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Thermal Stress and Creep Analysis of Failure tube of Secondary Super heater

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Abstract:

The objective of this paper is to work out the rupture time of super heater tubes. Thermal and structural analysis is performed on super heater for 2 completely different materials ASTM A213-T11 and ASTM A213-T22. The model of 1 set of secondary super heater was designed by CATIA v5. Thermal analysis of secondary super heater block is done that shows disturbed flue gas flow pattern and overheating in some regions of super heater. Fairly high temperature values on bottom bends of tube panels are seen in conjugate heat transfer analysis. For thermal stresses, Thermo-structural analysis is done in ANSYS. The stresses are found inside safe limits underneath isolated pressure and temperature loads but underneath combined loading larger values of thermal stresses are seen on affected bottom bends of the super heater panel. It's been determined from analysis, the hoop stress with material ASTM A213-T22 is a smaller amount in comparison to ASTM A213-T11 and von-mises stresses with material ASTM A213-T22 is a smaller amount in comparison to ASTM A213-T11. The temperature and pressure were used to calculate the lifetime of tube panel. It's determined that new material showed 17% increase in panel life in comparison to existing material.

Keywords:
Super Heater, Computational Fluid Dynamics, Thermal Stresses.

I. INTRODUCTION:

Boiler plays a major role in the electricity generation in a thermal power plant. In normal cases to increase the production of power generation coal fuelled power stations are used normally. A super heater tube directly passes the steam produced in the high pressure turbine. Steam from the water wall passes to the super heaters where it is heated above its saturation temperature until the maximum required operating temperature is achieved. Super heater increases the efficiency of the boiler. The superheated steam then flows through the main steam piping to the high-pressure turbine. Exhaust steam from the high-pressure turbine is guided to the boiler through re-heater tubes for reheating and from there to the intermediate and low-pressure turbines.

High reheating temperatures increases the output and improves the overall efficiency of a power plant. Internal pressurized tubes are critical components in water-tube boiler and steam reheater elements. Tubes in such application are vulnerable to high temperature, undergoes severe creep deformation or even final rupture. In a coal fired thermal power station, the reheater and super heater tubes are heated with temperature of about 530-1000˚C. Exposure of tubes to temperatures at the outer surface due to flue gases, high pressure inside the tubes because of the steam flow, and flame contaminated with corrosive residues for a long period of time usually causes reheater and super heater tube failures.

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Working Principle of Water Tube Boiler

The working principle of water tube boiler is very interesting and simple. Let us draw a very basic diagram of water tube boiler. It consists of mainly two drums, one is upper drum called steam drum other is lower drum called mud drum. These upper drum and lower drum are connected with two tubes namely down-comer and riser tubes as shown in the picture. Water in the lower drum and in the riser connected to it, is heated and steam is produced in them which comes to the upper drums naturally. In the upper drum the steam is separated from water naturally and stored above the water surface. The colder water is fed from feed water inlet at upper drum and as this water is heavier than the hotter water of lower drum and that in the riser, the colder water push the hotter water upwards through the riser. So there is one convectional flow of water in the boiler system. More and more steam is produced the pressure of the closed system increases which obstructs this convectional flow of water and hence rate production of steam becomes slower proportionately. Again if the steam is taken trough steam outlet, the pressure inside the system falls and consequently the convectional flow of water becomes faster which result in faster steam production rate. In this way the water tube boiler can control its own pressure. Hence this type of boiler is referred as self-controlled machine.

Carbon Steel: Carbon steel is steel in which the main interstitial alloying constituent is carbon in the range of 0.12– 2.0%. The American Iron and Steel Institute (AISI) definition says:

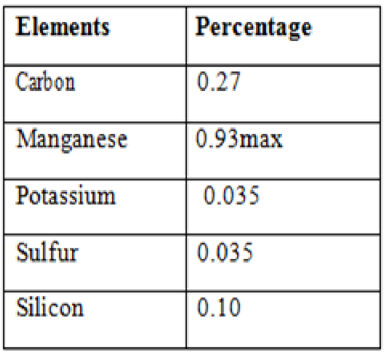
Steel is considered to be carbon steel when:

No minimum content is specified or required for chromium, cobalt, molybdenum, nickel, niobium, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect; The specified minimum for copper does not exceed 0.40 percent; The maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60.So me generally used carbon steels are SA192, SA 210 Gr A1, SA 210 Gr C, SA 106 Gr B,SA 106 Gr C . Among them SA Gr 210 A1 is widely used as a Super heater tube.

