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Effect of steamside oxidation and fireside corrosion degradation processes on creep life of service exposed boiler tubes

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ABSTRACT

In conventional steam plants, the efficiency mainly depends on the outlet steam temperature of boiler. The outlet steam temperature is maintained by subjecting different sections of boiler to high temperatures. In these harsh conditions boiler tubes undergo different degradation processes viz creep, fatigue, steamside oxidation, fireside corrosion and erosion. Therefore, life evaluation of boiler components is required at regular intervals of time for better functionality of power plant. Various life assessment techniques like microstructural evaluation, hardness measurements, Oxide scale measurements, Accelerated temperature tests are used for assessing the residual life of boiler tubes. In this paper, the creep life is estimated using destructive accelerated temperature tests on several T22 tubes from various sections of Platen Superheater, Final Superheater and Reheater of boiler. Accelerated temperature tests are carried out at higher temperatures under the nominal steam load and remaining life is estimated by extrapolating the results for the constant service temperature. But, the service temperature of tube never remains constant during a regular plant operation due to insulation effect of steamside oxidation and fireside corrosion. Further, during start up and shut down of plant, tubes undergo low cycle fatigue damage. Though, the life consumption of boiler tube due to fatigue is infinitesimal compared to creep because of thinner section of tubes. Therefore, the effect of cyclic operation is not considered, but the effect of steamside oxidation, fireside corrosion and erosion are incorporated in the accelerated temperature test results in estimating the residual life of boiler tubes. Further, these results are compared with the life obtained from Oxide scale thickness measurements carried out by Non-destructive Ultrasonic technique. In both the methods, metal temperature calculation using steady state conductive heat transfer equations play a crucial role in estimating the residual life. Mainly, these methods are based on thermal properties of oxide scale and short term stress rupture tests. Therefore, these methods can be applied for different grades of boiler materials such as T23, T24, T91 and T92 etc for residual life estimation.

1. Introduction

Failure of boiler tubes of coal fired power plants causes a huge economic loss in most of the countries. Therefore, life evaluation of boiler tubes in view of extending their life offers a huge economic gain for power plant operators. For residual life evaluation of the boiler tubes, the possible damage mechanisms should be understood thoroughly. The possible damage mechanisms in a boiler tube are Stress/Creep rupture, fatigue, fireside corrosion, erosion and steamside oxidation. Creep is main degradation process in the boiler tube components. The possible mechanisms in creep failure are short-term overheating or high-temperature creep [1]. The degradation processes like fireside corrosion, steamside oxidation and erosion bolsters the creep damage and may lead to early failure than the design life. Fireside corrosion occurs on the outer side of Superheater or Reheater tubes [2,3]. The fireside corrosion product in sub-critical boilers is formed due to liquid-phase deposition [4].

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The fireside corrosion scale thickness is mainly dependent on coal chemistry and boiler tube surface temperature, which leads to thinning of the boiler tube [5]. Similarly, steamside oxidation on inner surface of tubes leads to thinning of tubes and also acts as hindrance to heat transfer [5–8]. Due to thinning of the tube and heat hindrance, hoopstress and metal temperature increases during operation of power plant. Though, the residual life is not much being affected by increase in hoop stress but rise in metal temperature due to insulation effect of oxide decreases the residual life of boiler tube. The effect of these degradation processes are need to be incorporated in models for creep residual life estimation.

Most common residual life evaluation techniques existing in literature are microstructural observation, hardness measurement, Oxide scale thickness measurements, accelerated stress rupture tests and accelerated temperature tests [9–12]. The merits and demerits of the techniques are discussed in Ref. [13]. In this paper a service exposed boiler tube is taken as a case study for comparison of two methods mainly (1) Oxide scale thickness method using heat transfer equations [13] and (2) accelerated temperature method for creep life estimation. These are the two methods which estimate the residual life quantitatively. Most of our residual life estimation on service exposed boiler tubes from these two methods vary by one order. Therefore, the reason for this variation in life estimation is studied and the accelerated temperature method is modified to obtain the correct residual life values.

