ISSN: 2349-6495(P) | 2456-1908(O)

A Failure Analysis and Remaining Life assessment of Boiler Water Wall tube

Patel Sunny Sanjay[1], Dr R. K. Mandloi[2]

[1]M.tech Scholar, Dept of Mechanical Engineering, MANIT Bhopal, Madhya Pradesh, India
[2]Associate Professor, Dept of Mechanical Engineering, MANIT Bhopal, Madhya Pradesh, India

***Abstract*— *This paper presents failure investigation on the SA210GrC water wall tube by visual Site inspection, tube wall thickness measurements, chemical composition test, Hardness test and microstructure analysis with proper evidence collected to identify the exact cause of the failure. The water wall tube was failed with blister, bulging and creep cracks on outer surface located near to the Soot Blower. On-site wall thickness measurements were performed on some of the water wall tubes located at the same level of the ruptured tube. The tubes have significant wall thinning and erosion from outside. Mild corrosion deposition also seen in the inner side. Microscopic examinations on the failed rupture region and some distance away of the as-received tubes are also conducted in order to determine the failure mechanism and root cause. Failure mechanisms are also discussed and relevant data from few months back to the failure gathered to identify the failure reason. The failure mechanism is identified as a result of the combination of the significant wall thinning of water wall tube due to long term overheating and creep. Corrosion due to oxygen is also a cause of wall thinning. Root cause analysis identified that deaerator was not working efficient to remove dissolved gases was reason behind corrosion. Long term overheating was due to operating temperature above the design one. Finally all the parameters checked and rectified properly. Maintenance of Deaerator has been done to put it in the working condition.*

Keywords*— *Boiler, Creep, Corrosion, Root Cause Analysis, Water wall tube, Failure, Life Estimation

I. INTRODUCTION

Boiler tube failure is an expensive problem requiring valuable time and capital to correct it. Even when only a single tube failure the entire unit typically must be brought off line while repair is made. From the past some years due to technology it is easy to identify failure & correction is made but new difficulties also come with complex structure and operation for increasing efficiency. Now a days it's also one of the major problem for boiler outage and maintenance. In this paper the study is made on the failed water wall tube due to long term overheating and mild corrosion on inner side with some erosion on outer surface. In thermal power plant of 210MW unit due to bad coal firing, ash having Corrosion properties and fuel gas velocity also affects the boiler tube. Water chemistry affects the boiler tube failure due to corrosion phenomena. According to the failures by location, water wall tubes are the second highest failure location after super heater tubes. However, according to the failures by material properties, carbon steel tubes statistically lead as the most frequent material causing failures. Failure investigation on the SA210GrC water wall tube by visual site inspection, tube wall thickness measurements, Hardness test and microscopic examinations is presented in this paper. The tube originally has outer diameter of 63.5mm and thickness of 5.2mm. A water wall tube was situated at corner no-1, Tube no 4 from soot blower no.42 (left to Right). Onsite wall thickness measurements were also performed on all the rear water wall tubes located at the same level of the ruptured tube. The tubes had operated at temperatures of 400^0C. The operational steam pressure was reported as 14.71 MPa. The tubes are observed to have experienced significant bulging and blisters on surface. At the corresponding operating tube temperature the operational hoop stresses are determined and compared with the allowable stress for SA210GrC tube stated in ASME Code. Creep analysis on carbon steel made by some researchers to check the possibility of a thermally activated process involved in failure mechanism. Failure mechanisms are discussed and the main root cause of the failure may be deduced from the findings obtained from the analysis.

