Advances in Materials Technology for Fossil Power Plants
Proceedings from the Eighth International Conference
October 11–14, 2016, Albufeira, Algarve, Portugal
https://doi.org/10.31399/asm.cp.am-epri-2016p0600

J. Parker, J. Shingledecker, J. Siefert, editors

LIFE DIAGNOSIS AND EXTENSION OF A HIGH TEMPERATURE HEATING SURFACE

Haitao Cao, Hong Ma, Lei Zhang, Zhigang Shi, Fangping Zheng, Xipeng He

Xi'an Thermal Power Research Institute Co., Ltd, Xi'an 710032, China

ABSTRACT

Through inner wall oxidation scale thickness measurement, sampling tests and installation of wall temperature measuring device in the boiler, the equivalent wall temperature and its distribution of secondary high temperature reheater tube were estimated and verified, and the temperature field distribution of tube platen which is of single peak distribution in the direction vertical to tube platen and an apparent lower temperature distribution covered by the smoke shield at the side of boiler wall were both obtained. For the middlemost 10CrMo910, the wall temperature of individual tube was getting close to 600℃. Afterwards material state and residual creep life of tube platen were estimated and calculated. The results of estimate and calculation show that the tube platen in the middle is not suitable for further service due to its degraded material states and lower antioxidant ability. Thus with consideration of distribution characteristics of temperature field, parts of tube platens in the middle are proposed to be replaced with T91 tubes. Furthermore, to avoid onsite heat treatment, 10CrMo910 tube covered by the smoke shield in the boiler was reserved, and a small piece of 10CrMo910 tube was welded at the inlet and outlet ends respectively in the manufactory.

KEYWORDS: *Life Diagnosis; Extension; Oxidation Scale; High Temperature Heating Surface*

1 INTRODUCTION

A Power Plant is equipped with a 300 MW coal-fired generator unit and a tower-type once-through boiler which is of a subcritical, primary intermediate reheating, double combustion chamber (W-flame) type. The unit is equipped with 52 rows of secondary reheater tubes in total. These tubes are of 10CrMo910 in the original design, and have been put into operation for a period of about 100,000 hours and suffered from burst leakage more than once. Relevant analysis results indicate that these tubes have been in overheating service for a long time due to their severe material aging and relatively thick oxidation scales on inner and outer walls. For this reason, technical reform has been carried out for the heating surfaces by replacing the original 10CrMo910 tubes with 12Cr1MoVG ones. However, the results of sampling test for the new tubes after a service period of about 2 years upon the completion of replacement indicate that the room-temperature tensile strength of these tubes has been slightly lower than or close to the lower limit as required by the standard for new tubes, and the spheroidized microstructures of these tubes have also became worse. For this reason, study on strategy for life diagnosis and extension of secondary reheater tubes of the power plant has been carried out.

2 INNER WALL OXIDATION SCALE THICKNESS MEASUREMENT

Inner wall oxidation scale thickness measurement has been carried out on site for the heating surface using a high-frequency ultrasonic oxidation scale thickness measuring device. The measuring parts are located on both sides of the special steel welds (12Cr1MoVG and 10CrMo910) on the outlet header at the right side of boiler, as shown in Fig. 1.

