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Failure investigation of super heater tubes of coal fired power plant

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ABSTRACT

Cause of failure of two adjacent super heater tubes made of Cr-Mo steel of a coal based 60 MW thermal power plant has been portrayed in present investigation. Oxide deposits were found on internal surface of tubes. Deposits created significant resistance to heat transfer and resulted in undesirable rise in component temperature. This situation, in turn, aggravated the condition of gas side that was exposed to high temperature. Localized heating coarsened carbides as well as propelled precipitation of new brittle phases along grain boundary resulting in embrittlement of tube material. Continuous exposure to high temperature softened the tube material and tube wall was thinned down with bulging toward outside. Creep void formation along grain boundary was observed and steered intergranular cracking. All these effects contributed synergistically and tubes were failed ultimately due to overload under high Hoop stress.

1. Introduction

For any power plant, it is prime importance to generate electricity without forced outages. Failure of super heater tube of boiler is the major concern of forced outages at coal fired thermal power plant. Flue gas passes over super heater tubes leading to damage over the time of operation and termed as fireside damage/corrosion. Again the extent of damage is dependent on quality of coal, materials used, operation and maintenance. Interior of these tubes are also vulnerable and primarily dependent on quality of water used for generating high pressure steam. Continuous/steady flow of steam through these tubes is necessary to maintain tube materials under prescribed temperature. Otherwise, there is a possibility of shoot-up of temperature causing fast detoriation of materials and subsequent failure. In that case overall efficiency of the plant is dropped. Therefore, the study of tube failure and finding the solution is needed to avoid such incident in future.

Boiler tubes of a coal fired plant faced harsh environment all the way from inside steam to outside flue gases. Tubes are exposed to temperature in the range of 540–1000 °C, varying along length of tubes i.e. from base toward elevation. According to service condition, outside of tubes are exposed to high temperature. High pressure steam flows through inside and is discharged at a temperature of $>$ 500 °C depending on nature and capacity of plant. Temperature shoot up above specification is most common reason of failure for boiler tubes [1]. The reason is either scale formation on internal and/or external surfaces under prolong exposure at elevated temperature or non-uniform steam flow through partially blocked tubes [2]. Internal scale formation reduces heat transfer rate across tube wall. Moreover, scale formation causes non-linear (non-uniform) heating, resulting in the retardation of heat transfer further and reduction of thermal efficiency. External oxide formation generally depends on type/quality of coal, which produces flue gas. Mostly complex alkali sulfate scales are formed. This effect raises the temperature of tube locally and longtime exposure results in thicker oxide formation, subsequent exclusion of the same. The later phenomenon escalates wall thinning and rupture of the tube. Material de-generation and subsequent failure due to thermal fluctuation, have been studied by a number of investigators in recent past [3,4].

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It is to be noted, that in many cases a thin protective Fe_3O_4 layer is deposited on waterside of tubes. Protectiveness of this thin layer depends on pH level and degree of contamination of water. There are many failure mechanisms that have been reported depending upon the presence of contamination with flowing steam. These are primarily related with caustic corrosion, hydrogen damage or pitting [5–12].

This paper presents the analysis of failure of two adjacent super heater tubes in a coal based 60 MW power plant. Inside steam pressure was at 100 kg/cm^2. Within short span of time in the end zone of the super heater tubes three failures were reported. The incident happened with the component commissioned in 1988 and last overhauled in 2015. After routine maintenance, the system was operated for nearly four months and then first failure occurred. Subsequently, second failure was reported after 10 days and third one took place after 2 months. During entire operation period only schedule outages were made. Location of the failed region was close vicinity of top end of the tubes and very near to boiler drum where the flu gas temperature was ~900 °C.