II. HISTORICAL BACKGROUND OF THE BOILER

It was known that the boiler commissioned in January 1983 and the water wall tube at the furnace region first failed in December 2005. Hence, it was estimated that the tube has been in service for 22 years (105,600 h). Then it was failed at many places before it's estimated life. Scheduled preventive maintenance practices for inspection purposes was carried out 24 months prior to failure. This tube was failed in just 7000 h of satisfying work after the schedule overhauling of power plant. At that time it's average thickness was 5.2 mm. So, it was necessary to carry out the failure analysis. During the outages the inspection was carried out to observe conditions and any possible abnormalities especially in the refractory and the surrounding tubes. The activities are also conducted to remove the accumulations of the fly-ash and to perform appropriate maintenance activities on the refractory on regular basis. It may be estimated that the water wall tube failed during the service after the last preventive maintenance.

III. ROOT CAUSE ANALYSIS OF FAILED TUBE

3. 1 Visual Examination of failed tube

Fig.3.1: Water wall tube before failure tube

Fig.3.2:Bulging in the water wall

Fig.3.3: External metal wastage

Fig.3.4: Blisters at two locations

Fig.3.5: Mild corrosion deposit on ID surface in Blistered regions

In Fig 3.1 it is seen that the tube is in working condition (not failed) and the erosion due to abrasive property of the coal is damaging the surface. In fig 3.2 Bulging of the tube produced due to long term over heating creep damage or due to increasing temperature above the prescribed limit for long time. (1) External metal Wastage is due to corrosion or erosion. In fig 3.3 the Outer surface is covered with oil ash slag which is shining with coal ash layer and wall thinning with external damage is observed. (2) In fig 3.4 Thick-lip ruptures in steam-generator tubes occurred mainly by stress rupture as a result of prolonged overheating at a temperature slightly above the maximum safe working temperature. Thick-lip rupture may or may not be accompanied by sight swelling of the tube in the region adjacent to the rupture. In Fig 3.5 Mild corrosion deposit on ID side may be due to corrosion of protective layer of ferrous oxide. Due to the increasing temperature and bad water chemistry it is happened. (3) It is seen copper segregation at some point makes caustic corrosion.

3.2 Dimensional Measurement:

Location	Wall Thickness			
	0	**90**	**180**	**270**
Failed Edge	1.10	-	5.85	-
Bulged Edge	5.20	-	5.75	-

It is seen that the subsequent amount of wall thinning with 1.10mm thickness on the failed region. The opposite

ISSN: 2349-6495(P) | 2456-1908(O)

region of failed shows some amount of thick layer of wastages. Bulging is observed and it is due to creep or long term overheating.

3.3 Chemical Composition:

[Standard test method analysis of carbon & Low Alloy Chemical Composition (%)-Test Method-ASTM E415]

(Steel by spark Atomic Emission Spectroscopy)

An electric arc or spark is passed through the sample, heating it to a high temperature to excite the atoms within it. The excited atoms emit light at characteristic wavelengths that can be dispersed with a monochromatic and detected. The chemical composition of failed tube is

	C	Si	Mn	P	S
Original Tube	0.35	0.10 min	0.29-1.06	0.035 max	0.035 max
Tube Sample	0.191	0.272	0.785	0.013	0.003

It is seen that composition of tube is within limit.

3.4 Hardness Measurement Test

(HV_{10}) – Method ASTM E92

(Brinell hardness test with 10Kgf load)

It is used to measure the Hardness of metallic material. The test here used is HV10 with diamond indenter 136 ^{o}C included angle. Here 10 Kgf load is applied on the prepared sample for few seconds. Then the square indent diagonal is measured & the HV number is measured.

Blistered & Failed Edge – 132/132

Away from Failed Region – 147/151

Bulged Region – 151/149

Here in blistered region due to increase of temperature the material becomes softer & easy to rupture. Thick lip rupture happened in this area. In other area hardness is same.

3.5 Micro structural Examination

Test Method ASTM E 340

Macro Etching

The microstructure of the failed edge shows the growth of the grain boundary. The thick black slag is oxide filled cavities. The creep cracks on surface are due to overheating for long time. The pearlite and ferrite is the main constituent in steel. It is showing the failure due to overheating. Pearlite is dispersed all over.