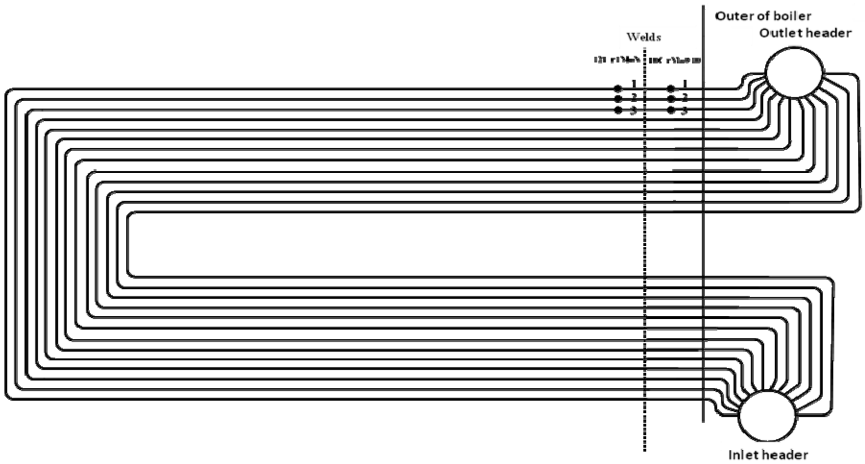


Fig. 1 Schematic Diagram for Measuring Parts of Tube Row

312 points have been measured on site in total. The results of measurement indicate that 10CrMo910 tubes with the oxidation scale thickness of 0.15 mm ~ 0.40 mm account for about 72% and those with the thickness above 0.40 mm account for about 27%; 12Cr1MoV tubes with the oxidation scale thickness below 0.10 mm account for 5.93% and those with the thickness of 0.10 mm ~ 0.40 mm account for 94.07%. Refer to Fig. 2 & 3 respectively for details.

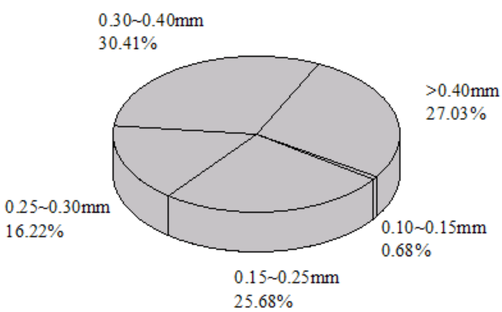


Fig. 2 Proportion of Oxidation Scale

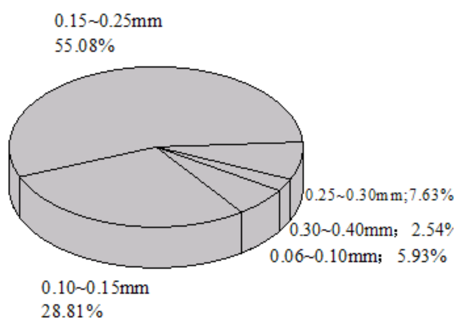


Fig. 3 Proportion of Oxidation Scale

Thickness of 10CrMo910 Tube *Thickness of 12Cr1MoV Tube*

3 EQUIVALENT TEMPERATURE CALCULATION

The oxidation scale thickness of inner wall of high temperature boiler tube has a quantitative relation as shown below with the equivalent temperature and operation time of the boiler tube [1].

$$T = -\frac{A_0}{\ln \frac{x}{2K_0 t^{1/2}}} \tag{1}$$

Where: x—inner wall oxidation scale thickness (μm); t—operation time (kh) of tube; T—equivalent temperature (K).

A_0 and K_0 are material factors of metal, which vary with different materials and require consideration of impacts of service environment and other factors during specific calculation.

Through comparison of equivalent temperature and average equivalent temperature between 10CrMo910 and 12Cr1MoVG tube rows (as shown in Fig. 4 – 7) using Formula (1), it is found that the temperature of tube rows at both ends is low while the equivalent temperature of the middle part is high, with the maximum temperatures being 566℃ and 592℃ respectively.

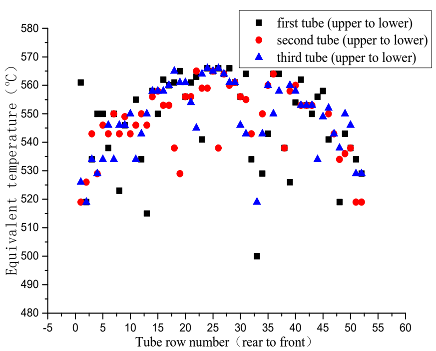


Fig. 4 Comparison of Equivalent Temperature among Different 10CrMo910 Tube Rows

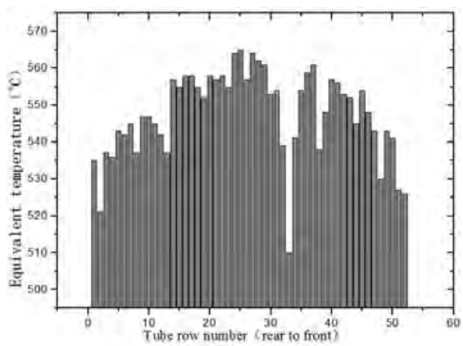


Fig. 5 Comparison of Average Equivalent Temperature among Short Sections of Different 10CrMo910 Tube Rows

