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Failure evaluation of SA 210C riffle water wall tubes in 70 MW CFBC boiler

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ABSTRACT

Boiler tubes used as water walls made up of ferritic steels is having some finite life, because of prolonged exposure in the furnace at elevated temperature, stress and aggressive environment, tube failure taking place. Now a day's premature failure of the boiler tube mainly in water walls is one of the very common phenomena in the thermal power plants. The present investigation was done on the as-received ASTM SA 210C failed boiler tube steel used as water walls in the Circulating Fluidized Bed Combustion (CFBC) coal fired thermal power plant. An attempt has been made to understand the cause, because identifying correct failure mechanism often helps to perform meaningful life assessment and also to prevent the future Boiler Tube Failure (BTF). The as-received of failed tube along with the parent (unused) tube from the water wall raiser panel were selected to study for mechanical and metallurgical properties. Tensile test and micro hardness examinations were carried out on both the parent tube and failed tube. Visual examination reveals "fish-mouth" appearance of the as-received failed tube because of short-term overheating. The micro structure of the parent metal has the conventional structure of ferrite (white constituent) and pearlite (dark constituent), whereas for the as- received failed tube reveals Widmanstatten ferrite. A detailed structure - property relationship has been made by using the combined techniques of Optical Microscopy (OM), SEM/EDAX and XRD. Tensile fractography depicts the presence of micro-voids coalescence in the fibrous network shows ductile mode failure in the as-received failed boiler tubes.

1. Introduction

SA 210C ferritic steels are extensively used in steam generator circuits of thermal power plants, cogeneration power plants and waste heat recovery boilers as heat exchangers operated at temperature around 300–400 °C fitted as water walls in the furnace. The pre-failure of the boiler tubes occurred frequently made the interest for most of researchers in the past few decades. Mainly because of the corrosion and erosion attack from the hot flue gas stream significantly enhances the higher wastage of metal when these tubes are exposed in the furnace at elevated temperature. The total cost of boiler tube failures in power plants is estimated to be about $5 billion a year [1]. Tube failures generally occurred in between fins, at bends and joints where the tube penetrates the support plate due to substantial adherent deposit formations. The scales present inside the water wall tubes have also been found to be one of the major contributors to the tube failure. Heat transfer rate across the tube also decreases due to the accumulated scales inside the tube. It will increase the metal temperature, and thereby result in corrosion and creep degradation. Moreover due to structural degradation

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of the boiler tube material, such as carbide coarsening and sigma-phase formation the embrittlement will also occur. The most common failure mechanism occurred in water walls tubes is "high-temperature creep" and "stress rupture" due to tubes are exposed to high temperature [2]. Barer et al. [3] observed the microstructures of the burst boiler tubes and reported that several factors which cause higher tube temperature namely, (1) increase in heat flux (2) internal scale build-up (3) reduced steam flow (4) uneven steam attemperation (5) uneven burner adjustment (6) non-uniform steam flow. Probably one or multiple factors might be responsible for the temperature rise result in tube failure. Dooley et al. [4] investigated that boiler tube failure due to boiler tube overheating actually involves two mechanisms: short-term overheat and long-term overheat. Short-term overheat occurs when boiler tubing is heated well above design temperature of the tubing material due to inadequate cooling of the tubes, often termed as 'thin-lip' failure, results in deformation of metal in the form of elongation and considerable reduction in tube-wall thickness looks like 'knife-edged' fracture surfaces. Actually prior to the tube failure, the tube wall thinning and local bulging will occur, because of softening of the material at elevated temperature and the fracture surface looks like a 'fish-mouth'. Short-term overheat damage can also occur even at a temperature below the critical temperature (A1) of material. Long-term overheat failure can also be named as high temperature creep. In high-temperature creep, premature failures occur when the temperature and stresses exceed the designed values. Even slight overheating or stress rise over extended period of time lead to this kind of failure. Long-term overheat damage usually occur with a small amount of creep deformation. Boiler life will drop dramatically if overheat was experienced by boiler tube [5]. Senthur Prabu et al. [6] investigated the mechanical and metallurgical properties of SA 210C tube steel exposed in high temperature application and revealed that Widmanstatten ferrite and ferrite-cementite matrix (alternate lamellas) is witnessed at the heat affected zone in both the weldments resulted higher strength due the higher percentage of quasi-eutectoid.

In the present study, a detailed investigation of the failures observed in vertical furnace water wall tubes of a boiler is reported. The failed tube was characterized by microstructure using optical microscope and SEM/EDS point analysis to understand the metallurgical behavior. Along with the micro hardness and tensile test were carried out on both the parent tube steel and as- received failed tubes to interpret the mechanical properties. The results revealed in this paper will be really useful to prevent the future Boiler Tube Failure (BTF).

2. Experimental procedure

The as-received ferritic SA 210C steel tube (failed) has the typical dimensions of 800 mm length, 5.5 mm thickness and OD of 60 mm as shown in the Fig. 1b. The chemical composition (wt%) of the SA 210C tube samples were shown in the Table 1.

2.1. Specimen preparation for metallography

The cross section portions of the parent and failed tube were sliced along the transverse direction using the wire-cut EDM process to get coupons having dimensions of 10 mm × 10 mm × 5.5 mm size. All the sample pieces were subsequently hot-mounted using Bakelite resin powder and standard metallographic procedures were adopted on the coupons by polishing using various grit size SiC emery sheets from 200 to 2000 and followed by disc polishing using alumina solution so as to get mirror-like polished surface of 1 μ finish. The polished coupons were then etched in 2% Nital for 20s before they were examined under an optical microscope. Microstructure studies were performed on both parent and failed tube (sheared portion of both front and rear).

2.2. SEM/EDS point analysis

Scanning Electron Microscopy (SEM)/Energy Dispersive X-ray Spectroscopy (EDS) analysis were carried out on both parent and failed tube (Inside surface, vicinity of V-shaped rupture and outside surface) using JEOL equipment to correlate the precipitation of oxides. EDS point analysis was also carried out to analyze the quantitative elemental profile at a micron level.

2.3. Mechanical characterizations

After the microstructure analysis, the mechanical tests like micro-hardness, transverse tensile have been conducted at room temperature to ascertain the mechanical properties of both parent and failed tube to correlate the structure-property relationship. On each tube (parent and failed tube) two trials were conducted at room temperature to check the repeatability of the results to minimize errors. In addition to that, to determine the mode of fracture the fractured tensile test tube steel were characterized for SEM fractography.

2.3.1. Hardness test

Micro hardness (VHN) studies as per ASTM E-384 were carried out on the transverse cross section of SA 210C boiler tube steel on both parent and failed tube (inner and outer) using the Vicker's micro hardness tester (Matsuzawa MMT-X with Hardcom Hv software) to characterize the hardness variation. The samples were mounted in Bakelite resin powder and standard metallographic procedures were adopted before subject to hardness test. The hardness readings were recorded by applied the standard load of 500gf at regular intervals of 0.25 mm, for a dwell period of 10 s across the width.

2.3.2. Specimen preparation for tensile studies

The tensile tests were performed to understand the tensile behaviour of the boiler tube steel (parent and failed tube). The tensile