Materials and Design 30 (2009) 129–134

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Weather resistance of low carbon high performance bridge steel

Jia Guo *, Chengjia Shang, Shanwu Yang, Hui Guo, Xuemin Wang, Xinlai He

School of Materials Science and Engineering, University of Science and Technology Beijing, Handian District, No. 30 Xueyuan Road, Beijing 100083, PR China

ARTICLE INFO

Article history:
Received 5 November 2007
Accepted 16 April 2008
Available online 25 April 2008

Keywords:
A. metal matrix
E. corrosion
G. metallography

ABSTRACT

Weathering resistance of low carbon (0.03–0.05 wt.% C) micro-alloyed bainitic steel made in laboratory scale was studied and compared with that of conventional weathering steel 09CuPCrNi by wet–dry cycle test in a 3.5 wt.% NaCl aqueous solution. The results show that corrosion resistance of the bainitic steel is better than that of 09CuPCrNi, attributed to homogenous bainite microstructure. Subsequently, this steel was trial-manufactured in industrial plant, and the yield strength of which achieves 500 MPa grade, additionally, the gauge of plate steel reaches 80 mm, and excellent mechanical properties across the thickness section are obtained. Microstructures of the plate are homogenous bainite at surface layer, which contributes to excellent corrosion resistance of the industry trail steel.

1. Introduction

Recently, bridge steel without painting or other protective coatings has been used widely for the sake of environment protection and low cost [1]. Therefore, it is of great importance to improve the weathering resistance of steel, especially for the high performance steel, as the thickness of which is thinner than that of conventional weathering steel.

Microstructures of conventional weathering bridge steels are mainly ferrite and pearlite, such as Cor–Ten (conventional carbon and weathering steel) series steel developed by American in 1933, BS968 steel made by Britain and SMA steel made by Japanese. However, those microstructures often lead to low strength level. Therefore, low carbon bainitic steels serving as bridge steel become a trend because of its high strength, excellent weld properties and economical manufacture process. On the other hand, reducing carbon contents is advantage not only to improve weld properties but also to obtain homogenous bainite in heavy plate for the low carbon microalloyed steel. Meanwhile, strength lost due to decrease of carbon content can be compensated though alloying technology and thermo-mechanical control process (TMCP) [2].

Chloride ion in marine atmosphere is one of the important factors leading to corrosion. Many authors have focused on the influence of alloying elements [3–5] and rust structure [6–8]. Recently, several studies about effect of microstructure on corrosion behavior have been carried out. Zhang et al. [9] reported that pearlite in weathering steel 09CuPCrNi deteriorated the corrosion resistance as revealed using an artificial atmosphere-salt spray testing unit. Chen [10] studied corrosion resistances of low carbon micro-alloyed steels with different microstructures (pure ferrite, ferrite and pearlite, ferrite and bainite), the results showed that corrosion rates were different even with the same chemical composition. Zhao et al. [11] developed 750 MPa grade low carbon microalloyed steels, the corrosion resistance of which was better than that of Cor–Ten A in wet–dry cyclic corrosion test, because negative effect of pearlite on corrosion was eliminated through optimizing the microalloying elements technology and TMCP process. However, little research has been done with respect to the corrosion behaviors of 500 MPa grade level thick plates in chloride environment, which are applied to bridge structure parts.

The aims of the present work were to study the initial corrosion behavior of bainitic steel with carbon content ranged in 0.03–0.05 wt.% and compare it with conventional weathering steel (WS) 09CuPCrNi using wet/dry cyclic test. 09CuPCrNi steel was industrial produced according to China National Standards GB/T 4171-2000, the chemical composition range and manufacturing process of which are same with that of Cor–Ten A. In addition, this steel was trial-manufactured in industrial plant, and 500 MPa grade steels with thickness of 80 mm was expected to obtain. Corrosion resistance of the industry trial steel was also measured by wet/dry accelerated corrosion test, because it is difficult to obtain the same results completely as that of the other tests even under same test conditions.

