Mechanical properties of heat resistant steel serviced for 30 months

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Abstract. Grade 91 steel pipe was replaced after about 30 months of service. In this paper, the tensile properties, microhardness and chemical composition of the pipeline steel are systematically tested and analyzed. The results show that the properties of the steel still meet the requirements of relevant standards.

1 Introduction

At present, there are two main development directions of heat-resistant steel for power station at home and abroad: ferritic heat-resistant steel and austenitic heat-resistant steel. Compared with austenitic heat-resistant steel, ferritic heat-resistant steel has lower thermal expansion coefficient, higher heat transfer coefficient, better cold and hot workability and higher performance price ratio. Although austenitic heat-resistant steel has high thermal strength and high-temperature strength, its applicability is weaker than that of ferritic heat-resistant steel due to its large thermal expansion coefficient, poor stress corrosion resistance, low cycle fatigue and thermal fatigue performance. Therefore, ferrite heat-resistant steel is recognized as the first choice of heat-resistant steel for power plant. At present, scholars at home and abroad have studied the high temperature mechanical properties of various steels.

Golański et al. [1] studied the microstructure and mechanical properties of 18Cr-12Ni-Nb steel for boiler superheater after long-term service. The results show that the change of microstructure has little effect on the strength and creep properties due to its low service temperature. Shakil et al. [2] studied the high temperature mechanical properties of high strength steel by steady and transient tensile tests. The results show that the yield strength reduction factor of S700MC steel decreases from 100 °C. Wang et al. [3] studied the mechanical properties of high strength Q960 steel when used in high temperature environment. The results show that the influence of temperature on mechanical properties of different types of high strength steel is different. Ban et al. [4] studied the mechanical properties of SHP steel at high temperature and proposed a constitutive model. The results show that the mechanical properties of SHP steel are significantly

different from those of conventional low carbon steel and refractory steel. Zhang et al. [5] studied the mechanical properties of Q345 steel at 200-900°C under artificial cooling with water or fire foam. Glassman et al. [6] studied the mechanical properties of A588 weathering steel at high temperature. Jacobs et al. [7] studied the relationship between mechanical properties and microstructure of X70 pipeline steel below 400°C.

In this paper, the mechanical properties of grade 91 heat resistant steel after 30 months of service are tested and analyzed.

2 Material and Experimental

The pipe is a section of pipe cut from the steam extraction valve. This section of pipe has been in operation for three years, with one and a half months of maintenance and shutdown every year, plus other shutdown time of about half a month. The actual operation time is about 30 months. The actual measurement shows that the outer diameter of the pipe is 265mm, the inner diameter is 155mm and the wall thickness is 55mm. The actual working pressure is 17.7MPa and the working temperature is 537°C. The material is P91 (ASTM A335), and the heat treatment state is normalized.

The geometry and dimensions of tensile specimens at room and high temperatures is shown in Fig. 1. The diameter of the test specimen is 10mm. The tensile tests were conducted at room temperature, 537°C and 565°C. The tensile test conducted at room temperature refers to GB/T228.1-2010 Metallic materials-tensile testing-part 1: method of test at room temperature. The tensile tests conducted at 537°C and 565°C refer to GB/T228.2-2015 Metallic materials-tensile testing-part 2: method of test at elevated temperature.

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Fig 1. Geometry and dimensions of tensile specimens at room and high temperatures.

3 Results and Discussions

3.1 Tensile properties

The macroscopic pictures of tensile fracture specimens at room temperature, 537°C and 565°C are shown in Fig. 2.

It can be seen from the figure that obvious plastic deformation has taken place at the fracture surface of all fracture samples under the test conditions.

Fig 2. Tensile fracture specimen of Grade 91 steel.

The tensile test results conducted at room temperature, 537°C and 565°C are shown in Table 1. The results show that the yield strength and tensile strength decrease with the increase of temperature. The elongation and reduction

of area increase with the increase of temperature. The yield strength and tensile strength are higher than 415MPa and 585MPa required by standard respectively.

Table1. Tensile properties of the Grade91 steel pipe.

No.	Test temperature (°C)	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Reduction (%)
1	24	512.03	696.47	19.96	59.746
2	24	511.22	693.72	22.76	66.822
3	24	520.76	707.41	20.44	63.566
4	537	356.48	429.77	21.58	85.145
5	537	344.47	414.75	21.12	86.058
6	537	348.05	419.56	22.48	85.543
7	565	323.15	389.77	23.40	88.900
8	565	318.31	379.06	23.06	89.283
9	565	319.57	382.00	24.42	89.410

The fracture morphology at low magnification under room temperature tensile test is shown in Fig. 3(a). It can be seen that the fracture surface is undulating and there are a large number of secondary cracks. The morphology at

high magnification is shown in Fig. 3(b). It can be seen from the figure that there are fine dimples and secondary cracks on the fracture surface.

Fig 3. Fracture morphology of tensile at room temperature.

The fracture morphology at low magnification under 537°C tensile test is shown in Fig. 4(a). It can be seen that the fracture surface is rough with holes in the middle and shear lip at the edge. The morphology at high

magnification is shown in Fig. 4(b). The size of dimples is larger than that of tensile fracture at room temperature, and the number of dimples is less than that of tensile fracture at room temperature.

Fig 4. Fracture morphology of tensile at 537°C.

3.2 Microhardness analysis

The Brinell hardness values of Grade91 steel pipe which has been in service for about 30 months are shown in

Table 2. It can be seen from the results that the hardness values of inner region, middle region and outer region are less than 250HB required by the standard.

Table2. Brinell hardness values of the Grade91 steel pipe.

Points		1	2	3	4	Average value
Sample	Outer region	212.18	212.56	212.22	212.31	212.32
	Middle region	215.63	215.91	215.83	216.27	215.91
	Inner region	217.24	218.36	218.08	217.47	217.79
ASTM A335 Grade91						≤250

3.3 Chemical composition analysis

The chemical composition of Grade91 steel pipe which has been in service for about 30 months is shown in Table

3. The results show that the chemical composition meet the requirements of the standard.

Table3. Chemical composition of the Grade91 steel pipe (wt.%).

Element	C	Mn	Si	Ni	Cr	Mo	P
Sample	0.09	0.51	0.34	0.18	8.87	1.02	0.012
ASTM A335 Grade91	0.08-0.12	0.30-0.60	0.20-0.50	≤0.40	8.00-9.50	0.85-1.05	≤0.02
Element	Ti	V	Nb	Zr	Al	S	
Sample	<0.01	0.22	0.083	<0.01	<0.01	<0.005	
ASTM A335 Grade91	≤0.01	0.18-0.25	-	≤0.01	≤0.02	≤0.01	

4 Conclusion

After 30 months of service, the mechanical properties and chemical composition of grade 91 steel pipe still meet the requirements of relevant standards.

Acknowledgments

The authors are grateful for the support by Shanghai Bureau of Quality and Technical Supervision Research Project (No. 2018-30 and No. 2018-27).

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