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Cause analysis of circumferential cracking of reheat steam hot section pipeline of 300MW unit

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Abstract: During the operation of reheat steam hot leg pipeline, circumferential cracking occurs, leading to the failure of high temperature steam leakage. In order to find out the causes of the cracking of the reheat steam pipeline and understand its health status, the comprehensive inspection and analysis of the cracked reheat steam pipeline are carried out by using the test methods of macro morphology analysis, non-destructive testing analysis, chemical composition analysis, microstructure analysis, mechanical property testing and scanning electron micro area analysis. The results show that the chemical composition of the cracked reheat steam pipeline meets the requirements of the design standard, the metallographic microstructure is ferrite + bainite + pearlite, the tensile strength and elongation after fracture are qualified, and the yield strength is slightly lower than the requirements of the standard. The main causes of the pipeline circumferential cracking: the low-temperature medium in the cold section of reheat steam is continuously discharged into the high-temperature pipeline and directly contacts with the inner wall of the pipeline repeatedly, forming alternating thermal stress, which causes the pipeline thermal fatigue damage cracking to leakage; and the insufficient yield strength will accelerate the speed of fatigue cracking to a certain extent.

1. Introduction

According to the requirements of TSG G0001-2012, the four pipes (including main steam pipe and high-pressure bypass pipe, reheated steam hot section pipe and low-pressure bypass pipe, reheated steam cold section pipe and high-pressure feedwater pipe) which are calculated by the Design Institute and manufactured by the piping plant belong to the pipes within the scope of boiler and are included in the management of special equipment. The four pipelines are important equipment of modern large-scale units, which are prone to various defects and failure modes during manufacture, installation and operation. Technical supervision and inspection shall be strengthened [1-8].

During the operation of a 330MW subcritical thermal power unit, cracks and leaks were found in the reheated steam hot section pipeline (hereinafter referred to as hot section pipeline) at 6.3m platform of the steam turbine workshop. The specification is ID679×38.3mm and the material is A335-P22.The boiler type of this unit is DG1025/18.2-II6 and the steam turbine type is C300/235-16.7/0.35/537/537. Up to this outage, the total operating month is 70000h.

According to TSG G0001-2012, the hot section piping with cracking and leakage failure belongs to the piping within the scope of the boiler, which is located in front of the main steam valve of the steam turbine reheater, and its design standard is DL/T 5054.Under BMCR condition, the medium pressure of reheated steam cold section pipe (hereinafter referred to as cold section pipe) is 3.74MPa and the medium temperature is 324℃.The medium pressure of hot section pipeline is 3.59MPa and the medium temperature is 540°C.The High-pressure Bypass warm pipe comes out after the high-pressure bypass temperature and pressure reducing valve, i.e. under normal operating conditions, the pipe is connected with the cold section pipe, and its medium temperature and pressure are the same as the parameters of the cold section pipe.The connection between the connecting pipe and the hot section pipe is shown in Figure 1.

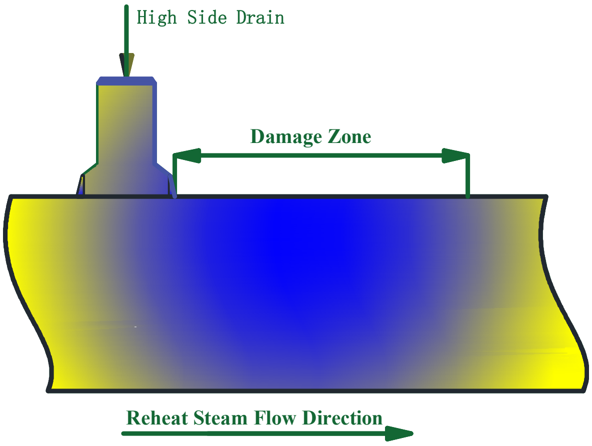


Figure 1 Connection mode ofhot section pipe

2. Test analysis

2.1 Observation and analysis of appearance and morphology

The cracking position of hot section pipeline is 11 o'clock to 1 o'clock in the direction of media flow, 140 mm behind the high-pressure bypass warm pipe socket. The cracks are circumferential and 100 mm in length, as shown in Figure 2. Through penetration inspection, it is found that there are a large number of cracked circumferential cracks with different lengths and lengths in the 1200 mm range of inner wall of the pipeline, and there are many radial cracks in the holes of the tube socket of the inner wall warm pipe socket. As shown in Figure 3.It can be seen that the distribution and shape of cracks in the inner wall of pipeline have obvious characteristics of thermal fatigue damage.