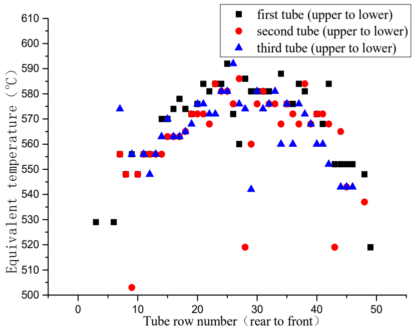


Fig. 6 Comparison of Equivalent Temperature among Different 12Cr1MoVG Tube Rows

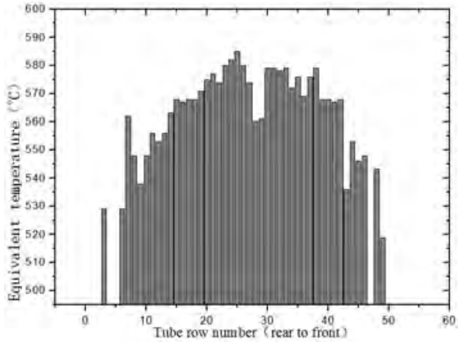


Fig. 7 Comparison of Average Equivalent Temperature among Different 12Cr1MoVG Tube Rows

4 SAMPLING TEST AND ANALYSIS

4.1 Information about Sample Tubes

11 sample tubes have been collected. Except that 1 (12Cr1MoVG for long section and 10CrMo910 for short section) contains welds and 1 is of external 10CrMo910 type, the rest 9 tubes are of 12Cr1MoVG. Refer to Fig. 8 for sampling positions.

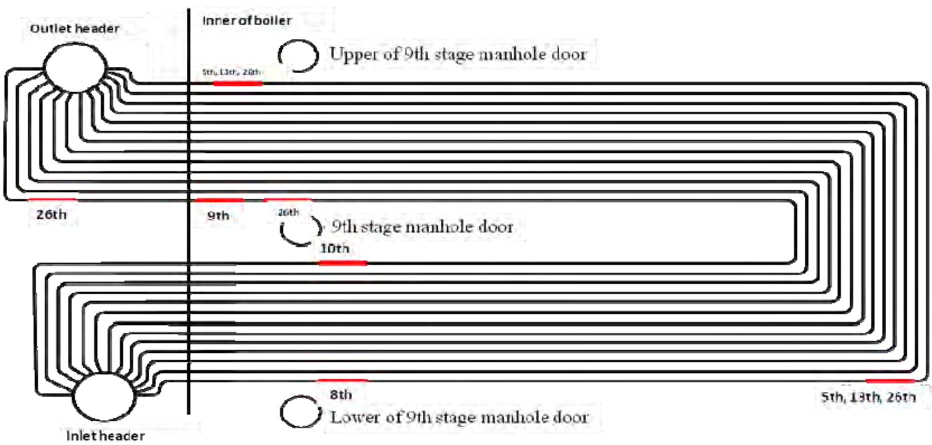


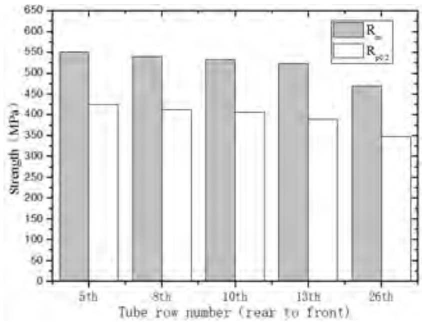
Fig. 8 Schematic Diagram for Sampling Positions of Tubes

4.2 Analysis on Test Results

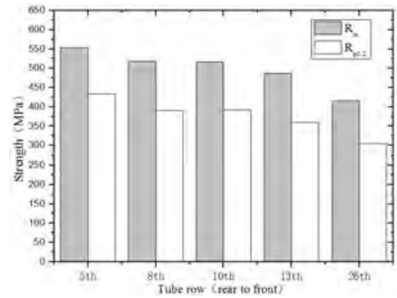
Refer to Fig. 9 – 13 for the results of tensile, metallographic and hardness tests of each sample tube.