Alloy Steel:

Alloy steel is steel that is alloyed with a variety of elements in total amounts between 1.0% and 50% by weight to improve its mechanical properties. Alloy steels are broken down into two groups: low-alloy steels and high-alloy steels. The difference between the two is somewhat arbitrary: Smith and Hashemi define the difference at 4.0%, while Degarmo, et al., define it at 8.0%.[1][2] Most commonly, the phrase "alloy steel" refers to low-alloy steels. Strictly speaking, every steel is an alloy, but not all steels are called "alloy steels". The simplest steels are iron (Fe) alloyed with carbon (C) (about 0.1% to 1%, depending on type). However, the term "alloy steel" is the standard term referring to steels with other alloying elements added deliberately in addition to the carbon. Common alloyants include manganese (the most common one), nickel, chromium, molybdenum, vanadium, silicon, and boron. Less common alloy, include aluminum, cobalt, copper, cerium, niobium, titanium, tungsten, tin, zinc, lead, and zirconium. Some generally used alloy steels are SA 209 T1,SA 213 T11,SA 213 T12,SA 213 T22,SA 213 T23,SA 213 T91,SA 213 T92. In our project we used SA 209 T1 as a Super heater seamless tube. Conventional Super heater Tube (SA 213 T-11)

TABLE 1: Chemical Composition



Elements	Percentage
Carbon	0.27
Manganese	0.93max
Potassium	0.035
Sulfur	0.035
Silicon	0.10

TABLE 2: Mechanical Properties

Tensile Strength	414 MPa
Yield Strength	183 MPa
Young's Modulus	1.72E5 MPa
Max Rockwell Hardness	79

Alternative Material ASTM SA 335 P5

TABLE 3: Chemical Composition

Elements	Percentage
Carbon	0.12
Manganese	0.60max
Potassium	0.02
Sulfur	0.01
Silicon	0.50

TABLE 4: Mechanical Properties

Tensile Strength	483 MPa
Yield Strength	276 MPa
Max Rockwell Hardness	89

Over heating

The overheating of reheater and super heater tubes are one of the most causative for the reheater tube failures. The overheating is also one of the less avoidable problem caused in boilers. Due to the improper combustion of the coal in the furnace and excess amount of impurities present in the air to lead the production of unwanted harmful gases which leads to the deterioration of the super heater and reheater tubes. The overheating of the reheater tubes mainly caused in the outer diameter of the tubes. The overheating reduces the properties of the reheater tubes and leads to failure. Welding Defect: The Reheater and super heater tubes are not available in a single set so, it should be bought for the required length and it is joined together by using welding process. Two layers of welding are done for withstanding high pressure and high temperature. First layer is done by using electric arc welding and the second layer is done by using gas welding. Due to the insufficient training of labors and other factors leads to improper welding of reheater and super heater tubes.

PROPOSED METHODOLOGY

The main causes of welding defects are due to the improper welding done during the onsite welding. This problem reduces the quality of welding which in turn due to the high temperature of the steam inside the tube walls and also high flue gas temperature on the outer walls slowly deteriorates the properties of the re-heater and super heater tubes. This can be overcome by covering the weldings by a ring over the outer surface of the tubes. This ring over the weldings protects the weld from the excess flue gas temperature and also from the impurities in flue gases.