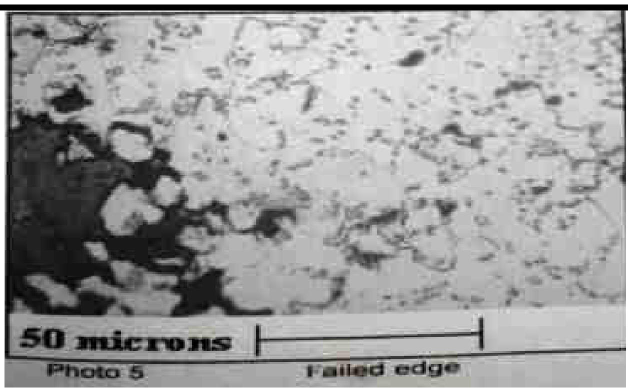

Fig.3.6: Oxide filled cavities and creep cracks on failed edge

The blistered and failed region shows a microstructure of ferrite and dispersed pearlite with grain boundary carbides. The region opposite to the failed region shows a structure of ferrite and in situ spheroidised pearlite. (4)

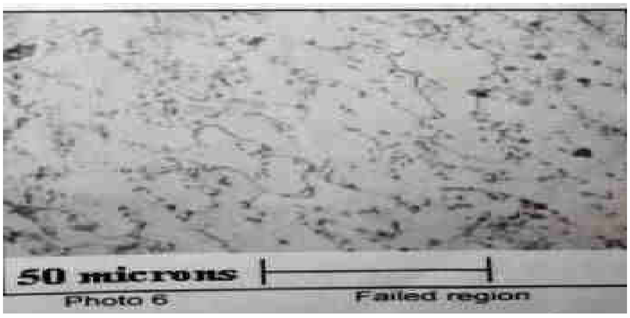

Fig.3.7 Fail region of blister

From both the Microstructure Fig 3.6 and Fig 3.7 it is seen that the failure cracks are filled with oxide and blister region with growth of grain boundary. Pearlite becoming decreased and dispersed in some point. Carbon from it goes to grain boundary. So that the boundary becoming hard and brittle which is prone to failure. At some point black dots can be seen are cavities filled by oxide. (5)

3.6 Creep Test-Larson Miller Parameter

The Larson-Miller parameter is a means of predicting the lifetime of material vs. time and temperature using a correlative approach based on the Arrhenius rate equation. (6) The value of the parameter is usually expressed as $LMP=T(C+\log t)$ where C is a material specific constant often approximated as 20, t is the time in hours and T is the temperature in Kelvin. Creep-stress rupture data for high-temperature creep-resistant alloys are often plotted as log stress to rupture versus a combination of log time to rupture and temperature. One of the most common time–temperature parameters used to present this kind of data is the Larson-Miller (L.M.) parameter, which in generalized form is

$$LMP=T[\log t_{r}+C]$$

T = temperature, K or °R
t_{r} = stress-rupture time, h
C = constant usually of order 20

According to the L.M. parameter, at a given stress level the log time to stress rupture plus a constant of the order of 20 multiplied by the temperature in Kelvin or degrees Rankin remains constant for a given material. (7)

When the creep test for specific SA210 was carried out by many scientists the relation between stress and Larson Miller Parameter found that as the stress increases LMP is decreasing logarithmically. From LMP the remaining life and the cumulative creep damage is found. When the cumulative creep damage crosses the value 1.0 it is failed.

In Fig 3.8 Stress vs.LMP for SA210 steel is drawn to obtain the LMP from the given stress and it is useful to find out the cumulative creep damage.

In Fig 3.9 Stress vs. Temperature for SA210 steel is drawn to show that the stress is badly affecting the remaining life with increase in temperature.