Two failed pieces of tubes made of Cr–Mo steel were chosen for this investigation. Sample-A (tube A) exhibited fish mouth cracking at one side and bulging at opposite side. Layer wise corrosion was observed near open end of crack and over remaining wall. Inner surface contained multiple cracks along longitudinal direction whereas the same was completely absent at outer surface. Sample-B (Tube B), also contained fish mouth cracking at one part of the tube. Inner side of the pipe was covered with loosely attached brownish substance. Excessive wall thinning was found close to failure. With respect to total designated service life, both the components failed after covering nearly ¾th of the same. To prevent such undesirable incident in future, the investigation was taken up to find out cause of failure and subsequently providing tentative remedial measure.

2. Experimental

Failed boiler tubes were visually examined to reveal the nature of fracture. Tubes were cut along cross section to study the appearance of inner wall. Samples were collected from different locations for investigation as indicated in Fig. 1. The marked locations with sample ID are collated in Table 1.

Samples- A1 to A4 and B1 to B3 were considered for metallographic examination. They were mounted, polished by conventional technique, etched with 3% Nital and examined in optical (Leica DM 2500 M, USA) and scanning electron (JEOL JSM 840A, JAPAN) microscopes. Fracture surfaces were cleaned using dilute EDTA solution followed by Kerosene oil and finally in Acetone by sonication. The samples were studied in SEM. Bulk composition of alloy was determined in ICP and LECO using chips, obtained from cleaned surface. Bulk hardness was evaluated near fracture and bulging zone in Brinell Scale using steel ball as indenter. Some amount of adhered corrosion products was collected and examined by X-ray diffraction technique to identify their nature. The investigation and corresponding inferences are described in the following sub-sections.

3. Results & discussions

3.1. Visual examination

The damaged tubes were observed in reflected light with naked eyes (Fig. 1 and 2). Two tubes were designated as Sample-A and sample-B. Both tubes experienced temperature in range of ~540 °C with stress level 100 kg/cm^2 during operation. Sample-A exhibited fish mouth cracking at one side (Fig. 1a) and bulging at opposite side of weld (Fig. 1b). Cut length of the tube was 400 mm and wall thickness of un-deformed region was ~5.80 mm with ~36.8 mm outer diameter. From weld seam the distance of cracking was ~40 mm and total crack length was ~50 mm with ~6.7 mm maximum opening. Layer wise corrosion was observed near open end of crack and the remaining wall thickness was reduced drastically (< 1 mm). Inner surface contained multiple crack formation along longitudinal direction (Fig. 1c) whereas the same was completely absent at outer surface. Outer surface was blackened owing to thermal effect (Fig. 1a) and the inside surface was deep brown with numerous reddish spots (Fig. 1c).

As mentioned above, bulging was observed at lower half of the same tube. After bulging outer diameter became ~42.0 mm with distance of deformation ~12 cm from weld seam. Thick scale was loosely adhered to the inner surface near bulging (Fig. 1d).

Sample-B, also contained fish mouth cracking at one part of tube and other part exhibited no such de-generation. Total length of cut portion of tube was ~250 mm, wall thickness was ~6.2 mm with outer diameter ~39.0 mm. Crack was adjacent to weld seam with length ~30 mm and maximum crack opening ~2.8 mm. Both inner and outer surface contained longitudinal cracking of variable length (Fig. 2a and b). Inner side of the pipe was loosely covered with fine brown whiskers, which were product of oxidation corrosion (Fig. 2b). Fracture surface was dull in appearance. The area contained layered brown structure due to oxidation corrosion owing to its exposure to air after failure (Fig. 2a). Excessive thinning was found at the close vicinity of failure.

3.2. Chemical composition

The concentration of alloying elements in alloy has been collated in Table 2. The chemical composition of bulk specimen confirmed Polish composition of Steel 10H2M, which was equivalent to DIN 10CrMo9-10 or T22. There was no difference in chemical composition of the failed tubes with respect to standard specification.

3.3. Microstructural examination

The optical microstructures of damaged components are shown in Fig. 3 and consisted of pre-dominantly polygonal ferrite. Close