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Study of Microstructure Degradation of Boiler Tubes Due To Creep for Remaining Life Analysis

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ABSTRACT
In the current scenario of power shortage in India, the main objective is to ensure availability of power plant and increasing its reliability. During assessment ,testing and inspection a simple question has to be asked again and again" How long the particular power plants can be operated safely and cost-effectively with satisfying increased requirements and operational availability with reduced pollutant emissions, even after their designed life. So to answer this important question regarding the operational capability of the existing plant the remaining life analysis (RLA) has to be done. The condition of the plant equipments can be assessed only by way of a RLA methodology. On the basis of RLA proper decision can be made about the plants safety and availability. There are many methods to carry out the RLA of the critical components out of which "microstructure study" is a method. In this paper we have tried to outline the RLA procedures and review the various damage mechanisms based on microstructure study. It is also presents the microstructure changes and properties of 106720 service hour exposed boiler tube in a 120 MW boiler of a thermal power plant.

***Keywords* -** service exposed boiler tubes, microstructure, remaining life analysis, creep.

I. INTRODUCTION

In recent years, from oil refinery to petrochemical and power generation industries, more and more plants throughout the world are facing a common issue—aging equipments like turbines, boiler tubes usually over 15 to 30 years old. Questions bearing in managers' minds are what is the machine condition and whether they can be continually operated (if yes, how long). The answer is important not only for safety concerns but also for cost reduction, especially with today's limited budgets, and is more critical with the equipments working at elevated temperature. Therefore, there is an increasingly strong desire for the engineering aftermarket service to perform "Remaining Life Assessment" of the equipments which are working at higher temperatures like boiler tubes.

Remaining life assessment is to use metallurgical and fracture mechanics Methodologies to predict the remaining life of structures and components that have been in service for an extended period of time usually close to or beyond the designed life. Traditionally, if parts are found with material degradations or damages during an overhaul, they might be scrapped and replaced for risk-free consideration; even though they might have some useful life. Remaining life assessment offers a possible tool to estimate the useful remaining lifetime and avoid premature scrapping of the parts. So remaining life assessment is considered to be attractive method / process for cost reduction and reduction downtime.

Remaining life assessment has often been improperly referred to as "life extension." Actually this analysis cannot extend the lifetime of the components. It can only assess the useful remaining lifetime, based on the metallurgical examinations and theoretical (fracture mechanics) calculations. If such assessments indicate the need for extensive replacements and refurbishments, life extension may not prove to be a viable option. Above and beyond this objective, remaining life assessment technology serves many other purposes. It helps in setting up proper inspection schedules, maintenance procedures, and operating procedures. It should, therefore be recognized at the outset that development of techniques for remaining life assessment is more enduring in value and broader in purpose than simply the extension of plant life. For instance, it has been possible to extend the inspections, on the basis of assessments based on fracture mechanics, resulting in considerable savings.

In implementing remaining life assessment procedures, appropriate failure definition applicable to a given situation be determined at the outset, and the purpose for which the assessment is being carried out must be kept in mind. While the feasibility of extended plant life may be one objective, a more common objective is the setting of appropriate intervals for inspection, repair, and maintenance. In this context, remaining life assessment procedures are used only to ascertain that failures will not occur between such intervals. It should never be assumed that having performed a remaining life assessment study for a 20 life extension, one could then wait for 20 years without monitoring. Periodic checks to ensure the validity of the initial approach are essential. In this sense, remaining life assessment should be viewed as an ongoing task, rather than a one-time activity.

A phased approach, in which the initial level includes no incursive techniques followed by other levels of actual plant monitoring, then followed by nondestructive inspections and destructive tests would be the most logical and cost-effective approach. In Level I, assessments are performed using plant records, design stresses and temperatures, and minimum values material properties from the original equipment manufacturer (OEM). Level II involves actual measurements of dimensions temperatures, simplified stress calculations, and coupled with the use of minimum material properties from the OEM. Level III involves in-depth inspection, stress levels, monitoring, and generation of actual material data from removed from the component (destructive testing). The degree of the detail and accuracy of the results increases from Level I Level III, but at the same time, the cost of the assessment also increases. Depending on the extent of the information available and the results obtained, the analysis may stop at any level or proceed to the next level as necessary.

