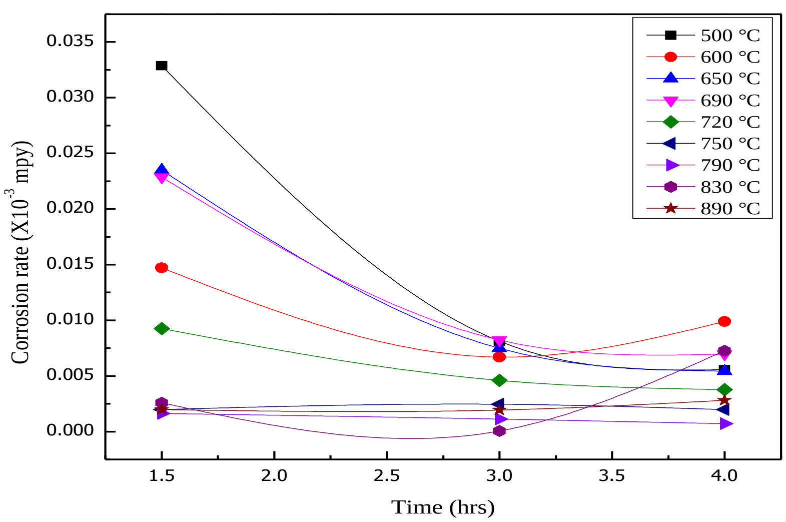

Fig. 6: Corrosion rate vs time plots for specimen quenched into water.

CONCLUSION:

1. The corrosion rate of the specimen consisting marten site increases as compared to as received specimen.
2. At 500 °C, the weight loss is 0.0013 gm by increasing the temperature upto 830 °C the weight loss also increases to 0.065 gm, but at 890 °C the weight loss decreases to 0.0025 gm, for1.5 hrs.
3. The highest corrosion rate is found 0.03287 mpy in quenched specimen at 500 °C for1.5 hrs.
4. The weight losses for quenched specimen decreases from 0.6437 gm to 0.1895 gm from 500 °C to 720 °C, in this range of temperature the oxidation was found aggressive due to diffusing out carbon from marten site.
5. In the presence of marten site, by increasing the temperature the corrosion rate decreases up to 790 °C. At 790 °C the least corrosion rate is 0.00162, 0.00116 and 0.00071 mpy at 1.5, 3 and 4 hrs.
6. The corrosion rate can be minimized by minimizing the formation of marten site in the microstructure.
7. The corrosion rate of mild steel increases with temperature while decreases for longer time of exposure and weight loss also increases with time and temperature.

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