a) Tensile test

Refer to Fig. 9 for the comparison between results of tensile test for 12Cr1MoVG tube. This figure indicates that the tensile strength of the No. 5 sample tube (the 1st one from the bottom of the 26th row at the outlet section) at the upstream and downstream sides of smoke, and the tensile strength of the No. 6 sample tube (the 1st one from the top of the 26th row at the inlet section) at the downstream side of smoke do not meet relevant requirements for new tubes as specified in relevant standards; the tensile strength and the specified plastic elongation at the outlet section are slightly lower than those at the inlet section; the strength of tube trends to gradually lower from the outside tube rows to the middle tube rows.



(a) Comparison among Average Values at Inlet Section



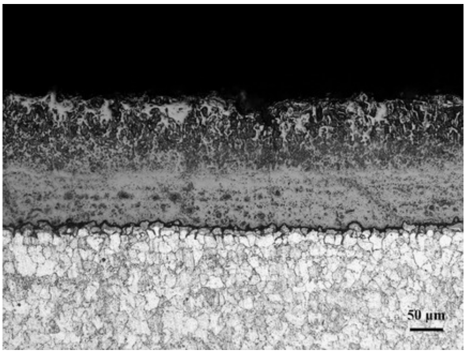
(b) Comparison among Average Values at Outlet Section

Fig. 9 Comparison among Average Values of Tensile Strength and Specified Plastic Elongation of 12Cr1MoVG Sample Tube

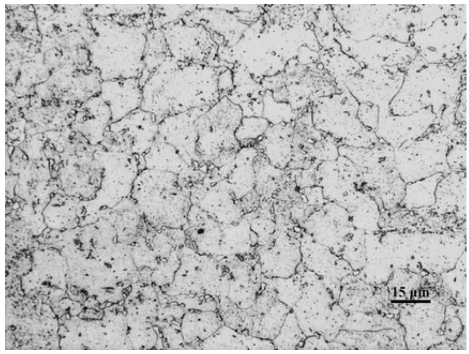
b) Metallographic test

Refer to Fig. 10 for the typical microstructure picture of sample tube. The grain size of each 12Cr1MoVG sample tube or tube section is of Grade 8 [2]. The microstructure of the No. 5 sample tube (the 1st one from the bottom of the 26th row at the outlet section) is of ferrites + carbides, with the grain size of Grade 8. Carbides are mostly distributed at the grain boundaries of ferrites, with only a few pearlite marks. The maximum oxidation scale thickness of this tube is 0.26 mm. The structure of the No. 6 sample tube (the 1st one from the top of the 26th row at the inlet section) at the downstream side of smoke is of ferrites + carbides, with carbides mostly distributed at the grain boundaries of ferrites, and only a few pearlite marks. The maximum oxidation scale thickness of this tube is 0.18 mm. For the rest 12Cr1MoVG sample tubes, the structure is of ferrites + pearlites + carbides, and the maximum oxidation scale thickness is 0.11 mm.

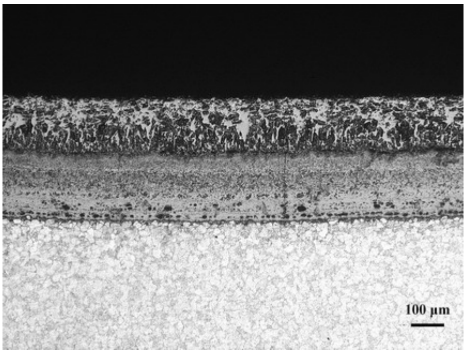
The microstructures of two 10CrMo910 sample tubes or tube sections are of ferrites + bainite. Carbides are mostly distributed at the grain boundaries of ferrites, and partially chainlike. For these sample tubes or tube sections, the grain size is of Grade 7–8, and the maximum oxidation scale thickness is 0.32 mm and 0.40 mm respectively. Oxidation cracks along grain boundaries on outer wall are of about 1 grain size in depth respectively.



