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Application of Nano Materials to Enhance Creep Strength of Platen Super Heater Tubes and to Minimize Boiler Outage in Ultra Super Critical Power Plants

KEYWORDS: Nano-structured materials, high temperature creep strength availability, composites, microstructure degradation, fossil fuel power plants, ultra super critical power plants, nano crystallization, and quantum mechanics.

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ABSTRACT *Power generation through fossil fuel power plants is one of the basic needs to rescue the gap between power supply and demand. It is a continuous process to minimize the gap between supply and demand. Clean and efficient power generation needs incorporation of advance technologies in traditional system of power generation.*

Power production in fossil fuel power plants is totally based on optimum utilization of available heat energy to produce high quality steam and to achieve this goal availability of the steam is to be optimized. Latest modifications in rankine cycle are not sufficient to justify optimum utilization of heat available.

Nano-structured materials posse's special properties in comparison with the material with identical composition with normal grain size. This paper will report my work on the nano-structured alloy and composites to improve creep strength in super heater tubes in boiler. Composites and micro structures are two important variables can be used as characteristic variables to improve high temperature strength of super heater tubes.

Nano materials can be used to improve thermodynamic properties of tube material such as high temperature creep strength and micro structural degradation at high temperature can be minimized to optimize boiler outage during power generation.

Introduction
The electricity sector in India had an installed capacity of 254.049 GW as of end September 2014. India became the

World's third largest producer of electricity in the year 2013 with 4.8% global share in electricity generation surpassing Japan and Russia. Captive power plants have an additional 39.375 GW capacity. Non Renewable Power Plants constitute 87.55% of the installed capacity, and Renewable Power Plants constitute the remaining 12.45% of total installed Capacity. India generated around 967 TWh (967,150.32 GWh) of electricity (excluding electricity generated from Renewable and captive power plants) during the 2013–14 fiscal. The total annual generation of electricity from all types Of sources was 1102.9 Terawatt-hours (TWh) in 2013. As of March

2013, the per capita total electricity consumption in India was 917.2 kWh. The per capita average annual Domestic electricity consumption in India in 2009 was 96 kWh in rural areas and 288 kWh in urban areas for those with Access to electricity in contrast to the worldwide per capita annual average of 2,600 kWh and 6,200 kWh in the European Union. Electric energy consumption in agriculture is highest [citation Needed] (18%) in India. The per capita electricity Consumption is lower compared to many countries despite cheaper electricity tariff in India With the ever-increasing demand for electricity it is very necessary for the power plants to generate electricity without Forced outages.

Boiler Super Heater tube failure is the prime reason of forced outages at coal fired thermal power plants & Waste Heat Thermal Power Plants.

Coal reserves in India are one of the largest in the world. As on April 1, 2012, India had 293.5 billion metric tons (323.5 billion Short tons) of the resource. The production of coal was 532.69 million metric tons (587.19 After combustion, the flue gases passes

over the super heater Tubes, abrasive in nature of coal may damage Super Heater Tubes. It has hampered working of power station and overall efficiency of power station. So study of boiler tube leakage And finding the solution for the problem is need of thermal power station Continuous increment in demand of electricity with clean and efficient power generation is a major challenge for modern ultra super critical power plants. Environment constraints to reduce pollutions with desired increment to efficiency of modern power plants are key elements need advance research. Platen super heater zone is a critical zone of boilers subjected to higher operating temperatures. Due to continuous impact of higher temperature on platen super heater tubes due to flow of high pressure high temperature steno the life of platen super heater tubes affects power generation efficiency and availability. To achieve this objective either some new material through advance research are to be identified which can sustain higher pressure and temperature of steam during continuous flow for life enhancement. Nano material offer quick response to improve the material high temperature strength and heat carrying capacity for enhancement of tube life. Carbon nano tubes (CNTS) exhibits some outstanding performance due to their excellent thermal, electrical properties.

To ensure the maximum availability and reliability of ultra super critical power plants platen super heater tubes are always on the hot spot. In terms of materials or mechanisms the chances of failure of tubes at platen super heater section are to be minimized. Efficiency of power generation with economic aspects is two major constraints require proper concentration during operation and research. To achieve higher efficiency steam generation at very high temperature and pressure plays vital role. Boiler tube failure at platen super heater section is the most significant cause of unplanned outages and reduces availability at fossil fuel power generation plants. Energy analysis of power plant unit indicates the major causes of higher portion of waste heat. Nano materials have the capability of enhancement in desired properties of tube material to with stand higher pressure and temperature of steam. In recent time the research is focused on development of nano materials for sustainable performance of platen super heater transfer co-efficient at high temperatures to prevent tubes failures and to increase available operating hours for optimization of planned outage cycle is of prime importance. Various publication mentioned in the reference show superior performance of nano materials at high temperatures. Continuous flow of steam at higher pressure and temperature in platen super heater tubes require on atonal up gradation as continuous operation may change the grain size or grain boundary of tube material. Nano-crystaline materials according to the ASTME 2456-06 "Terminology for Nano Technology" have grain sizes less than 100 mm and represent excellent level of micro structural uniformity. At micro level analysis micro structural uniformity of tube material is of prime attention. Micro structural degradation of material at higher temperature is the cause of non uniform micro structure. Change in grain size or conversion of constituents into another constituent may be the major cause of material degradation. Micro structure based approach indicates six stages of spheroidization of carbides in ferrite steel. Sherby-Dorn parameter establishes a logical correlation of micro structure with mean service temperature materials for high temperature application require.