In evaluating the failure criteria or remaining life, one needs to understand the various failure mechanisms that can occur. In boiler machinery components which are working on elevated temperature, the failure criteria can be governed by one or a combination of the following failure mechanisms:

- Fatigue—high cycle or low cycle
- Corrosion/corrosion fatigue
- Stress corrosion cracking (SCC)
- Erosion—solid particle or liquid
- Erosion corrosion
- Creep rupture/creep fatigue
- High temperature corrosion/
- Mechanical (foreign objective) damage

However, in remaining life assessment, usually only those mechanisms depending on temperature and time are taken in to account. For example, for boiler tubes engineers usually focus on thermal stress induced low cycle fatigue, creep rupture and tempering embitterment cracking. These failures usually are slow processes; therefore, they can be assessed and forecasted by examining the warning evidences in the material.

Countless works have been done to study the behaviors of fatigue crack initiation/ propagation and creep or rupture in steels and alloys. Scientist and engineers have reached such a level that, by knowing the flow size or microstructure deterioration / damage. One can theoretically calculate and predict the remaining life time of the parts, based on the knowledge of the material properties and understanding of the stress distribution.

II. CREEP LIFE ASSESSMENT METHODOLOGY

Creep is high temperature damage mechanism which includes time dependent deformation and high temperature creep cracking. In other words creep damage is the result of permanent plastic deformation at elevated temperatures and at stresses much less than the high temperature yield stresses. Microstructure damages detected by the presence of creep voids at the grain boundaries which have tendency to coalescence during the time and form a cracks these cracks generally propagates in an inter-crystalline manner in components that fail over an extended time. So the Life assessment methodology based on creep failure analysis can broadly be classified into three levels[1]. Level 1 methodology is generally employed when service life of the components is less than 80% of their design lives. In level 1, assessments are performed using plant records, design stress and temperatures, and minimum values of material properties from literature. When service life exceeds 80% of the design life, Level 2 methodology is employed. It involves actual measurements of dimensions and temperatures, stress calculations and inspections coupled with the use of the minimum material properties from literature. However when life extension begins after attaining design life, Level 3 methodology is employed. It involves in-depth inspection, stress analysis, plant monitoring and generation of actual material data from samples removed from the component. The details and accuracy of the results increase from level 1 to level 3 but at the same time the cost of life assessment increases. Depending on the extent of information available and the results obtained, the analysis may stop at any level or proceed to the next level as necessary.

One of the crucial parameters in estimation of creep life is the operating temperature. Although steam temperatures are occasionally measured in a boiler, local metal temperatures are rarely measured. Due to load fluctuations and steam side oxide-scale growth during operation, it is also unlikely that a constant metal temperature is maintained during service. It is therefore more convenient to estimate mean metal temperature in service by examination of such parameters as hardness, microstructure, and thickness of the steam-side oxide scale for tubes. Because the changes in these parameters are functions of time and temperature, their current values may be used to estimate mean metal temperature for a given operating time. The estimated temperature can then be used in conjunction with standard creep rupture data to estimate the remaining life. Several methods for estimation of metal temperature have been reviewed elsewhere .

(2.a) Hardness based approach

Changes in strength of low-alloy steel with service exposure depend on time and temperature. Thus change in hardness during service may be used to estimate mean operating temperature for the component.

This approach is particularly suitable when strength changes in service occur primarily as a result of carbide coarsening neglecting stress induced softening. The database on changes in hardness due to long-term service is employed to assess remaining life[2].

(2.b) Microstructure based approach

Toft and Marsden demonstrated that there are basically six stages of spheroidization of carbides in ferrite steels. Using Sherby-Dorn Parameter, they established a reasonable correlation of microstructure with mean service temperature [3].Similar semi quantitative and qualitative approaches involving database on changes in microstructure as a function of service history have been widely used [4].Oxide scale thickness based approach. Extensive data from literature indicate that in relatively pure steam, the growth of oxide scales is a function of temperature and time of exposure. Several expressions have been proposed in the literature to describe oxide scale growth kinetics [5,6].

III. CREEP RUPTURE AND STRESS RUPTURE

Evidence of creep damage in the high temperature regions of boiler tubes has been observed in some instances [7]. The stresses and metal temperature at these locations are assessed against the creep rupture data for that particular grade of steel/or material. Traditionally one has used a Larson-Miller (LM) plot of the type shown in Figure (1).

The degree of safety margin depends on the user and what lower bound design curve is applied. Since these curves are based upon the chemistry, variation in chemistry for a particular grade can Have an effect on the Larson-Miller curve.

In assessing remaining life of the components due to creep, such as at boiler tubes, crack initiation is used as the criterion. However, with the emergence of cleaner steel and fracture mechanics and an increasing need to extend the life of a component, application of crack growth techniques have become common in the past decade. For crack initiation as the fracture criterion, history-based calculation methods are often used to estimate life.