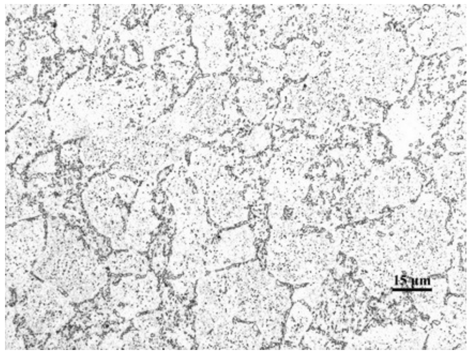
(a) Morphology of Inner Wall Oxidation Scale of 12Cr1MoVG at Upstream Side of Smoke



(b) Microstructure Morphology of 12Cr1MoVG at Upstream Side of Smoke



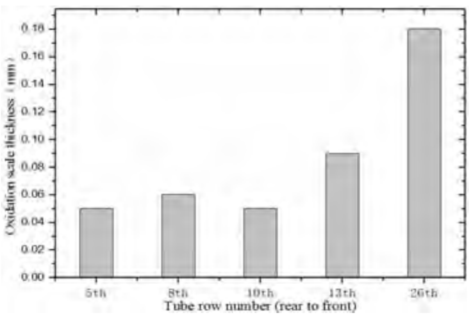
(c) Morphology of Inner Wall Oxidation Scale of 10CrMo910 at Upstream Side of Smoke



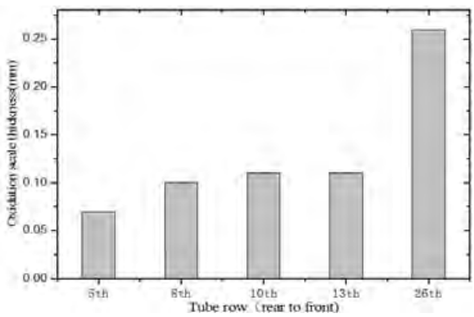
(d) Microstructure Morphology of 10CrMo910 at Upstream Side of Smoke

Fig. 10 Microstructure Morphology of Typical Sample

Results of comparison of oxidation scale thickness among 12Cr1MoVG tube sections in different tube rows at the inlet and outlet sections, as shown in Fig. 11, indicate that the outside tube rows have thin oxidation scales and the middle ones have thick oxidation scales.



(a) Comparison of Oxidation Scale Thickness among Different Tube Rows at Inlet Section

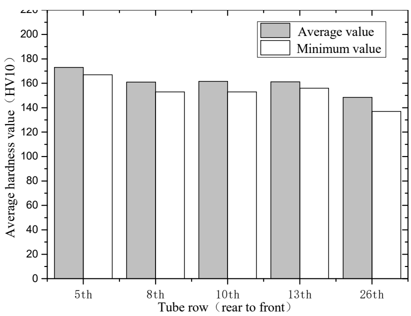


(b) Comparison of Oxidation Scale Thickness among Different Tube Rows at Outlet Section

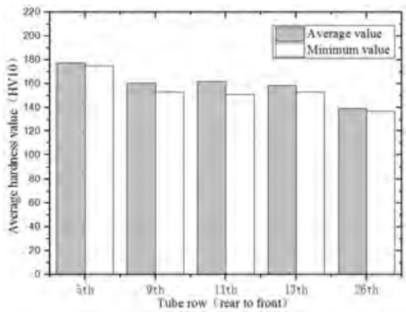
Fig. 11 Comparison of Oxidation Scale Thickness among 12Cr1MoV Tube Sections in

c) Hardness test

Among all 12Cr1MoVG sample tubes, the hardness of individual sample tube is slightly lower than the lower limit as required in the standard for new steel tubes, and that of the rest tubes is normal. The results of comparison of average and minimum values among tube sections, as shown in Fig. 12, indicate that the average hardness of tube row trends to lower from the outside to the middle part.