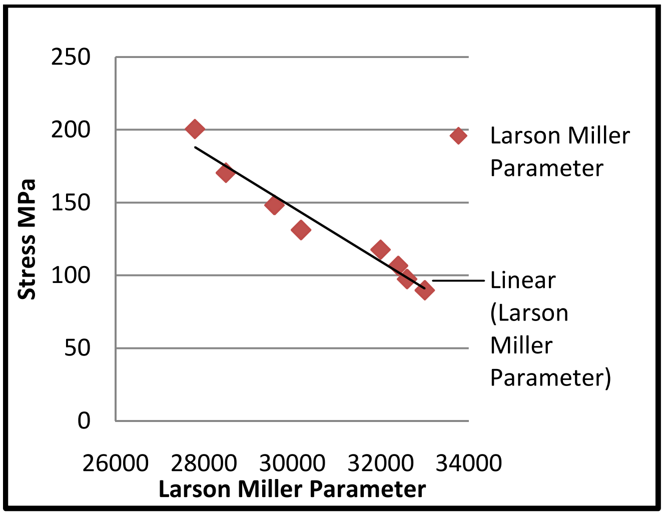

Fig.3.8: Stress vs. Larson Miller Parameter

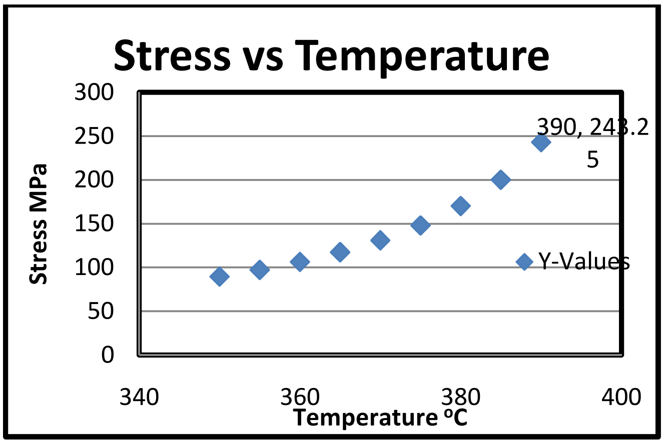

Fig.3.9: Stress vs. temperature

From the graph stress vs. LMP the cumulative creep damage obtained for three different conditions. The first condition is to consider that the failure may occurred at constant temperature 350°C. The second condition is to consider that the failure occurs at constant temperature of 400°C. The third condition is to consider linearly increasing temperature with 5°C to the basic.

Table. 3.1: Creep test for the tube working at temperature 350 °C constant

Period of Service h	Wall thickness mm	Hoop Stress MPa	Temp °C	Larson Miller Parameter	Time to Rupture hr	Cumulative Creep damage
1,44,000	5.2	89.81	350	33000	2580861540	5.58×10^{-5}
1000	4.79	97.50	350	32600	113568510	5.66×10^{-5}
1000	4.38	106.63	350	32400	753364840	5.792×10^{-5}
1000	3.97	117.64	350	30200	331511889	5.822×10^{-5}
1000	3.56	131.19	350	29600	8245576	1.794×10^{-4}
1000	3.15	148.26	350	28500	2406920	5.948×10^{-4}
1000	2.74	170.45	350	27800	251807	4.565×10^{-3}
1000	2.33	200.44	350	26400	59866	0.0212
1000	1.92	243.25	350	26000	3383	0.3167
1000	1.51	309.29	350	25800	1489	0.988
1000	1.10	424.58	350	25500	988	1.912

From Table No 3.1 if the temperature was maintained at 350 °C constant than it's cumulative creep damage even after 7000h becomes 0.3167 at 1.92mm. It will be safe for long time even at 1.51mm thickness.