The paper is organized as follows: §2 consist of experimental procedure required for the estimation of residual life of boiler tubes. §3 is comparison of residual life obtained from both the methods. §3.4 incorporate the effect of steamside oxidation and fireside corrosion on accelerated temperature tests of service exposed tube. §4 consist of conclusions of the residual life studies.

2. Experimental details

2.25Cr-1Mo (T22) Platen Super Heater boiler tube is taken as a case study for the residual life estimation. A section of boiler tube is obtained from the power plant to carry out the necessary studies for residual life estimation. The dimensions and operating conditions of the boiler tube are given in Table 1. The outer surface of tube is exposed to flue gases and inner surface is exposed to steam. Due to these service operations, there is a loss in material on outer surface and inner surface because of fireside corrosion and steamside oxidation, respectively. The oxide scale thickness on inner tube is determined using Non-destructive Ultrasonic testing machine of Babcock & Wilcox [6]. The measured oxide scale thickness is used in calculating the creep damage life of the service tube. Apart from Non-destructive examination, accelerated stress rupture tests are carried out on the sectioned tube. Three samples of ASTM E8M standard are subjected to accelerated temperature tests at 675 °C, 650 °C and 625 °C. The stress applied on all the three samples is constant and equivalent to hoop stress as in equation (8). These stress rupture values and oxide scale thickness data is analysed for the residual life estimation of the boiler tubes. The rupture data of service exposed T22 tube is given in Table 2.

3. Results and discussion

3.1. Creepdamage

The main degradation phenomenon is creep. The creep damage is quantified using a destructive method and a Non-destructive method. The destructive method is accelerated temperature rupture tests on service exposed tubes, wherein the rupture life is extrapolated at service temperature. In this method, effect of fireside corrosion and steamside oxidation is not taken into account. Therefore, a modified method is developed by incorporating the effect of the other degradation processes like steamside oxidation and fireside corrosion. The remaining life obtained from accelerated stress rupture tests and modified new method is compared with the life estimated from internal oxide-scale thickness values. A common set of heat transfer equations are used for both the internal oxide-scale method and modified accelerated temperature rupture method. The methods are discussed below.

3.2. Residual life calculation using internal oxide-scale thickness measurement

The residual life calculation using internal oxide scale thickness measurement, heat transfer equations and creep master cure is established in our previous work [13]. Taking an interval of every 1000 h, outer diameter (D_o), thickness of tube (b), hoop stress (σ), oxide scale thickness (X) and average metal temperature (T_{avg}) are calculated using equations (1)–(7), respectively. For a particular stress and average metal temperature, rupture life (t_r) is obtained from the contours of standard ASME 2.25Cr-1Mo rupture data as shown in Fig. 1. The life fraction (t/t_r) is obtained from Robinson's rule as shown in equation (8). The residual life with respect to life fraction can be obtained from Fig. 2. The remaining life value estimated from this internal oxide scale method is 2,72,000 h.

$$D_o = D_o(0) - \text{fireside corrosion rate}^*t \quad (1)$$

Table 2
Accelerated temperature rupture values of service exposed tube.

Temperature (°C)	675	650	625
Rupture time (h)	106	438	3331

Table 1
Service conditions of the boiler tube.

Description	Value
$D_o(0)$ in mm, outer diameter of boiler tube at time t = 0	47.63
$D_o(\tau)$ in mm, outer diameter of boiler tube at time t = τ	47.50
b(0) in mm, thickness of boiler tube at time t = 0	9.80
b(τ) in mm, thickness of boiler tube at time t = τ	9.49
P, operating pressure in Kg/cm^2	135
T_g, temperature of flue gas in Kelvin	1173
T_s, temperature of steam in Kelvin	783
X(τ), oxide scale thickness in mm at time τ	0.16
τ, Service exposed time in hours	1,05,178
K_1, thermal conductivity of oxide scale in W/mK	35
K_2, thermal conductivity of metal tube in W/mK	0.592
H, convective heat transfer co-efficient of flue gas to metal surface in W/m^{2}K	109.44