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Microstructures and Corrosion Properties of X80 Pipeline Steel in Alkaline Sand Soil

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KEY WORDS: (X80 pipeline steel), (heat treatment), (weld fusion zone), (heat affected zone), (microstructure), (corrosion properties), (alkaline sand soil)

1. Introduction

Underground metal structures are usually expected to have a long working life, often 50 to 100 years. Structures such as natural gas, crude oil pipelines and water mains are only some of the many structures reported to have been affected by soil corrosion around the world [1]. The fundamental cause of the deterioration of pipeline buried underground is soil corrosion [2].

X80 pipeline steel is a fairly new steel used as pipeline material in China and other countries[3,4]. The heat affected zone(HAZ)and weld zone(WZ)may contain a mixture of ferrite, pearlite, bainite and martensite. In this work, microstructures of X80 pipeline steel that resulted from welding were prepared by different heat treatments. Electrochemical corrosion measurements, and surface analysis techniques were used to determine the effects of different microstructures of steel on corrosion of X80 steel in yulin water-saturated alkaline sand soil. The aim of this work is to provide essential insight into the mechanism of corrosion of pipe steel and its welds in alkaline sand soil.

2. Experimental

The test coupons were cut from X80 pipeline steel. The coupons were heated to 1200°C and held at the temperature for 10 min. Heat treatments, including water-quenching, oil- quenching and air-cooling, were then applied to obtain different welding HAZ microstructures.

The specimens were buried in water-saturated yulin alkaline sand soil that was extracted from 1 m depth where pipelines were buried in the highly salted region in North-West China.

All electrochemical tests were carried out with three-electrode system, the measurements were done with M2273A potentiostat (EG&G, USA). Polarization curves were determined potentiodynamically with a scan rate of 0.5 mV/s. All measurements were carried out at room temperature. Furthermore, the samples were taken to SEM combined with EDS to investigate surface corrosion morphology and chemical compositions. The structure of corrosion products were analyzed by XRD.