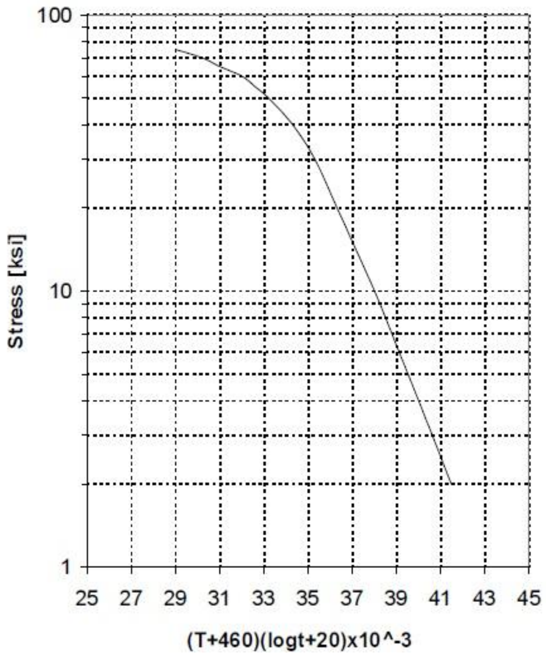


Fig.(1) Larson Miller Curve For Alloy Steel(ASTM A470 Class 8)

(3.a) Methods for Crack Initiation Due to Creep

For the analytical method, one must have accurate operating history of the components, which may consist of temperature, applied loads, changes in operation, such as shut downs or variation in speed or pressure. A simplistic estimation of the creep life expended can be made by assessing the relaxed long-term bore stresses and rim stresses against the standard rupture data using the life fraction rule.

(3.b) Metallographic examination

Metallographic techniques have been developed that can correlate changes in the microstructure and the onset of incipient creep damage, such as triple point cavitations at the grain boundaries. For this technique, measurements by replication technique are taken on crack sensitive areas that are subjected to the higher temperatures and stresses. These areas are generally indicated by experienced analysis of previous damages. The Creep damage measured by replication is classify into four damage stages

- Isolated cavities (A)
- Oriented cavities(B)
- Macro-cracks (linking of cavities) (C)
- Formation of macro-cracks (D)

Fig(2) shows the location of the four stages on the creep strain /exposure time curve [12]

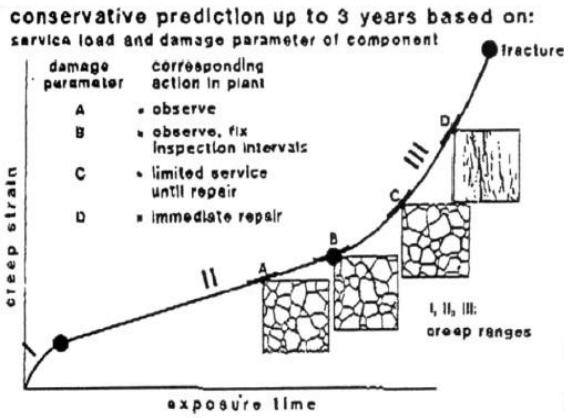
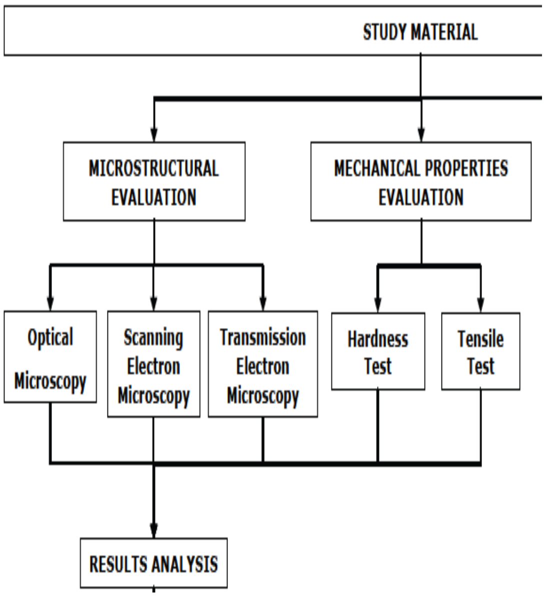


Fig.(2) Replicas For Remaining Life Assessment

IV. STUDY METHODOLOGY

The methodology used to evaluate the micro structural degradation in boiler tubes due to creep has been determined from the experience gained from previous studies of boiler tubes degraded in field and in laboratory[8] Figure(3).