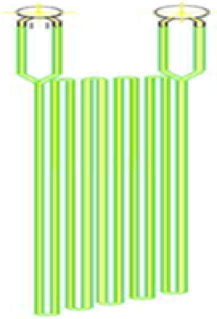


Fig 1: Two Dimensional Auto CAD Super Heater Drawing

Fig 2: Some of the Damaged Super Heater Tubes

TECHNICAL SPECIFICATION OF SUPER HEATER TUBE, FLUE GAS FLOW & STEAM

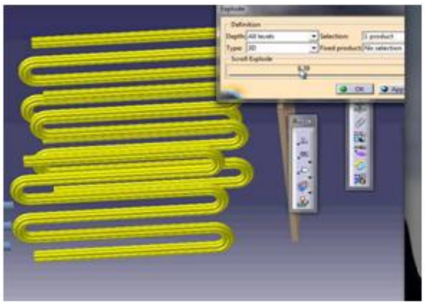
S. No.	Description	Unit	Values
Flue Gas Parameters			
1	Flow	Nm^3/hr.	176042
2	Specific Heat	Kcal/Nm^3 deg.c	0.31
3	Velocity	m/s	6
4	Temperature	Deg.C.	1200
Tube Parameters			
5	Tube Size	mm	Dia 42 x 3.5
6	Material		SA 335 Gr.P11
Steam Parameters			
7	Flow	Kg/Hr	60,000
8	Temperature	Deg.C	400
9	Pressure	kg/Cm^2	80
10	Velocity	m/s	25

The below figure 3 shows the proposed design of the reheater and super heater tubes with ring over the weld material. The ring material is made of SA213 T22, which covers over the welded part to protect it from the impurities affecting the welded portion of the tubes.

Fig 3: Proposed design of the reheater and super heater tubes with ring over the weld material

The ring over the welded material doesn't affect the temperature and pressure of the steam flowing inside the tubes and thus it doesn't reduce the efficiency of the boiler and also increases the life of the boiler tubes.

Solid Modeling of Tube



II. CFD ANALYSIS

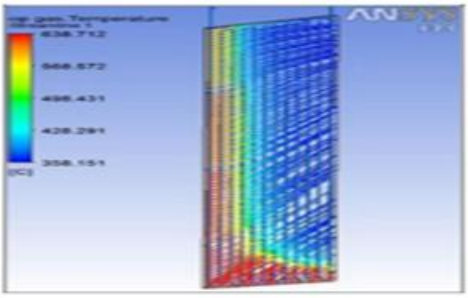
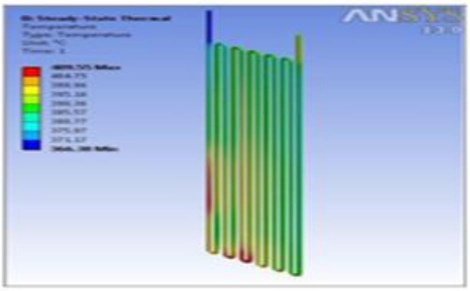


Fig 4: Furnace gas flow over ninth panel of SSH

From figure 4 it is seen that, temperature distribution on ninth panel is not uniform over the entire panel. Below figure shows results of similar analysis for first panel.



Computational fluid dynamics is used in order to analyze the system with the combined effect of temperature and pressure, Ansys multi physics environment is used. Also to find the temperature distribution, thermal stress, thermal strain, velocity of the moving fluid and its pressure differences in a pipe the flow analysis needed to be carried out. It helps to predict the various parameters in order to test the efficiency of the SA 213T91 material and also to check the new design. Design wise SSH is a bunch of tubes. It has 47 panels each having 6 loops. Each loop has two sections. First five loops have outer diameter of 50.8mm and thickness of 4.06mm.

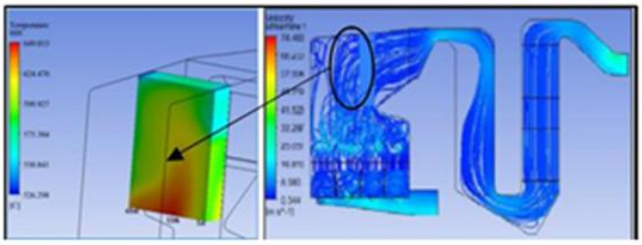


Fig 5: CFD analysis with SA213 T22 material

The figure shows the CFD analysis done in the SA213 T22 material without the rings around the weldments. The pressure distribution inside the pipe is shown in the analysis. The exact temperature values were collected from the MTPS and given as input for the analysis to get the real time results.

