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Research and development of weathering resistant bridge steel of Shougang

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Abstract. To introduce the composition design and mechanical properties and microstructure of the weathering bridge steel which would be used for bridge of Guanting reservoir. We adopt cyclic immersion corrosion test to study corrosion resistance difference of weathering bridge steel and common bridge steel. At the same corrosion time, the weight loss and corrosion rate of weathering bridge steel are lower than the common bridge steel's. Testing phase composition of rust layer by X-ray diffraction, two kinds of test steel's rust layer is mainly composed of Goethite and Fe_3O_4 and Fe_2O_3. At the same corrosion time, the percentage composition of goethite in rust layer of weathering bridge steel are significantly higher than common bridge steel's, the higher goethite content is, the compacter rust layer structure is. The compact rust layer would prevent the water and air passing the rust layer, and then preventing the further corrosion reaction, improving the corrosion resistance performance of weathering bridge steel.

1. Introduction

Since the beginning of the 20th century, the United States, Germany, Britain and Japan have been researched weathering resistant steel deeply[1-2]. Corten steel which has excellent properties of high-strength and weathering resistant was developed by The United States Steel Corporation in 1930 s. Weathering resistant steel has advantages in atmospheric corrosion compared to ordinary steel and economical efficiency compared to stainless steel. So the United States first time to apply weathering resistant steel to the bridge of the New Jersey highway, after that, Japan, Britain, Germany began constructions of weathering resistant steel bridge.

The reason of China's weathering resistant bridge development slowness is design and costs. In 2016, Guanting Reservoir Bridge is designed to use weathering resistant steel to build the first large-scale highway avoid coating steel bridge project in China, The bridge is crossed the Guanting Reservoir which is the important fresh water resource for city of Beijing. The construction of the bridge in water resource pays attention to environmental protection, so that the bridge is strictly requested in designing, materials and manufacturing. Shougang supply weathering resistant steel for its scientific research on bridge processing. In this paper, we focus on research procedure, microstructure, mechanical prosperities and weather resistant prosperity of Q345qENH produced by Shougang.

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2. Technical requirements and research procedure

2.1. Technical requirements

The chemical composition (mass fraction,%) of the weathering resistant bridge steel according to GB / T714-2015 is listed in table 1. Weather resistance index I is calculated by chemical composition according to ASTM G101, I (weather resistance index) of weathering resistant bridge steel require≥6.0. In terms of welding, Pcm(crack sensitivity coefficient)is decided to designers and manufactures of Guanting Reservoir Bridge. Table 2 is mechanical performance requirements.

Table 1 Chemical composition requirements of Q345qENH.

Element	C	Si	Mn	Nb	V	Ti	Cu	Ni	Cr
GB714 -2015	≤ 0.11	0.15 ～ 0.50	1.10 ～ 1.50	0.01 ～ 0.10	0.01 ～ 0.10	0.006 ～ 0.030	0.25 ～ 0.50	0.30 ～ 0.40	0.40 ～ 0.70

Note 1： $I = 26.01(\%Cu)+3.88(\%Ni)+1.20(\%Cr)+1.49(\%Si)+17.28(\%P)-7.29(\%Cu)(\%Ni)-9.10(\%Ni)(\%P)-33.39(\%Cu)^2$;
2： $Pcm = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B$；

Table 2 Mechanical performance requirements of Q345qENH

Rel /MPa	Rm /MPa	Y/T ratio	A%	-40℃impact energy /J
≥345	≥490	≤0.85	≥20	≥120

2.2. Research procedure

In terms of composition, according to the formula of weather resistance index I, it is known that the improvement of weather resistance index mainly needs to ensure the content of Cu, Ni, Cr, Si and P, however, these elements will deteriorate the welding performance as well. In this way, we design composition on the foundation of weathering resident element content, at the same time reduce the carbon and manganese content to ensure the welding performance.