2. Materials and experimental procedures

Steels A1 and A2, respectively, with 0.03% and 0.05% carbon contents were designed, the corrosion resistance of which was compared with that of WS 09CuPCrNi. Chemical compositions of these steels are listed in Table 1. Steels A1 and A2 were melted in 25 kg vacuum induction furnace and cast in a metal mould. The forged ingots were soaked at 1250 °C for 2 h, and then hot-rolled to 6 mm-thick plates with a finish rolling temperature 880 °C before water quenched. Subsequently, this steel was trial-manufactured in industrial plant, chemical composition of which is

---

* Corresponding author. Tel.: +86 1062334979; fax: +86 1062332428.
E-mail address: guojia1017@sohu.com (J. Guo).

0261-3069/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2008.04.038

Table 1
Chemical composition of various carbon contents steels and WS (wt.%)

Heat	C	Si	Mn	S	P	Nb	Ti	Cu	Ni	Cr
WS	0.082	0.28	0.38	0.006	0.018	0.035	0.008	0.29	0.24	0.33
A1	0.03	0.30	1.77	0.005	0.01	0.04	0.021	Cu, Ni, Cr, Mo(total) $\leqslant$ 1.2%		
A2	0.05	0.29	1.77	0.005	0.01	0.05	0.019	Cu, Ni, Cr, Mo(total) $\leqslant$ 1.2%		
B	0.045	0.30	1.40	0.005	0.008	0.04	0.021	Cu, Ni, Cr, Mo(total) $\leqslant$ 1.2%		

