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LIFE ASSESSMENT OF POWER PLANT BOILER STEELS

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ABSTRACT
Many components of power plant boiler are exposed to elevated temperatures, aggressive environment, creep, fatigue, and other damage mechanisms that can cause degradation, deformation or cracking of components. Thus, it is possible for the life expectancy to be reduced. Steamlines, heaters and superheaters often require life assessment after the boiler has been in operation. It is important to assess the condition of boiler components periodically and to estimate the remaining life to provide guidelines for replacement. A properly managed life assessment program can extend the life of boilers by many years, thus avoiding major capital expenditure for the utilities. Boiler and pressure vessel codes and standards provide methods and rules that can be used to evaluate remaining life.
Keywords: degradation**,** life assessment, boiler, standards and codes

1. INTRODUCTION
Many components of power plant boiler are exposed to elevated temperatures, aggressive environment, creep, fatigue, and other damage mechanisms that can cause degradation, deformation or cracking of components. Since the parts and machines that are serving the thermal power generation and in other like plants operating at elevated temperatures are subject to damage due to fatigue as well as to creep because of the frequent start-and-stops and changes in the working conditions, precise assessment of the damage incurred in them is a matter of special importance in designing and maintaining such a plant. Thermal power plants around the world are aging and need to be assessed to ensure continued safe operation. Replacement is frequently not an option because of high capital costs, and the much lower cost of continuing the operation of the older plant [1]. However, reliability and safety are issues that have become much more important in recent years, so the assessment of damage and of the risk associated with failure have become increasingly important.

2. MECHANISMS OF DEGRADATION
For equipment operating at high temperature, there are many different mechanisms of degradation, some of which interact, and the rate of accumulation of damage is not simple to predict.

2.1. Creep
Creep is one of the most serious high temperature damage mechanisms. It involves time-dependent deformation and high temperature creep cracking generally develops in an intercrystalline manner in components of engineering importance that fail over an extended time. These include boiler superheater and other components operating at high temperature. At higher temperatures, as can occur

with local overheating, deformation may be localized, with large plastic strains and local wall thinning. At somewhat lower temperatures and under correspondingly higher stress levels, fracture can be transgranular in nature. Figure 1. shows example of typical cracks caused by creep.

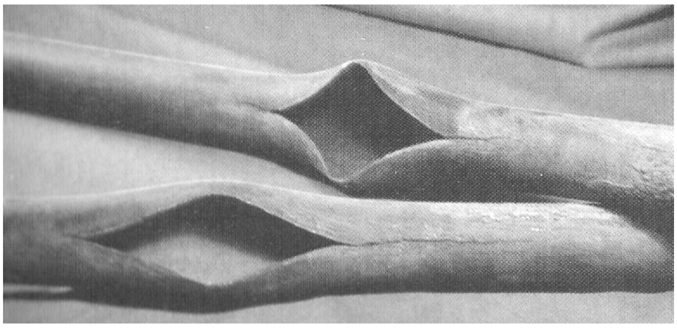

Figure 1. Two superheater tubes from a utility boiler (9,7MPa), failed by creep[2]

2.2. Microstructural degradation

Microstructural degradation is a damage mechanism that can lead to failure by some other process such as creep, fatigue or more rapid fracture. It is important that it is recognized as a mechanism of damage as it can result in a significant loss in strength in a material. It is appropriate to discuss this following directly upon the discussion of creep damage, because the two mechanisms are closely bound together and, indeed, are difficult to separate. It has already been noted that Cr-Mo steels that are liable to fail by creep in a short time may display spheroidization of the carbides but little, if any, void formation. Another example of microstructural degradation is decarburization of carbon or alloy steel when exposed to an oxidizing atmosphere at high temperature. There is a loss of strength in the surface layer of the steel.

2.3. Fatigue and creep-fatigue interaction

Fatigue, involving repeated stressing, can lead to failure at high temperature as it does at low temperature. In components operating at high temperature it often arises through temperature changes that can lead to cyclic thermal stresses. This can lead to thermal fatigue cracking. The cracking tends to develop in areas of high constraint, and the detailed mechanism may be one of local creep deformation. Creep-fatigue interaction is a complex process of damage involving creep deformation and cyclic stress and the predominant damage mode can range from primarily fatigue crack growth at higher frequencies and lower temperatures to primarily creep damage where hold times are long and temperature is at the high end of the scale. Figure 2. shows cracks resulted by corrosion-fatigue.

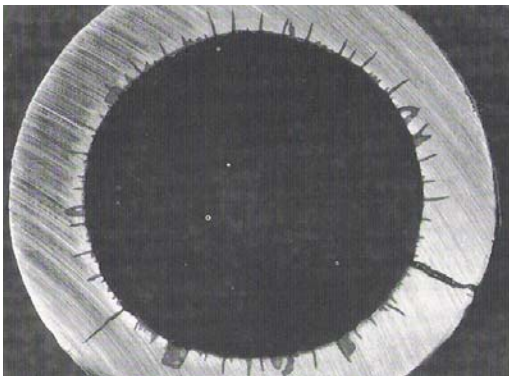

Figure 2. A family of longitdinal cracks resulting from fluctuation in internal pressure[2]

There are also other important mechanisms of degradation that can arise in a number of different ways like embrittlement, hydrogen damage, graphitization, thermal shock, erosion, liquid metal embrittlement, high temperature corrosion [1].