In terms of microstructure, In order to ensure the steel has high strength, low yield ratio and high toughness, microstructure is designed as AF (acicular ferrite) +PF (polygonal ferrite).AF is the assurance of strength and low temperature toughness, PF control yield strength, so as to ensure low yield ratio.

3. Mechanical prosperities and microstructure

3.1Mechanical prosperities

Industrial production of 8-60mmQ345qENH weather resistant bridge steel is showed as table2. 375 MPa ≤ yield strength ≤ 455MPa, 547MPa ≤ tensile strength ≤ 606MPa, 0.67≤Y/Tratio≤0.82, 24% ≤elongation≤29%,- 40 ℃ impact energy ≥ 182J.These prosperities satisfy performance requirement of Guanting Reservoir Bridge project and national standard of GB / T714-2015.At the same time, Charpy V-Notch impact test were conducted at -20℃、-40℃、-60℃、-80℃、-100℃ to determine the ETT_{50}(ductile-brittle transition temperature). ETT_{50} of 16mm and 60mm steel is around -60 ℃ as shown in Fig. 1.

Table3. Mechanical prosperities of Q345qENH produced by Shougang.

Steel	Thickness/mm	Rel/MPa	Rm/MPa	Y/T ratio	A%	-40℃impact energy /J		
Q345qENH	8	409	606	0.67	26.5	182	196	188
Q345qENH	16	434	547	0.79	24.0	247	257	202
Q345qENH	24	407	564	0.72	29	294	383	306

Q345qENH	44	455	553	0.82	25.0	290	290	281
Q345qENH	60	375	561	0.67	25.0	197	234	197

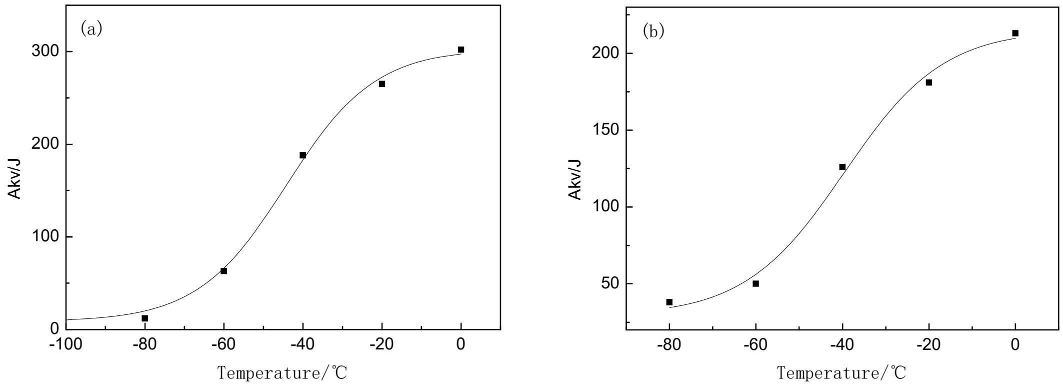

Fig.1 Ductile-brittle transition temperature curve of Q345QENH.(a)16mm,(b)60mm.

3.2 Microstructure
Microstructure examination of 16mm and 60mm steel is shown in Fig. 2, the examination position is 1/4 thickness of the sample. Fig. 2a shows PF+AF and Fig. 2b shows PF+AF+ a small amount P. Acicular ferrite is conducive to improving the strength of steel and low temperature toughness.