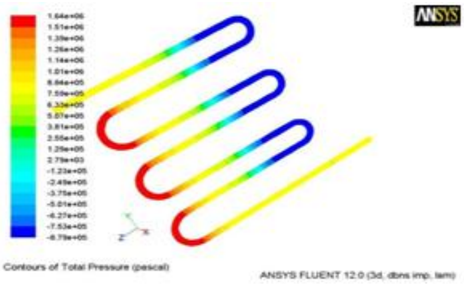


Fig 6: CFD Analysis of SA 213 T22

The SA213 T91 material with ring around the weld material has also been analyzed by using Ansys Fluent software and the pressure, temperature distribution and deformation of the tubes has been found out. The figure 3 represents the Analysis carried out in the SA 213 t91 material with rings around the weld tubes.

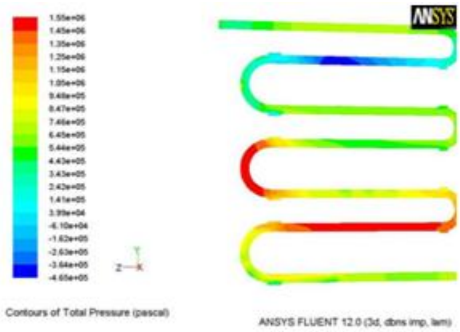
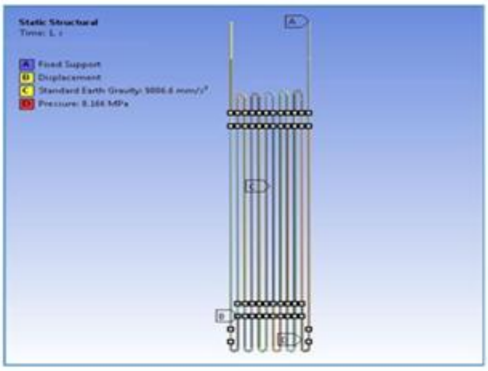


Fig 7: CFD analysis of SA213 T916

Significance of isolated temperature and pressure load analysis is to see the dominant factor causing stresses. Thermo structural analysis simulates the actual scenario. This analysis is carried out before and after the flow modifications. Improvement in the stresses can be compared from results of these two analyses. Top welded portion is not modeled separately. Displacement constraint is used to model spacers.

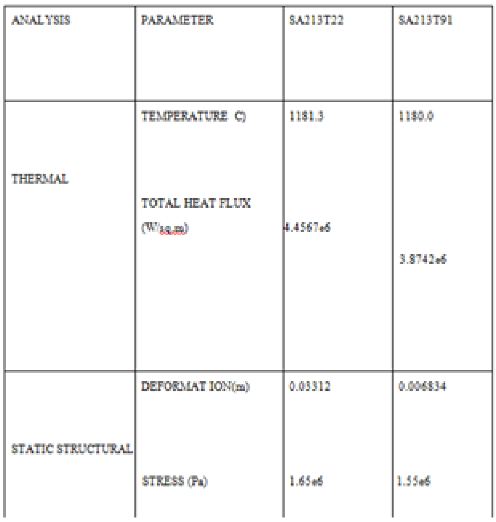
Spacers are used to maintain fixed distance between the tubes. This helps to avoid damage to the tubes while transporting as well as in operation. Displacement constraint is modeled such that tube is able to expand along the length as well as along the diameter due to pressure and temperature loads, as tube panels are free, hanging from top. To take this hanging effect, Earth's gravity effect is considered into analysis. Operating steam pressure of 88 atm. is applied on inner walls of the tube. Results of the hoop stress analysis shows that stresses are well within the limits. Maximum stress value of 92MPa is seen on bottom bends. As internal steam pressure is same on all tube walls, hoop stress is same on all the bends.