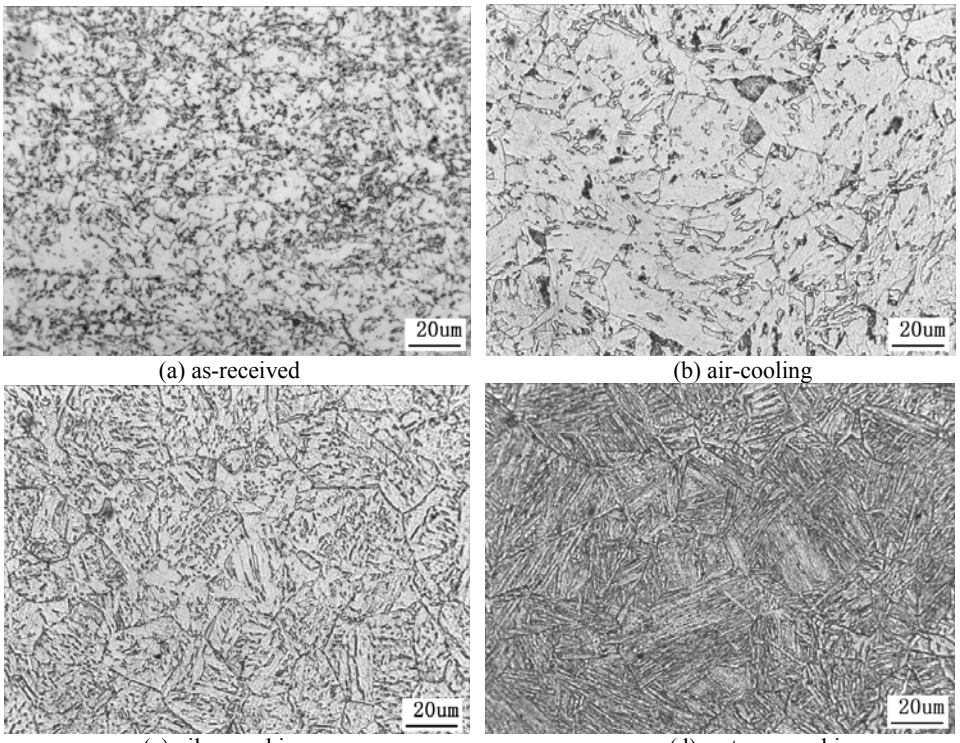
3. Results

3.1 Microstructure Observations

The metallographic views of the microstructures of X80 pipeline steel with the different heat treatments are shown in Fig.1. It is seen that the microstructure of as-received steel (Fig.1a) is a uniform acicular ferrite(AF) structure which consist of granular bainite (GB), polygonal ferrite(PF) and a small amount of pearlite (Fig.1a)[12]. Upon air cooling, the microstructure of X80 steel which simulated the softening zone in the welding heat affected zone (Fig.1b) contained granular bainite(GB), polygonal ferrite(PF) and a certain amount of pearlite (dark areas). The microstructure obtained by oil-quenching which simulated welding coarse grain heat affected zone (CGHAZ) region(Fig.1c) was composed of lath-shaped granular bainite and mlarge martensite/austenite (M/A) constituent. The steel icrostructure obtained by water quenching which simulated the hardening zone in HAZ (Fig.1d) consisted of upper bainite(lath-shaped bainite ferrite and discontinuous short clavite cementite) and well-distributed lath martensite [5]. The microstructure grains of X80 after the three different heat treatments grew to a great extent, and the microstructure inhomogeneity increased.

3.2 Electrochemical measurements

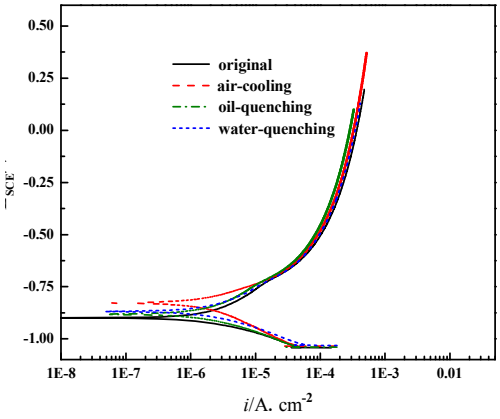
Fig.2 shows the potentiodynamic polarization curves of X80 steel with different microstructures buried in soil for 10, 30 and 50 days, respectively, where E is the corrosion potential, and i is the corrosion density. There was a common feature for the measured the potentiodynamic polarization curves of X80 steel, i.e., there is no obvious passive region, which indicates no protective layer or a stable passive film is formed on the sample surface in yulin water-saturated soil. There is an obvious tendency for polarization curves to shift "right" (to higher current densities) with 50 days corrosion on as-received, air-cooled, oil-quenched and water-quenched steels respectively. The fitting results for the open circuit corrosion potential(E_{corr}) and corrosion current density(i_{corr}) are listed in Table 1. At four different microstructures, the i_{corr} increased significantly with the increase of corrosion time. After 10 and 30 days corrosion, the i_{corr} with four different microstructures varied with in a small range, there was the largest i_{corr} for water-quenched steel after 10 days and the smallest i_{corr} for as-received steel after 30 days corrosion. After 50 days corrosion, there was the smallest i_{corr} for as-received steel and the largest i_{corr} for water-quenched steel, the values of the i_{corr} fitted on air-cooled and oil-quenched steels were between these extremes.