3. LIFE ASSESSMENT METHODS FOR POWER PLANT PIPING AND TUBING

Piping and tubing in steamlines, heaters, boilers, and superheaters are subjected to elevated temperatures that can cause degradation, deformation or cracking. Thus, it is possible for the life expectancy to be reduced. Therefore, it is often necessary that piping and tube life assessment be conducted. Some methods can be applied for plant piping and tubing exposed to elevated temperatures, like following [3]:

- Hardness testing,
- Microstructural evaluation,
- Creep cavitation damage assessment,
- Stress-rupture tests (life fraction),
- Oxide-scale-based life prediction,
- High-temperature crack growth methods.

In any component, the failure criteria need to be defined and established. Failure does not always involve fracture or rupture. Progressive damage of high-temperature components under operating conditions leads to exhaustion of life, thus leading to failure. Damage may be defined as a "progressive and cumulative change acting to degrade the structural performance of the load-bearing component or components that make up the plant". Life may be defined as the "period during which a component can perform its intended function safely, reliably, and economically" [3].

4. BOILER AND PRESSURE VESSEL CODES

Boiler and pressure vessel codes and standards provide methods and rules that can be used to evaluate remaining life of boiler components. Annex I of the Pressure Equipment Directive 97/23/EC (PED) requires that the design must take appropriate account of all foreseeable degradation mechanism such as fatigue [4]. For other degradation mechanism, such as creep interaction with fatigue there are very few methods available. The methods used to evaluate fatigue vary from exemption calculations, to simplified methods, to detailed methods.

4.1. Fatigue evaluation

Many boiler and pressure vessel codes and standards provide provisions to exempt fatigue evaluations. Exemptions are based on the components meeting the code design rules and details. Fatigue exemption rules are also a function of construction details.

If fatigue evaluations cannot be exempted, the next step would be to use simplified fatigue evaluation methods. Once again these methods are based on the components meeting the code design rules and details. Simplified fatigue analysis rules may be conservative with respect to determining stresses used in fatigue life evaluations. More detailed methods for determining stresses such as finite element analysis may be used to obtain more exact fatigue evaluation.

For detailed fatigue evaluations, detailed stress analyses are normally used, but not always necessary. These stress analyses are all based on determining stresses and involve either classical plate and shell theory or finite element analysis. Codes and standards evaluate calculated stresses differently in their fatigue assessment procedures.

Table 1. Codes and standards for fatigue evaluation methods[5]

1.	ASME Section VIII Division 2, (ASME VIII-2)
2.	British Standard, PD 5500
3.	German Technical Rules for Steam Boilers, TRD
4.	European Standards for Water-Tube Boilers, EN 12952-3
5.	European Standard for Unfired Pressure Vessels, EN 13345

4.2. Creep and fatigue interaction methods

Creep occurs in components that are stressed at elevated temperatures for long periods of time, such as superheaters and reheaters. The creep damage is based on the length of time the components stressed at a particular magnitude and temperature. Therefore, the creep damage at a particular stress and temperature is the ratio of time of operation to allowable time for creep. The total creep usage fraction is the summation of the individual creep damage ratios. The TRD 508 and EN 12952-4 method for creep life determination is simplified but an effective method for creep consideration and for creep-fatigue interaction. These rules are for in-service monitoring of creep and creep-fatigue life of water tube boilers, but are used for creep and creep-fatigue evaluations.

For detailed creep and creep-fatigue evaluation ASME Section III can be used. Subsection NH was written for nuclear component design and is very complicated, time consuming, and is not considered useful for every day designs of power plant boilers.

Table 2. Codes and standards for creep and fatigue interaction evaluation methods[5]

1.	German Technical Rules for Steam Boilers, TRD
2.	European Standards for Water-Tube Boilers, EN 12952-4
3.	ASME Section III, Subsection NH

5. FINAL REMARKS

Elevated-temperature failure mechanisms and metallurgical instabilities reduce life or cause loss of function or operating time of high-temperature components. In addition, once a failure occurs from creep, fatigue, or an embrittlement degradation phenomenon at high temperature, the analysis team is often confronted with the question: How long will similar components last? Or, when should the next inspection be performed? To address these questions, life assessment methodologies are often used. Because the failure analyst is often asked questions concerning remaining life, fitness-for-service, inspection intervals, and reliability of structural components and equipment, it is necessary that the failure analyst be aware of life assessment methodologies to address the questions and concerns of the industry he or she serves. Life assessment method advances and changes in technologies for structural components and equipment will require the investigator to adapt to the need of the industry. Furthermore, the failure investigator role has expanded from providing accurate identification of life-limiting failure mechanisms and degradation phenomena to also providing the time for degradation or damage, and crack growth rate to be used in life assessment estimates. Thus, the failure investigator's input is essential for meaningful life assessment of structural components.

6. REFERENCES

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