- Adequate strength to resists deformation at high temperature and pressure.
- Adequate fatigue strength against vibratory stresses.
- Good strength / resistance to service environment to with stand oxidation corrosion and erosion.
- Structural ability to resist damaging metallurgical changed at operating conditions.

In ultra super critical boilers super heater zone is sensitive zone subjected to high temperature and pressure of steam. Steam carrying boiler tubes in this section are most critical components which may fail due to creep. Platen super heater tubes are made up of SA213-T12, SAT213-T23, SA213-T91 and super 304H. these materials having good thermal capacity and provide a path to advance research. Advance research in materials used for high temperature application has major constraint of cost. Power plant economics plats a vital role in economics generation of power. This era requires use of nano. Materials to improve micro structural properties of materials used for platen super heater tubes. Operation effects on ultra super critical boiler components as

- High temperature effect or ageing
- High temperature corrosion – ash attack
- High velocity flue gas with particulate burden or erosion
- Thermal cycling
- And steam side oxide scale formation has manifestation in reference to mechanical and metallurgical aspects.

Metallurgical aspects are
–creep life
- Structural integrity
-steam starvation
-sudden rupture
Are of prime importance need metallurgical advancement.

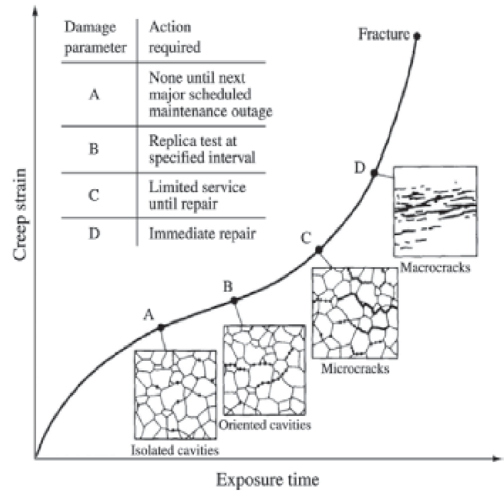

Figure 1. Creep life assessment based on cavity classification[2].

Micro structural damage and phase precipitation under high temperature environment cause material degradation and reduce creep strength of platen super heater tubes. At high temperature orientation character sties change may take place and grain size increased. Density of dislocation decreased with increasing temperature and stress. Ferritic steels have excellent high temperature mechanical properties and better oxidation resistance. High temperature creep strength can be determined by sub grain. Strengthening and second phase precipitation strengthening. Combined effect of stress and temperature on the second phase precipitation plays important role. Organization pattern of aged components can be investigated by metallurgical microscopy scanning electron micro scope and transmission electron micro scope. As the operating temperature increases the grain size will increase in grain boundary. Nano material application to control grain size and grain boundary is a better solution with high effectiveness and economics power generation with least boiler outage. Nano particles may be categorized as

- Nano composites
- Nano – nano composites
- Metal oxides coatings

The parameters which affect the characteristics of nano – materials are

- Chemical composition of matters
- Fabrication process
- Material science
- Size of particles

Evolutionary nano materials can be used to improve thermal properties or boiler tubes.

*In nano materials the gravitational force become negligible and electromagnetic forces will be dominant. These properties of nano-material make them superior from macro scale material. Quantum mechanics can be used to describe motion and energy of nano-particles. Compelled crystallization of nano materials with proper granulation with advance boiler tube materials may give excellent results. Nano-Technology is based on manipulation of matter

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on an atomic, molecular or super molecular level.

Interface and colloid science are effective tools in nano-technology. Nano-Technology is evolutionary and revolutionary in nature. In carbon – nano technology – nano tubes, fullerene and nano diamonds are used. Nano materials can be used with base metal to improve thermal conductivity and convective heat transfer coefficient to enhance heat transfer rate. Zirocania and alumina can be used to improve heat transfer rate of tube material. Magnetically soft nano materials like FINEMENT are most suitable for high temperature applications to enhance thermal stability. Nano structural eutectic alloys high strength at elevated temperatures nano – composites are widely used in these days because the properties of nano – composites depends on the properties of their individual parents and on their morphology and interfacial characteristics.