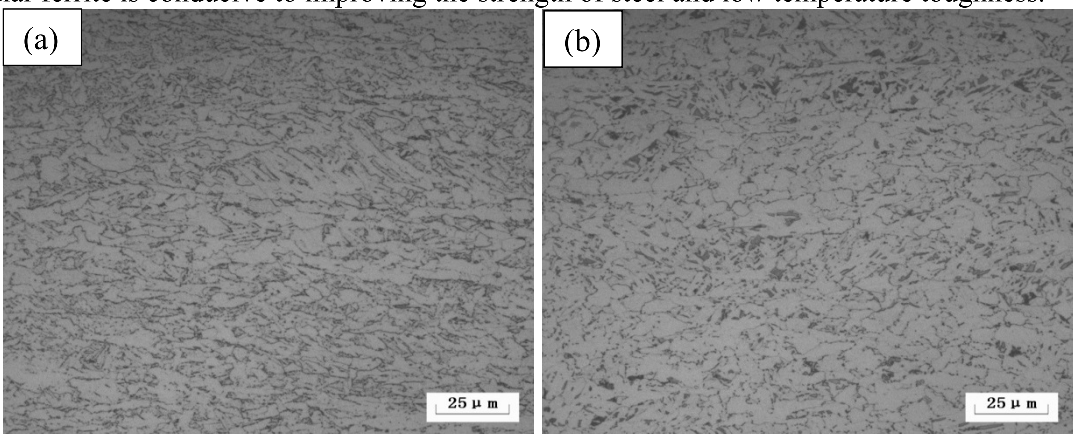

Fig.2 Microstructure of Q345QENH.(a)16mm,(b)60mm.

4. Weather resistant prosperity
In this chapter, we contrast weathering resistant steel Q345qENH with ordinary bridge steel Q345qE. To evaluate the weather resistant prosperities, simple size (60mm×40mm×3mm) was employed according to TB2375-1993. Corrosion solution selected 0.01mol / L $NaHSO_3$, testing temperature was 45±2℃, humidity choose 70 ± 5% RH, each cycle was 60 ± 3min, and infiltration time is 12 ± 1.5 min.The test cycle were 1 day, 2 days, 4 days, 8 days, weight loss and corrosion rate of different test cycles were measured, the composition and structure of rust layer were analyzed and observed.

4.1 Discussion of weight loss
Test cycles were 1,2,4,8 days of two kinds of steel, weight loss and corrosion rate are shown as Figure3. At the same cycle, weight loss and corrosion rate of weathering resistant bridge steel Q345qENH is significantly lower than Q345qE, the difference of weight loss will be further expanded with the increase of experimental time, and the corrosion rate of Q345qENH is 51.5% of Q345qE at 8 days.

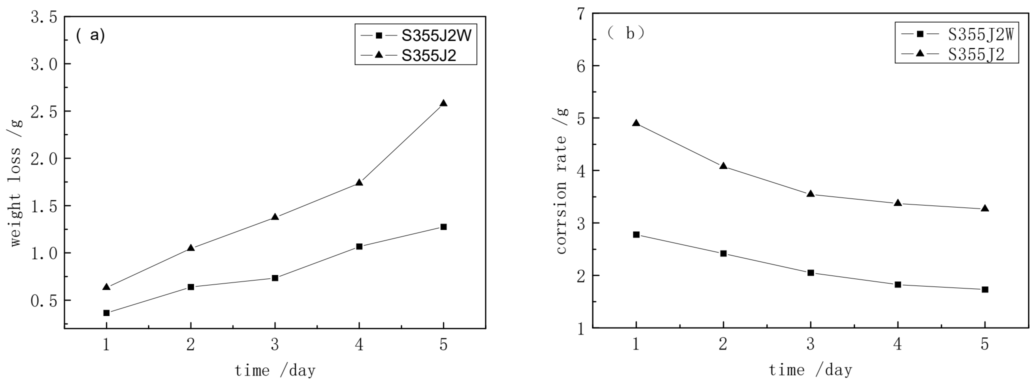

Fig.3 Curves of weight loss and corrosion rate.(a) weight loss,(b) corrosion rate.

4.2 Discussion of rust layer

As shown in table 4, component of rust layer at 8 days are composed of α-FeO (OH), Fe_3O_4 and Fe_2O_3, α-FeO (OH) has a compact structure, so the more α-FeO (OH), the better corrosion resistance performance [4-5]. The content of α-FeO (OH) in Q345qENH rust layer is obviously higher than Q345qE,we can conclude weathering resistant steel has a better performance at corrosion resistance. As shown in Fig. 4, rust layer appearance of Q345qENH and Q345qE at 8 days under SEM, Fig. 4a of Q345qENH possesses a more compact structure than Fig. 4b of Q345qE, which is exactly consistent with component analysis. The dense rust layer would prevent oxygen and water in the air from traversing protecting coat, and then protect steel substrate from corrosion.