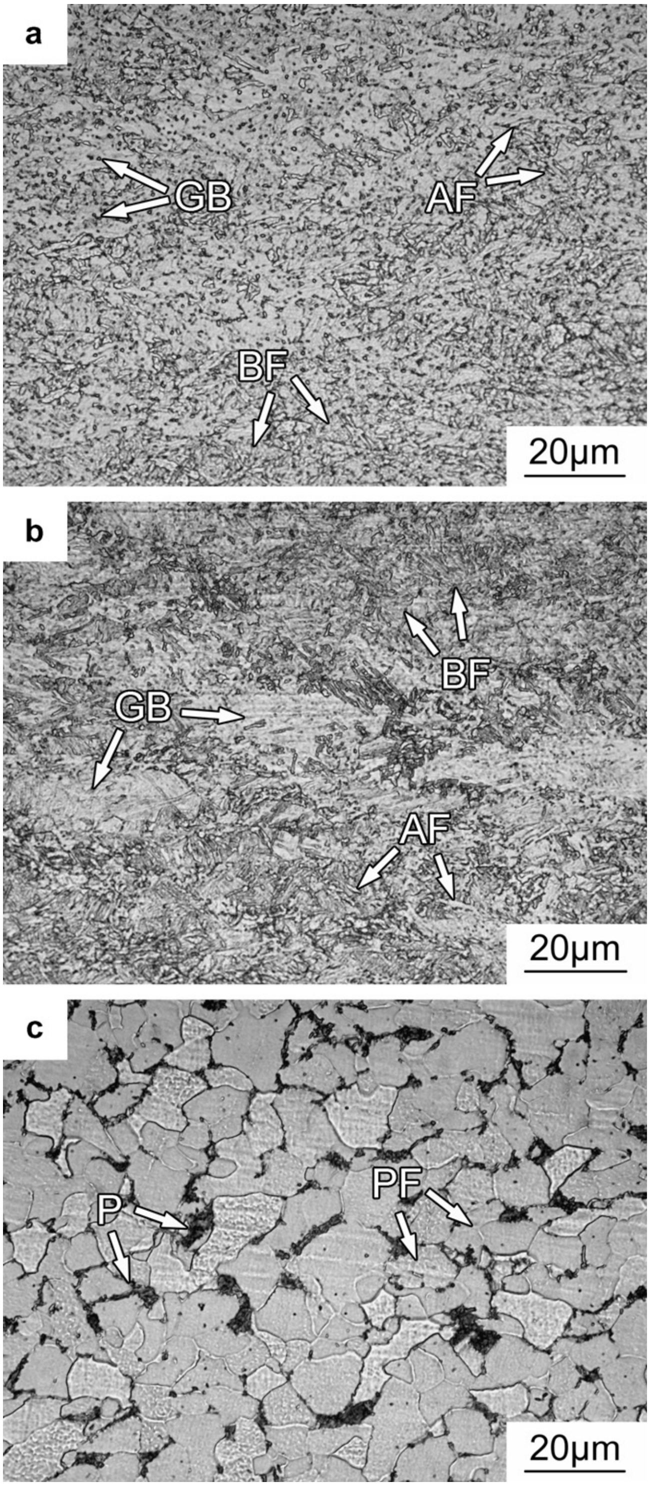

Fig. 1. Typical optical micrographs of steels A1 and A2: (a) 0.03C% with quasi-polygonal ferrite, granular bainite and bainite ferrite; (b) 0.05C% with granular 2bainite, bainitic ferrite and a little bit of acicular ferrite and (c) WS with ferrite and pearlite.

also shown in Table 1. The bridge steel was processed by TMCP with accelerated cooling rate more than 10 °C/s, and finish cooling temperature 550 °C, for obtaining optimum mechanical properties. The thickness of plates reached 80 mm.

Pieces of 60 × 40 × 5 mm were cut from steels A1, A2, WS and B for corrosion test, it should be noted that the pieces cut from steel B near the surface layer. All pieces were mechanically ground with 400–1000 grit silicon carbide abrasive paper, and cleaned with acetone, then rinsed with distilled water. A1, A2 and B were compared with WS in the cyclic wet–dry corrosion test. The test included two parts: (1) immersing samples into 3.5 wt.% NaCl solution at 40 °C for 18 min and (2) drying the specimen at 42 °C, 50% RH for 62 min. The accelerated corrosion test lasted for 360 cycles, and the specimens were taken out in three batches after 36, 72, 108, 144 and 180 cycles, respectively, for weight loss measurement. The rust layers formed on specimens were removed by immersing the specimens into Clark's solution (100 ml HCl, 1.19 g/ml + 20 g Sb_2O_3 + 50 g $SnCl_2$) and stirring for around 10 min at 25 °C.

Samples for metallographic observations were prepared by conventional grinding and polishing techniques, and then etched with 3% nital solution. The cross-section of the rust layers was analyzed using scanning electron microscopy (SEM).

The impedance measurements were carried out in 0.5 wt.% NaCl aqueous solution to evaluate the protection performance of rust formed on the steels. Electrochemical impedance spectra (EIS) measurements were performed using a Solartron 1255B frequency response analyzer in combination with a PAR 1287A potentiostat at room temperature. The sinusoidal potential for measurements was close to open circuit potential, amplitude 10 mv, and frequency ranged from 10^6 to 10^{-2} Hz.

3. Results and discussion

3.1. Effects of low carbon content on the weathering resistance

The microstructures of steels A1, A2 and WS are exhibited in Fig. 1. The predominant microstructures of A1 and A2 are granular

Table 2
Mechanical properties of steels A1 and A2

Sample no.	Rm (MPa)	Rel (MPa)	A (%)	Ak (half size)/J		
				20 °C	−20 °C	−40 °C
A1	843	712	14.5	99.3	102.7	94.7
A2	955	770	11.3	76.3	74	78.3

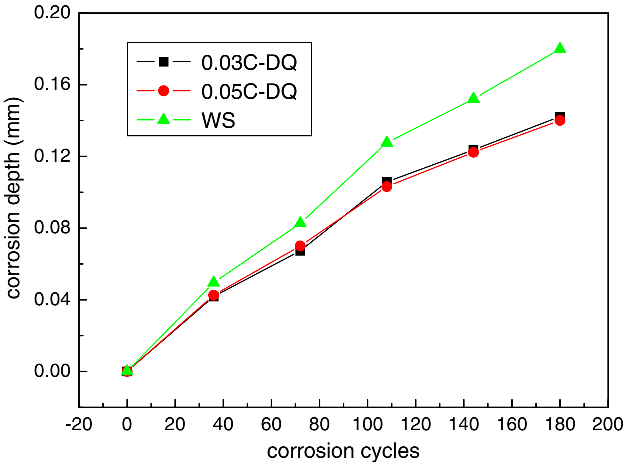

Fig. 2. Corrosion depth of LCS and WS vs. corrosion cycles.