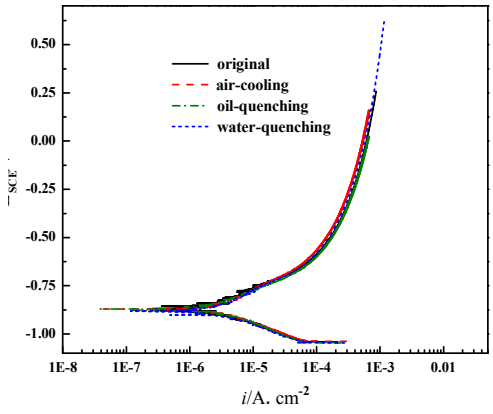
(a) as-received (b) air-cooling

(c) oil-quenching (d) water-quenching

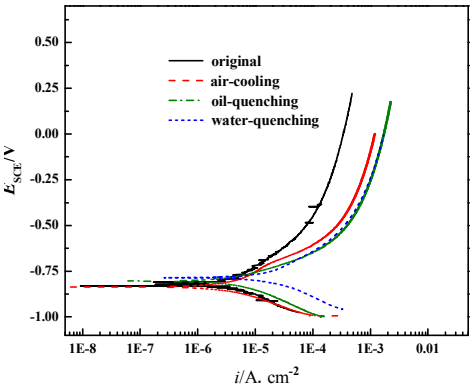
Fig.1 Metallographic views of the microstructures of X80 steel as-received (a) and with different heat treatments of (b) air-cooling,(c) oil-quenching and(d) water-quenching



(a) 10d



(b) 30d

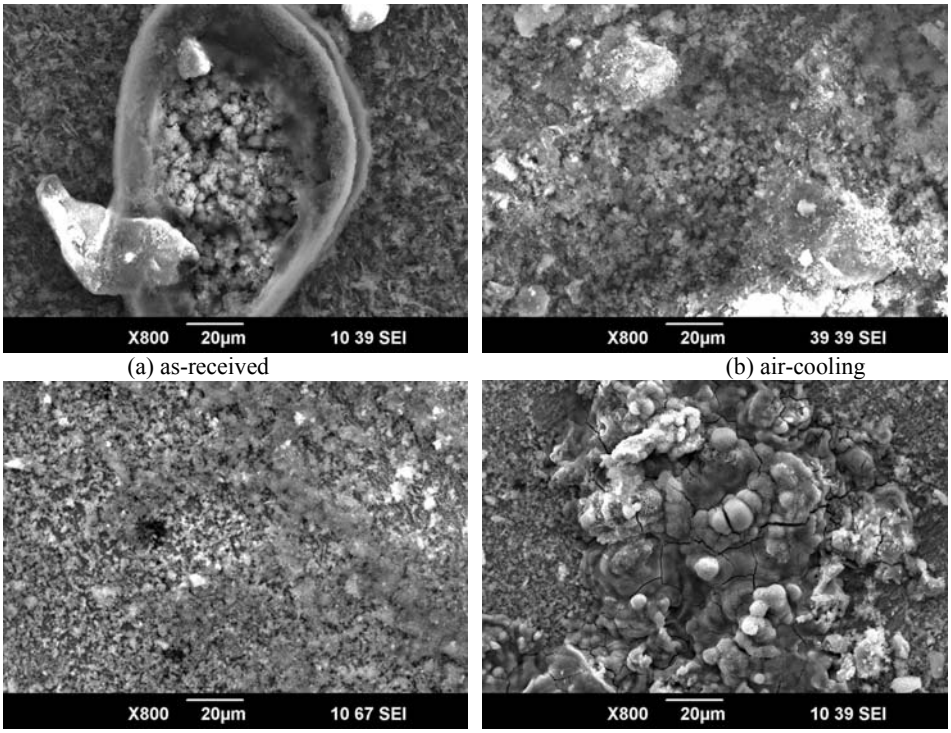


(c) 50d

Fig. 2 Polarization curves of X80 steel with different microstructures that buried in alkaline sand soil

Table1 Fitted results of polarization curves for X80 steel

Heat treatments	Exposure time/d	i_{corr} / μA·cm^{-2}	E_{corr} / mV
as-received	10	2.217	-899.54
	30	2.368	-881.02
	50	3.036	-831.98
air-cooling	10	2.051	-827.96
	30	3.308	-869.97
	50	3.522	-835.99
oil-quenching	10	1.950	-881.53
	30	2.717	-870.27
	50	5.546	-804.31
water-quenching	10	2.346	-868.60
	30	2.475	-882.74
	50	16.48	-785.88



(a) as-received (b) air-cooling

(c) oil-quenching (d) water-quenching

Fig. 3 The surface topographies of X80 steels after corrosion for 50 days in alkaline sand soil (a)as-received, (b)air-cooling, (c)oil-quenching and (d)water-quenching