(a) Comparison of Average and Minimum Hardness among Tube Rows at Inlet Section

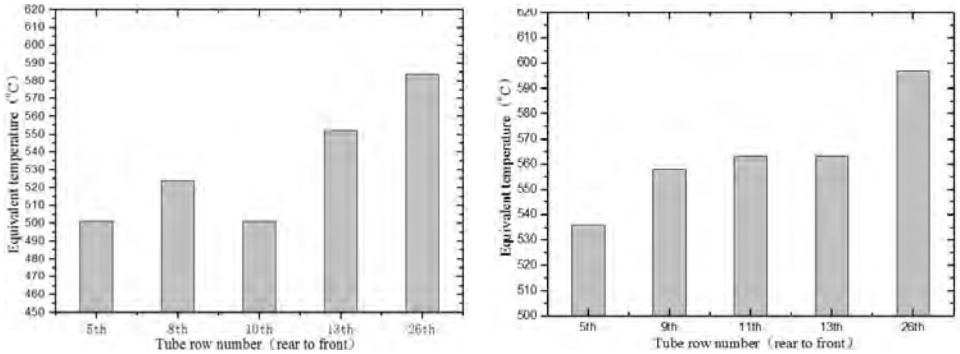


(b) Comparison of Average and Minimum Hardness among Tube Rows at Outlet Section

Fig. 12 Comparison of Average and Minimum Hardness among 12Cr1MoVG Tube Sections at Inlet and Outlet Sections

d) Equivalent temperature calculation and wall temperature analysis

The results of equivalent temperature calculation for sample tubes indicate that the estimated maximum temperatures of 12Cr1MoVG and 10CrMo910 sample tubes, occurring on the middlemost tube platen, are 597℃ and 561℃ respectively, showing consistency with the rules acquired through on-site test, as well as obvious characteristics of "low at sides and high in the middle". Refer to Fig. 13 for details.



(a) Comparison of Equivalent Temperature among Different Tube Rows at Inlet Section

(b) Comparison of Equivalent Temperature among Different Tube Rows at Outlet Section

Fig. 13 Comparison of Equivalent Temperature among 12Cr1MoVG Tube Sections in Different Tube Rows at Inlet and Outlet Sections of Heating Surface

4.3 Setting of Wall Temperature Measuring Points in Boiler

According to the results of measurement, calculation and analysis, 2 long-life wall temperature measuring points in boiler have been set in total on the 4th horizontal tubes from the top of the 26th and 27th rows from the rear of boiler on the heating surface. Prior to reform for life extension, the 2 wall temperature measuring points in boiler have been put into operation for a period of about 35,000 h.

Refer to Fig. 14 for typical measured temperature data. The results of measurement indicate that over-temperature exists at measuring points where the design metal temperature is 580℃, but the average measured temperature is about 595℃, and the maximum temperature is up to 620℃. These measured data indicate that the measuring devices in boiler have a swift response, and can accurately reflect real wall temperatures and temperature changes of boiler tubes under various conditions.