III. RESULTS

The following table shows the comparison between the two materials analyzed using the FLUENT software,

Table 5: Report from the analysis



ANALYSIS	PARAMETER	SA213T22	SA213T91
THERMAL	TEMPERATURE C) TOTAL HEAT FLUX (W/sq.m)	1181.3 4.4567e6	1180.0 3.8742e6
STATIC STRUCTURAL	DEFORMAT ION(m) STRESS (Pa)	0.03312 1.65e6	0.006834 1.55e6

The heavy scaling on the surface of the wall tubes acts as a thermal barrier for the effective heat transfer operation with hot steam temperatures will result in excessive metal temperature. Hence it is recommended to replace the outlet section in total with higher chromium contained steel SA 213 T91 to ensure trouble free surface. It also recommended using the rings around the welding in order to increase the life of the boiler tubes by reducing the cracks caused due to improper welding.

Thermo Structural Analysis

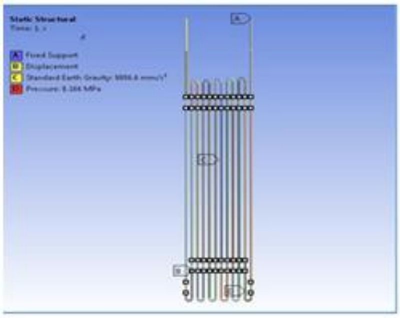


Fig 8: Equivalent Stress of Coil

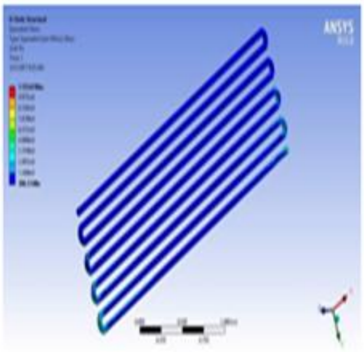


Fig 9: Equivalent stress of coil

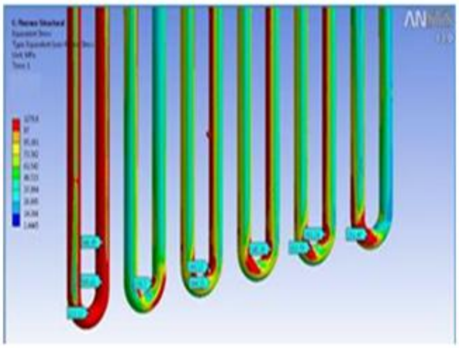


Fig 10: Thermo structural stress before flow modifications.

Hardness (HV) = 595.453-0.012603P--------------- (1)
Where,
P= Larsen-Miller parameter = T (20 +log t)---------- (2)

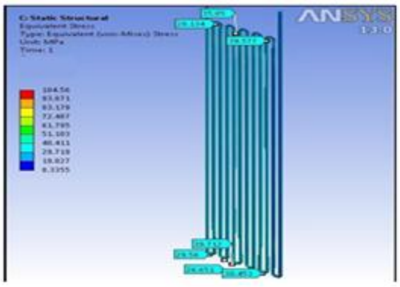


Fig 11: Thermo structural stresses after flow modifications

From expression (1), operating temperature is evaluated. To evaluate creep life, variation of Larsen-Miller parameter with stress to rupture graph for 1Cr-0.5Mo is used. Using expression (2), Creep life of failed tube sample is found out to be 815676.6 Hrs. (approx. 92 years)at 8.116 MPa pressure. From failure history of the tube it is seen that, tube has failed much before its creep life. It indicates that in present failure, creep is not contributing as a main mode. Also useful creep life for modified condition is found out using similar methodology and it comes out to be 11 years.

IV. RESULTS ANALYSIS

From the isolated thermal and hoop stress analysis it is seen that SSH tube panels are safe with isolated temperature and pressure loads. While for combined loading, before modifications SSH panels show high stresses on bottom bends of 12thpanel which represents panels between 5 to15. After flow modifications, due to improved temperature distribution, stresses are reduced significantly.