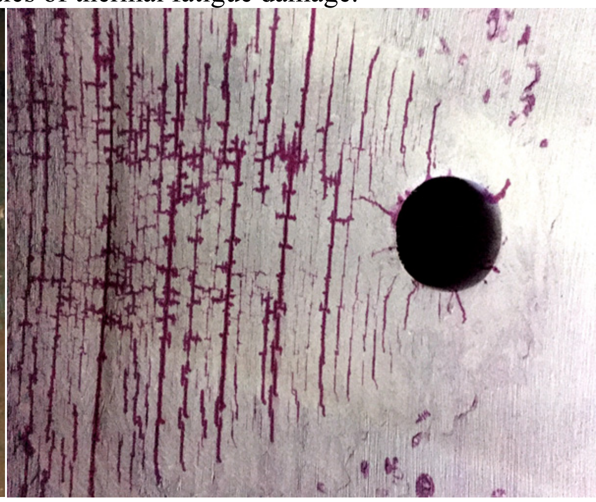
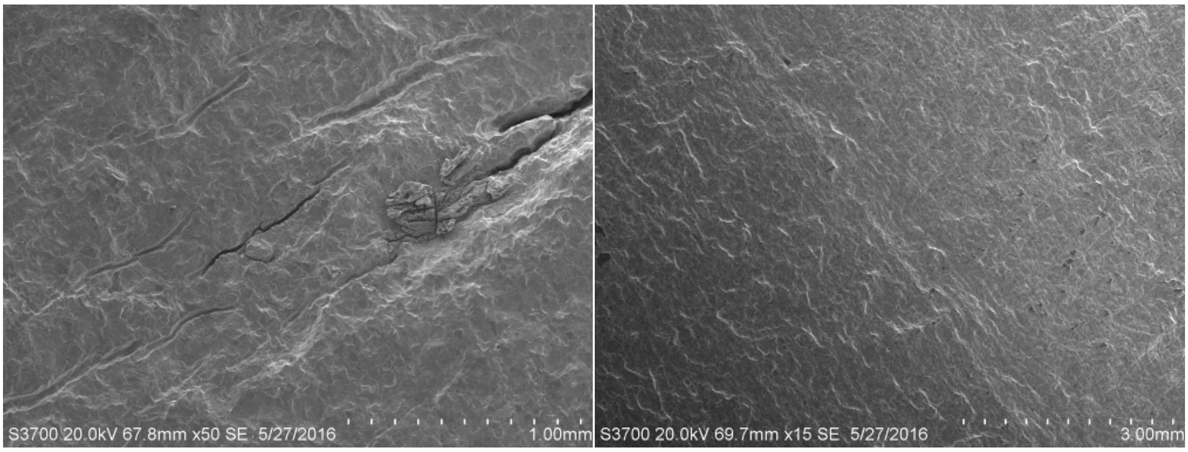


Figure 2 Cracks on the outer wall of the pipeline Figure 3 Cracks in the inner wall of pipeline

2.2 Observation and analysis of fracture characteristics

The fracture surface is smooth with no obvious plastic deformation. Severe oxidation products are present on the surface and the fatigue glow extending radially from the inside to the outside is clearly visible as shown in Figure4.Scanning electron microscope (SEM) is used to analyze the micro-morphology of the fracture. It can be seen that the fatigue crack originates from the inner wall of the pipeline and propagates radially. The tear ribs are radially distributed with cracks and friction marks[9]. It shows typical fatigue fracture morphology characteristics as shown in Figure5.

Figure 4 Macro-morphology of fracture



(a) Splitting source area (b) Expanded area

Figure 5 Micro-morphology of fracture

2.3 Detection and analysis of chemical composition

Chemicals of hot section pipeline samples are detected, and the detection data are shown in Table 1.The results show that the chemical composition of the pipeline conforms to the standard.

Table 1 Test results of chemical composition Unit:%

Detection Elements	C	Si	Mn	Cr	Mo	P	S
ASMESA-335/SA-335M	0.05~0.15	≤0.50	0.30~0.60	1.90~2.60	0.87~1.13	≤0.025	≤0.025
Sample	0.11	0.35	0.50	2.29	0.96	0.010	0.005

2.4 Microstructure inspection and analysis

Microstructure examination was performed on the cracked reheat steam pipe samples. The structure state of inner wall, half wall thickness and outer wall of pipe base material is relatively uniform, which is composed of pearlite + ferrite + granular bainite with uniform axial distribution and no obvious spheroidization is observed, as shown in Figure 6. There are several parallel cracks propagating radially in the inner wall, and there are oxide layers inside each crack, but the length and degree of internal oxidation of each crack are different, which indicates that the time of crack formation is different. As shown in Figure 7.