3.3 Corrosion Product Analysis

It is seen that corrosion product on as-received steel was compact(Fig.3a),and covered uniformly the specimen surface, resulting in a low corrosion rate. As seen in Fig.3b and c, corrosion products were loose and porous. Furthermore, the corrosion product on the water-quenching X80 steel(Fig.3d) were quite loose, with many wider cracks in the oxide layer. Therefore, the different corrosion rates of steels with the different microstructures are attributed to the compactness and completeness of the corrosion product layer formed on the steel surface. EDS analysis showed that the corrosion products on X80 steels with four different microstructures were basically iron oxide. The composition of corrosion products was determined by XRD analysis，is basically α-FeOOH, γ-FeOOH and Fe_3O_4. The combined analysis of SEM, EDS and XRD showed that the different microstructures of steel result in the different physical structure and compactness of corrosion product, rather than different composition, leading consequently to the different corrosion rate of steel.

4. Discussion

4.1 Corrosion Electrochemistry of X80 Steel in Alkaline Sand Soil

The cathodic reaction of X80 steel in aerated, alkaline sand soil solution is dominated by the reduction of oxygen:

$$2H_2O + O_2 + 4e \rightarrow 4OH^- \quad (1)$$

The anodic process is more complicated, including dissolution of steel and formation of iron compounds with different chemical valences, i.e.:

$$Fe - 2e \rightarrow Fe^{2+} \quad (2)$$

$$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2 \quad (3)$$

$$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3 \quad (4)$$

$$Fe(OH)_3 \rightarrow FeOOH + H_2O \quad (5)$$

$$8FeOOH + Fe^{2+} + 2e \rightarrow 3Fe_3O_4 + 4H_2O \quad (6)$$

$$3Fe(OH)_2 + 1/2O_2 \rightarrow Fe_3O_4 + 3H_2O \quad (7)$$

EDS and XRD results show that all iron oxides, as suggested in Eq 5-7, are possible in alkaline sand soil. Effect of the iron oxide deposit layer on steel corrosion is mainly through a physical blocking effect, which inhibits the access of corrosive species to the steel surface. Therefore, compactness of the deposit layer is a main factor that affects the protectiveness of the steel.

4.2 Effects of Microstructure on Corrosion of X80 Steel

The microstructure of the steel influences the properties of the corrosion layers, such as morphology and proportion of the various chemical compounds present[6]. The present work shows that corrosion of **X80** steel is affected by its microstructure. The **X80** steels with heat treatments have a higher corrosion rate than the as-received **X80** steel(Table 1). Upon air cooling, there is more pearlite distributed at the grain boundaries in the ferrite matrix. Since the cementite contained in pearlite is electrochemically more stable than ferrite [7], a galvanic effect between the cementite and ferrite will enhance the corrosion of the ferrite, resulting in a higher corrosion rate. When the steel is oil-quenched, granular bainite and M/A islands formed in the steel. Although a complete understanding of the electrochemical activity of these two phases is still lacking, the present results indicate that they

will increase the activity of the steel, as indicated by the increasing corrosion current density(i_{corr}) and increasing corrosion rate. By water-quenched, upper bainite and martenite were formed in the steel. However, Low transformation temperature products in welding process like martensite and upper and lower bainite have a higher tendency to corrode than other microstructures[8]. Thus, the microstructure of X80 steel with water-quenched had a highest corrosion rate.

5. Conclusions

Studies of the effect of the microstructure and corrosion time on corrosion properties of X80 pipeline steel in an alkaline sand soil has been carried out. The most important results are:

(a) The corrosion product layer on the as-received X80 steel was compact and complete, provided effective protection to the steel. However, the corrosion product layers formed on the heat-treated steels were generally inhomogeneous, loose, porous and defective, wouldn't effectively protect the steel.

(b) The cathodic/anodic reactions of X80 steel were dominated by oxygen reduction. The corrosion morphology and properties of X80 steel were dependent on the integrality and compactness of iron oxide deposit layers which was through a physical blocking effect to afford the protection.

(c) The microstructure of X80 steel affected the properties of corrosion product layers. Generally, X80 steels with heat treatments had a higher corrosion rate than the as-received steel. The increase of pearlite content enhanced the corrosion of ferrite through a galvanic effect. The appearance of upper bainite and martenite in microstructure increased further the activity of the steel.

Acknowledgements

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