Fig. 2 : Failure of Platen Super Heater Tube

Fabrication process with controlled nano – sized second phase dispersion can be optimized to enhance thermal stability and mechanical properties of super heater tube materials. Nano composites have nano fillers dispersed in matrix. Nano – composite materials have wide range in the form of three dimensional metal matrix composites. Nano – particles and nano – layers have very high surface to volume ratio and aspect ratio which keep in enhancement of mechanical properties with super thermal conductivity. The inorganic comp orients which can be used as nano materials mat have three dimensional frame work system such as zeolites, two-dimensional materials such as metal oxides and metal phosphates and one dimensional or zero dimensional materials such as (Mo_3Se_3) – n in the form of chains and clusters. By modifying the micro structure of tube material through penetration of nano – particles with variable density and variable size thermal properties of boiler tube material may be optimized. The composition and micro structural can be well controlled by using different target or electrodes. Use of alloying elements with base metal may improve the creep strength but at the same time considerable micro structural changes at high temperature restrict optimum value of thermodynamic variables.

Contribution of Paper

Every research is based on hypothesis and requires logical approach to justify the statement of problem by the way of experimental techniques or statistical analysis. Modern power plants are based on supercritical and ultra supercritical technology with basic objective of generation of high quality steam. Fossile fuel power plants are dominant power production units and have been producing about 85% of the total power generation of our country. Macro level study of variables of steam generation provides an outline of failure causes but in order to identify the root causes of failure at high temperature zone micro level study of operating parameter may provide a road map for solution. High temperature high pressure and higher flow rate of steam through boiler tubes in super heater section may cause generation of uneven thermal stresses in the tube material. Fish-bone diagram based on cause and effect study indicates that the high temperature operating parameters affect the tube material in two ways. External impact of high temperature parameter is responsible for variation in tube geometry and dimensions. Due to decrease in tube thickness the strength of tube material decreases in experiential order and when the thickness of tube material deceases beyond the safe value the tube may fall and will be a cause of boiler outage. External impact as reduction in tube thickness can be controlled by proper control on wear and tear rate of material. To improve wear resistance nano material may be super imposed.

Internal impact of operating parameters is related to micro structured variation which generated micro structural degradation.

Micro structural variations are based on two aspects. Metallurgical aspect is higher values of temperature pressure

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and flow rate of steam which may affect the grain size and grain boundary. The grain size and grain

Fig. 3 : Failure of Platen Super Heater Tube

boundary may vary. Due to change in orientation of atoms and molecules at micro level the creep strength of tube material reduces and tube may fail due to reduction in fatigue strength at higher temperature. Chemical aspect is based on variation in bonding system due to uneven forces which may cause conversion of strong chemical bond into weak bonds/ due to reduction in strength of chemical bonding the tube material may fail at higher temperatures. In current technological developments the steam temperature can be increased up to 600 C against the current traditional value of 540 C. After optimum value of steam temperature, increase of steam temperature by 1 C may improve the efficiency by remarkable increase. Future trends indicates that if it will be possible to increase the temperature of steam up to 1000 C the fossil fuel power plant will be most efficient plants but if requires high order of technological advancement latest modifications in rankine cycle or gas power cycles are not sufficient to justify optimum utilization of heat available for production of turbine work.

Challenges in Future

In order to reduce the irreversibility and to maintain the process of extension isentropic various mechanisms have been used but still require higher level of R & D wrok. Due to scale formation during continuous running of power plant at high pressure and temperature heat transfer rate decreased and due to reduction in heat transfer rate accumulation at grains of tube may cause consideration variation in constituents and due to variation in constituents in reference to time, temperature transformation the actual life of tube material may be considerably less than designed life. Nano materials may play vital role to improve convective heat transfer coefficient of tube material which alternately the heat accumulation at tube surface and minimizes the chances of tube failure due to creep phenomenon. The spirit behind this paper is to act as a catalyst to initiate activities towards continuous improvement in the performance of individual units and a achieving world class power generation standards. Research in the direction of advance nano materials which can sustain higher temperature & be able to minimize heat accumulation in tube material at granular level is a challenge for scientist and engineers. Nano particles produce a bridge between bulk materials and atomic or molecular scale. Interface an colloid science has given to many materials which may be useful as nano – material. Nano – technology is evolutionary and revolutionary in nature. In evolutionary approach some material is improved by using nano – technology while in revolutionary approach nano – particles originate from nano – technology. Nano – technology used to produce nano materials by the use of revolutionary or evolutionary approach improves the following key properties through state of art technology.

- Electrical conductivity
- Thermal conductivity
- Molecular perfection
- Self assembly

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