Table.3.2: Creep test for the tube working at temperature 400 ^{0}C constant

Period of Service h	Wall thickness mm	Hoop Stress MPa	Temp ċ	Larson Miller Parameter	Time to Rupture hr	Cumulative Creep damage
1,44,000	5.2	89.81	400	33000	1,68,93,591	8.52×10^{-3}
1000	4.79	97.50	400	32600	7888601	8.64×10^{-3}
1000	4.38	106.63	400	32400	5395106	8.83×10^{-3}
1000	3.97	117.64	400	30200	2523480	9.22×10^{-3}
1000	3.56	131.19	400	29600	82603	0.0213
1000	3.15	148.26	400	28500	26424	0.0591
1000	2.74	170.45	400	27800	3265	0.366
1000	2.33	200.44	400	26400	864.96	1.156
1000	1.92	243.25	400	26000	60.548	-
1000	1.51	309.29	400	25800	-	-
1000	1.10	424.58	400	25500	-	-

From Table No 3.2 if the temperature was higher than design parameter for long time constantly than also it will fail in 6000h.

Table. 3.3:Creep test for the tube working at temperature 350 ^{0}C + 5 ^{0}C

	Wall thickness mm	Hoop Stress Mpa	Temp ^{o}C	Larson Miller Parameter	Time to Rupture hr	Cumulative Creep damage
1,44,000	5.2	89.81	350	33000	2580861540	5.58×10^{-5}
1000	4.79	97.50	355	32600	666882796	5.72×10^{-5}
1000	4.38	106.63	360	32400	263665090	6.09×10^{-5}
1000	3.97	117.64	365	30200	70844250	7.51×10^{-5}
1000	3.56	131.19	370	29600	1200735	8.34×10^{-5}
1000	3.15	148.26	375	28500	231303	4.33×10^{-5}
1000	2.74	170.45	380	27800	17166	0.06
1000	2.33	200.44	385	26400	2883	0.40
1000	1.92	243.25	390	26000	128.98	7.75

From experiment with increase in temperature (5 ^{0}C in base temp) with decreasing thickness of boiler in Table No 3.3 shows cumulative creep damage crossing 1 after 7000h and this theory fits to assumption that failure was done due to long term overheating.

So it was confirmed from that the failure was occurred after 7000h due to long term overheating and creep. The corrosion in the inner side of the tube was due to pitting/oxygen corrosion.

IV. CONCLUSION

Failure investigation on the SA210GrC water wall tube by visual site inspection, tube wall thickness measurements, hardness measurement, microscopic examinations and creep analyses was presented. On-site wall thickness measurements were performed on all the rear water wall tubes located at the same level of the ruptured tube. The tubes were observed to have experienced significant wall thinning. Microscopic examinations on the failed rupture region and some distance away region of the as-received tubes are also conducted in order to support in determining the failure mechanism and failure root cause. The combination of the significant localized wall thinning of the rear water wall tube much lower than the required minimum thickness due to long term Overheating and a thermally activated process of creep problem due to increase of temperature was identified as the failure mechanism of the problem. The damaged refractory behind the rear water wall tubes in furnace was found chronologically to be the main root cause of the failure.

REFERENCES

[1] K.S.N. Vikrant, G.V. Ramareddy , A.H.V. Pavan , Kulvir Singh. Estimation of residual life of boiler tubes using steam side oxide scale thickness. *International Journal of Pressure Vessels and Piping* . 2013, 104.

[2] Y. Appalanaidu, SayanGupta. Probabilistic damage estimation in piping components against thermal creep and fatigue . *Nuclear Engineering and Design* . 2014, 273.

[3] Farhad Daneshvar-Fatah, Amir Mostafaei , Reza Hosseinzadeh-Taghani, Farzad Nasirpouri. Caustic corrosion in a boiler waterside tube: Root cause and mechanism. *Engineering Failure Analysis* . 2013, 28.

[4] Ahmad, J. Failure investigation on rear water wall tube of boiler. *Engineering Failure Analysis.* 2009.

[5] Dhua, S.K. Metallurgical investigation of failed boiler water-wall tubes received from a thermal power station. *Engineering Failure Analysis* . 2010, 17.

[6] J.H.Bulloch, A.G.Callagy, S.Scully. A failure analysis and remnant life assessment of boiler evaporator tubes in two 250 MW boilers. *Engineering Failure Analysis.* 2009.

[7] P.Henner. *Carbon Steel hand book.* 2007.