Fig(3) Methodology applied to evaluate the micro structural degradation

- Microscopy techniques have to be used to compare the microstructures of the samples.
- Optical microscopy has to be performed for a preliminary evaluation and possible correlation with the Toft and Marsden criterion [9].
- Analysis of the microstructure has to be performed by scanning electron microscopy. By means of extraction replicas of each of the samples.
- Room temperature tensile tests with flat specimens should obtain from the samples.
- Vickers hardness tests need to be performed in different regions of the cross section of each sample
- From the readings of the geometrical data, the operating conditions and time, the remaining life of the tubes operating under creep conditions could be estimated. There is a well-established methodology for that. [10]

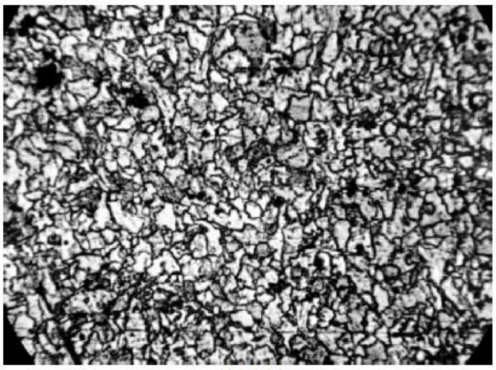
V. RESULTS OF METALLOGRAPHY EXAMINATION OF METAL

After first 15–20 thousand hours operation of pipe-lines made of steel BS 3059/622/50 SE at the temperature of 545 °C and pressure 14 MPa the considerable changes of structures occur. The changes of ferrite chemical composition, coagulation of carbide in ferrite, and also increase of sizes of carbides along the grain boundaries was observed. (Table 1)

Time, hours	0	30000	70000	90000
The quantity of Cr in Cr carbides, %	18.6	20.3	21.6	29.3
The quantity of Mo in Mo carbides, %	45.3	46.8	48.7	48.9
The quantity of V in V carbides, %	66	67	67.8	69.2
The quantity of carbide phases, %	1.2	4.62	13.3	20.3

Table [1] Changes of chemical composition of carbide phases

The microstructure of metal of a steam line is presented on photographs (Fig. 4, 5, 6 and 7). They show that microstructure of specimens consists of ferrite, pearlite (Table 1). The microstructure of metal of a steam line is presented on photographs (Fig. 4, 5, 6 and 7). They show that microstructure of specimens consists of ferrite, pearlite and non-metallic inclusions [11].

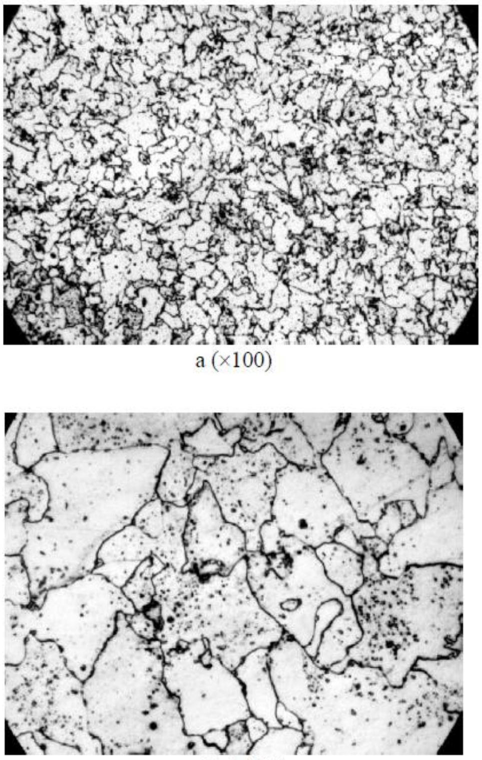


a (×100)

b (×500)

Fig.(4) Microstructure of not operated steel BS 3059/622/50 SE

The microstructure of not operated steel (Fig. 4 a, b) consists of pearlite (black phase), ferrite (white phase) and non-metallic inclusions. The photographs (Fig. 5 a, b) show the microstructure of 30000 hours operated steel.