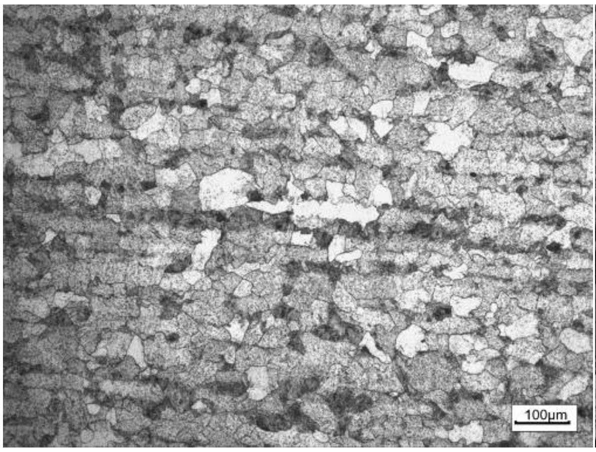


Figure 6 Microstructure at 1/2 wall thickness

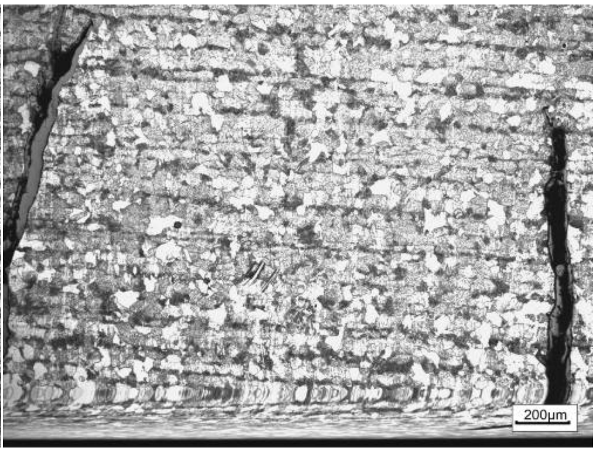


Figure 7 Internal wall cracks and oxide layers

2.5 Testing and analysis of mechanical properties

Mechanical properties of reheater steam pipes were tested by transverse and longitudinal sampling respectively. The results are shown in Table 2. It can be seen that the tensile strength and elongation after breaking of the pipe base material meet the requirements of ASME SA-335/SA-335M standard; the impact absorbent power and hardness ASME SA-335/SA-335M standard are not required, but DL/T 438-2016 in Chinastipulates the hardness of A335-P22 material as 125~179HB. It can be seen that the hardness test results meet the requirements of Chinese standards; however, the yield strength of the material is slightly lower than the standard requirements, and the low yield strength represents its poor resistance to thermal fatigue, which is conducive to the accelerated diffusion of thermal fatigue damage.

Table 2 Test results of mechanical properties(20℃)

Test items	Yield strength (R_{el})		Tensile trength (R_m)		Post-break elongation (%)		Impact bsorbent power (J)	Hardness (HB)
	Transverse	Portrait	Transverse	Portrait	Transverse	Portrait	Transverse	1/2 radius
ASME SA-335	≥205	≥205	≥415	≥415	≥14	≥22	--	--
Measured value	202	203	478	483	31	32	95.2	138~153

3. Analysis of test results

In conclusion, the main reason for cracking of hot section pipeline is thermal fatigue damage, which results in low yield strength of material and poor resistance to thermal fatigue, accelerating the expansion of thermal fatigue.

According to the operation requirements of the power plant, in order to ensure that the high-pressure bypass temperature and pressure reducing valve can be opened smoothly in emergency, the high-pressure bypass warm pipe valve is in normal open state during operation. According to this requirement, the low temperature medium of 324℃ in operation is continuously discharged into the medium environment of 540℃. The temperature difference of the medium is 216℃. After entering the hot section pipeline, the low temperature medium diffuses with the high-speed flowing steam and contacts the inner wall of the hot section pipeline directly. In a certain area, the temperature gradient is generated and the thermal stress is formed. The cold and hot alternate and repeat for a long time, which finally causes thermal fatigue damage to the hot section pipeline. Fatigue cracks with reticulated cracks on the inner wall of the pipe.

4. Conclusions and Suggestions

The main reason for circumferential cracking of reheat steam hot section pipeline during operation is thermal fatigue damage. The material has low yield strength and poor resistance to thermal fatigue, which accelerates the expansion of thermal fatigue. Unreasonable arrangement of High-pressure Bypass warm pipe system, incorrectly introduces cryogenic medium directly into high-temperature medium environment for mixing temperature. Because no measures such as inner sleeve are taken to protect high-temperature pipeline, cryogenic medium directly impacts the inner wall of pipeline and forms periodic temperature fluctuation, which causes the inner wall of pipeline to bear alternating thermal stress for a long time and finally causes fatigue cracking failure of pipeline in hot section of reheater steam.It is recommended to change the arrangement of the hot water drainage pipe system of the high pressure bypass pipe and introduce the warm pipe medium into the low pressure drainage expansion vessel of the steam turbine so as to avoid the "cooling" effect and impact of the low temperature medium on the hot section pipe of reheated steam, which can not only avoid the fatigue damage of the pipe, but also improve the thermal efficiency of the unit.

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