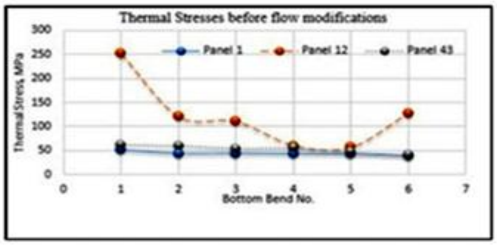


Fig 11: Thermo-structural stresses before flow modifications.

From comparative study of results of both cases, it is seen that post modifications results show improved temperature and stress pattern that depicts along with maximum temperature value, temperature distribution is also critically important from thermal stresses and failure point of view. Figure 10and 11show comparative values and nature of stress pattern. Initially stresses were high on 1st and 2nd bends. Also overall stresses were showing high values up to 260MPa. While after flow modifications due to uniform temperature profile, stresses are within the acceptable limit.

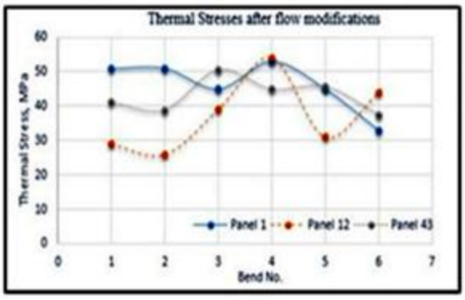


Fig 12: Thermo-structural stresses after flow modifications

Plant data also shows same failure regions as seen in CFD and thermal analysis. Figure 12 shows failure occurrence frequency in plant. This data is available from maintenance log sheets maintained on plant site. Creep analysis concludes that current tube failure is free from creep. However useful creep life with modified condition is calculated.

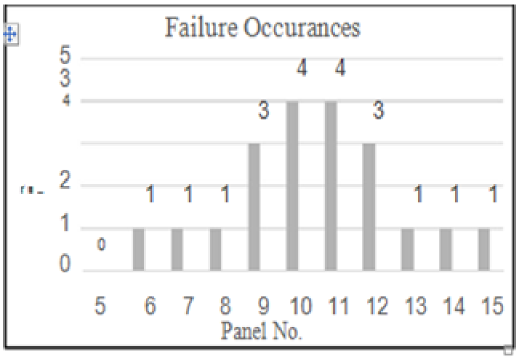


Fig 13: Failure occurrence frequency (Plant Site Data)

V. CONCLUSION:

The reheater and super heater tubes have been tested and analyzed by using the ANSYS Workbench software. I had also done the static structural and thermal analysis at various material grades by using fluent. Thus by various analysis we have concluded that the root cause for the boiler tube failure is scale formation and the weld failures. The scale formation can be overcome by using the better grade steel SA213 T91 and the weld failures can be reduced by providing a ring over the weld materials. The ring over the weld material increases the life of the weld and improves the efficiency of the boiler tubes. Since the invention of new material in secondary coil tube which has more efficient than the conventional material our alternative material in super heater results in saving fuel consumption, increases steaming rate and boiler efficiency. Analysis results show good correlation with plant data.

Non uniform flow of the flue gases is the main cause of current tube failure. This failure is recognized as cumulative damage of the tube as a result of localized heating, high hoop stresses and non-uniform temperature profile. Creep analysis shows that creep life of the tubes is good and does not contribute in current failure but after modification, creep life is reduced due to rise in temperature. Excessive stresses on the bottom bends are relieved on modifying the flow pattern and hence temperature profile. It is seen that, thermal stresses depend on temperature distribution along with the temperature value. CFD and CAE are good and efficient tools to simulate flow thermo structural system as it shows good correlation with ground data. This study can be further extended to include metallurgical aspects of failure like steam and gas side erosion, corrosion etc. Some of the common applications of Super heater are given below, In steam power plants it captures the waste heat from boiler stack gases (flue gases) and transfers it to the boiler feed water.

Air-side Super heaters HVAC (Heating, Ventilation and Air Condition) can save energy in buildings by using cool outside air as a means of cooling the indoor space. Refrigeration: This is commonly used in industrial refrigeration where vapor compression refrigeration is essential. Systems with Super heaters aim to produce part of the refrigeration work on high pressures, condition in which gas compressors are normally more efficient.

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