Table 4 Component of rust layer at 8 days.

Steel	Test cycle/day	α-FeO(OH) /%	Fe_3O_4/%	Fe_2O_3/%
Q345qE	8	42.4	26.4	31.2
Q345qENH	8	51.8	13.0	35.2

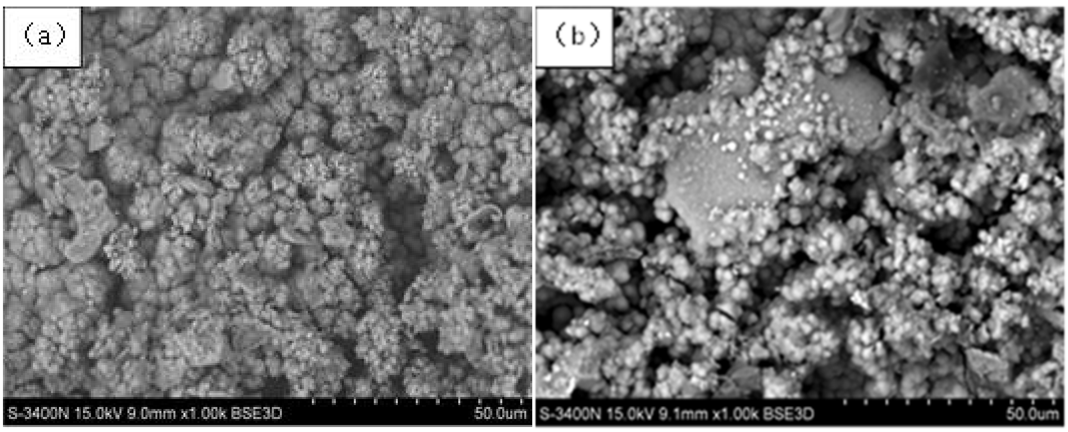

Fig.4 Rust layer appearance at 8 days.(a) Q345qENH,(b) Q345qE

5. Conclusion

1. Q345qENH weathering resistant bridge steel produced by Shougang, weather resistance index> 6.0,strength , plastic and toughness can meet the national standards of ASTM G101 and GB714-2015. The ductile-brittle transition temperature of the steel is around -60 ℃, which provides higher security for bridge.

2. Q345qENH weathering resistant bridge steel produced by Shougang has a better corrosion performance than Q345qE.The results of alternate immersion test show that weight loss and corrosion rate of Q345qENH are obviously lower than t Q345qE bridge steel. Especially, the corrosion rate of Q345qENH is 51.5% of Q345qE at 8 days.

3. α-FeO (OH) content of Q345qENH is higher than Q345qE, the dense rust layer would prevent oxygen and water in the air from traversing protecting coat so that protect steel substrate from corrosion.

References

[1] WANG Dongcai,GUO Liang. Current status and development of weathering resistant steel[J]. Science & Technology of Baotou Steel, 1993,3:59-73.

[2] WANG Lei,QIU Ruipang.Current status and development of weathering resistant steel[J].Journal of Highway and Transportation Research and Development , 2014,5:257-260.

[3] YU Qian. Current status and development of weathering resistant steel[J]. Journal of Iron and Steel Research,2007.19(11):1-4.

[4] CHEN Xiaoping, WANG Xiangdong, etc. Anti-corrision mechanism of rust layer with atmospheric corrosion resitiance [J]. corrision and protection,2009,30（4）:241-243.

[5] Keiser J T，Brown C W. Characterization of the passive film formed on weathering steels δ-FeOOH [J]. Corrosion Science,1983,（23）:251-253.