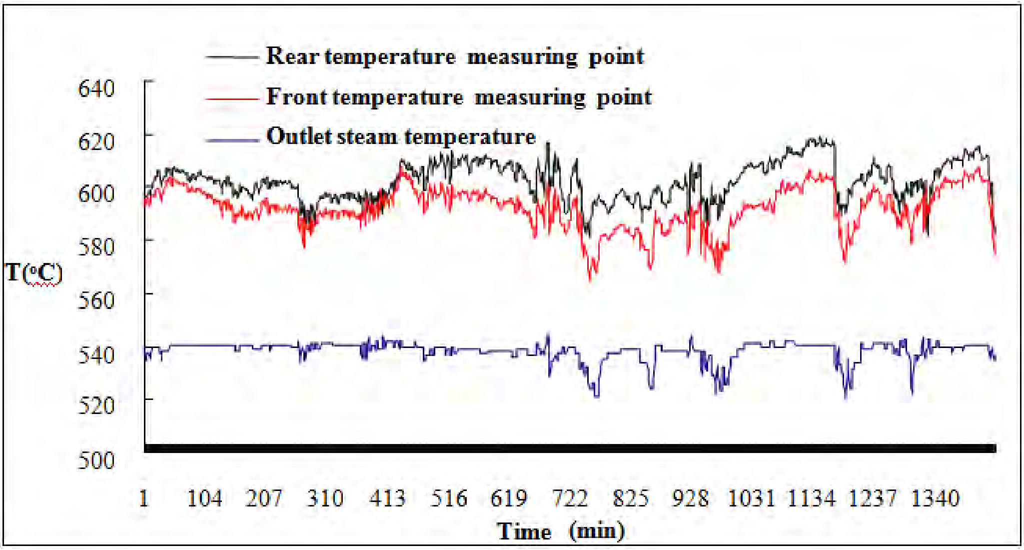


Fig. 14 Typical Measured Temperature Data

4.4 Comprehensive Analysis on Wall Temperature of Tube

The structure type and combustion mode of "W"-flame boiler determine the characteristics of low smoke temperature at front / rear side of boiler and high in the middle. The smoke corridor formed due to a relatively large pitch between the two tube platens in the middle further highlights the high temperature characteristics of tube platens in the middle.The wall temperature, estimated based on the inner wall oxidation scale thickness obtained through field measurement and sampling test, verifies the obvious characteristics of low wall temperature for tube platens at front / rear side and high wall temperature for tube platens in the middle.

For 10CrMo910 short sections, based on the inner wall oxidation scale thickness obtained through field measurement, it is estimated that the maximum equivalent wall temperature at single point is 564℃, the maximum average wall temperature of tube platen is 559℃, the average wall temperature of 10 tube platens in the middle is higher than that of 10 tube platens on both sides by about 38℃, and the average wall temperature of all measuring points is 539℃. For 12Cr1MoVG tube sections, it is estimated through sampling test that the maximum wall temperature is 597℃ and the average wall temperature of all sample tubes is 563℃. Through wall temperature measurement, it is found that the average wall temperature at measuring points in the middlemost two tube rows is about 595℃ and the maximum temperature is up to 620℃.

Through analysis on comprehensive test results, we can know that the average temperature of tube platens in the middle of the heating surface is higher than that of tube platens on both sides by about 30℃. Under the action of smoke shields around the furnace, the wall temperature of the rest 10CrMo910 short sections is lower than that of relatively remote 12Cr1MoVG tubes by about 20℃. The wall temperature of 12Cr1MoVG tubes of half of tube platens in the middle is basically higher than the recommended value (i.e. 570℃).

4.4 Estimate of Residual Creep Life

The Larson-Miller method has been applied to estimating the residual creep life of 10CrMo910 and 12Cr1MoVG sample tubes under the worst states [3,4]. During estimate, the pressure is taken as 1.5 times the safety factor.

The calculation results indicate that under normal quality of raw materials and stable operation conditions, the residual creep life of 10CrMo910 and 12Cr1MoVG tubes is greater than 100,000 hours, provided that no consideration is given to the impact of oxidation cracks along grain boundaries on the surfaces of tubes.

5. COMPREHENSIVE ANALYSIS AND CONCLUSIONS

According to design and operation of the heating surface, due to prominent deviation of "∧"-type smoke in the boiler, the tube wall temperature of tube platens in the middle of the heating surface is relatively high. The equivalent wall temperature of tubes at inlet and outlet sections of tube platens within the range of 1/2 of furnace depth was greater than 570℃, and that of the middlemost individual tube was close to 600℃. Therefore, for tube platens in the middle, 10CrMo910 used in the original design has been replaced with 12Cr1MoVG which is of a low grade through reform.

According to test results, analysis and conclusions, considering current conditions and existing problems, the tube platens within the range of 1/2 of furnace depth have been replaced as recommended, to ensure long-term operation safety and stability. The alternative tubes have the same specifications as the original design, and are of ASME SA-213 T91 [5]. Moreover, to facilitate field installation and avoid onsite heat treatment, a small piece of 10CrMo910 (or ASME SA-213 T22) tube has been welded at the inlet and outlet ends respectively in the manufactory, and the original 10CrMo910 short sections at the outlet section in boiler have been shortened by cutting, so that new and old 10CrMo910 tubes at the outlet section are located within the protection range of smoke shield at the side wall. In addition, the manufacturer has also, according to relevant recommendations, carried out tube replacement and reform for secondary reheater.

References:

[1] DL/T 884-2004. Power plant metallography inspection and assessment guideline[S].

[2] GB/T 6394-2002. Metal-methods for estimating the average grain size[S].

[3] DL/T 654-2009. The technical guide for the life assessment of units in fossil-fuel power plant[S].

[4] G. hongbo, X. shouming, Z. Jie. Microstructural changes and residual life prediction of 12Cr1MoV steel[J]. *Journal of Materials Engineering*, 2005(3), pp. 40-42

[5] 2010 ASME Boiler and Pressure Vessel Code [S].