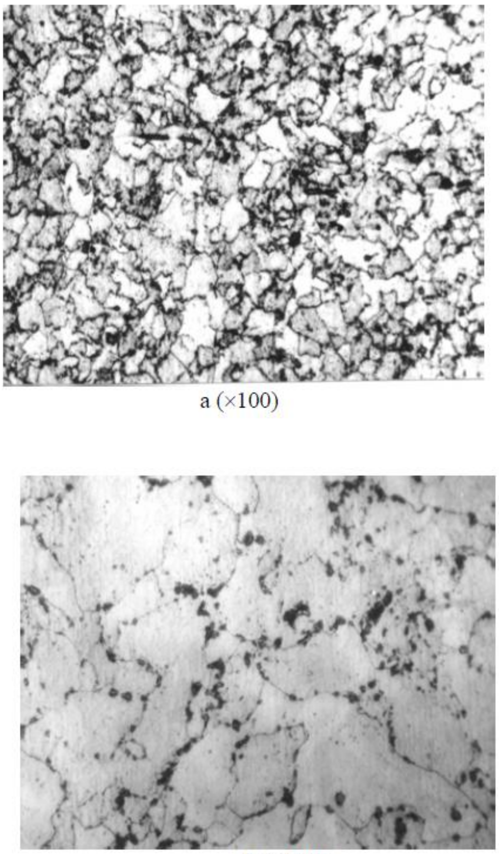


a (×100)

b (×500)

Fig.(5) Microstructure steel BS 3059/622/50 SE after 30000 hours

The microstructure of steel corresponds to number 6 of a scale of standards. Changes of the microstructure are visible on the photographs. The microstructure consists of ferrite, pearlite and non-metallic inclusions. On the boundaries of ferrite grains line-ups of carbides are visible (Fig. 5 b).On the photographs (Fig. 6 a, b) the microstructure of 70229 hours operated steel are presented.

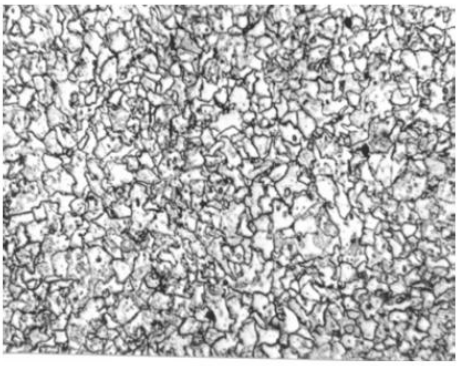


a (×100)

b (×500)

Fig.(6) Microstructure steel BS 3059/622/50 SE after 70000 hours

The microstructure of steel corresponds to number 6 – 7 of a scale of standards. The microstructure consists of ferrite, pearlite and non-metallic inclusions. In comparison with a microstructure of 29572 hours of operated steel, an amount of carbides and their coagulation in ferrite increases (Fig. 6 b). On the photographs (Fig. 7 a, b) the microstructure of 94942 hours operated steel are presented.



a (×100)

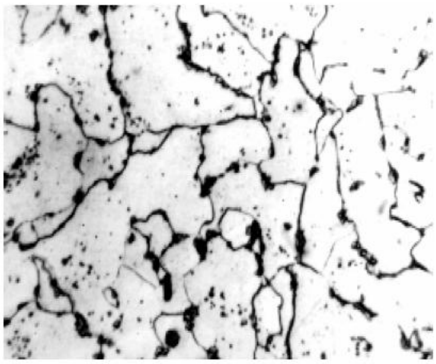


Fig.(7) Microstructure steel BS 3059/622/50 SE after 90000 hours

The microstructure of steel corresponds to number 7 of a scale of standards. The microstructure consists of ferrite, carbides and small amount of pearlite. In the body of grains of ferrite it is possible to see the small particles of carbides, but the major part of carbides are between the boundaries of grains (Fig. 7 b). Observed changes of the steel structure determine changes of mechanical and physical characteristics of the metal of pipelines.

VI. CONCLUSIONS

Continuous time high temperature operation may leads to changes of steel structure. There will be a change of constituents of ferrite and pearlite of steel. The grains of ferrite grow and their coagulation occurs, pearlite is diminished. The alloying elements,(chrome, molybdenum and vanadium) during a high temperature long-term operation from ferrite solid solution to transforms into a carbide phases. During a long-term operation at high temperature the amount of carbides increases and coagulation of carbides occurs, therefore freedom of dislocations mobility increases, and it increases a creep of material and defines change of other mechanical characteristics. On evaluating a further opportunity of operation of a steam line the basic limiting parameter of the long time operated heat-resistant steels is disparity of carbides. All mentioned properties have non-linear changes. Long-term operation at working temperature of 545 °C lead to change of ultimate tensile strength and yield strength, elongation and reduction of area, impact strength and hardness.

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