Boiler Tube Analysis

Reduce Future Boiler Tube Failures
Look to the Industry Leader for Comprehensive Tube Assessment

Boiler tube failures continue to be the leading cause of forced outages in fossil-fired boilers. To get your boiler back on line and reduce or eliminate future forced outages due to tube failure, it is extremely important to determine and correct the root cause. Experience shows that a comprehensive assessment is the most effective method of determining the root cause of a failure.

With more than 125 years experience designing, fabricating, building and servicing boilers, Babcock & Wilcox is a recognized industry leader and a logical source for tube failure evaluation.

A tube failure is usually a symptom of other problems. In addition to evaluating the failure itself, you should investigate all aspects of boiler operation leading to the failure to fully understand the cause. Babcock & Wilcox can assist you in this full-scope investigation with our experienced field service engineers helping to gather all the pertinent information. In many cases, the field investigation can isolate the root cause that led to the tube failure.

World-class Research Center

For tube sample analyses, B&W can draw on the experience and capabilities of our world-class ISO certified Alliance Research Center (ARC), Alliance, Ohio. We have metallurgical and chemical engineering expertise to complement our knowledge of boiler design and operation. At the ARC, we analyze hundreds of samples every year and provide a full range of failure analyses and material evaluation services.

Materials can be examined at magnifications as great as 100,000X using our Scanning Electron Microscope (SEM). In conjunction with the SEM, our electron probe microanalysis capability allows analysis of chemical elements on the tube surfaces which aids in root cause evaluation. Deposits, whether on the water side or gas side of the tube, also can be analyzed at the ARC using X-ray diffraction and mass spectroscopy techniques.
Finding the Root Cause is Critical

Have you ever repaired a tube leak and put the boiler back in service, only to be forced off-line by another leak? Identifying and correcting the root cause is essential. Shown on the following pages are some of the failure mechanisms found in fossil boiler tubes. When you see tubes in your boiler like those illustrated, take advantage of B&W’s tube expertise to help you determine and eliminate the root cause of the problem. Better yet, let us assist you in putting together a complete condition assessment program to help you find tube problems before failures occur.

**Caustic Attack**

**Symptoms:** Localized wall loss on the inside diameter (ID) surface of the tube, resulting in increased stress and strain in the tube wall.

**Causes:** Caustic attack occurs when there is excessive deposition on ID tube surfaces. This leads to diminished cooling water flow in contact with the tube, which in turn causes local under-deposit boiling and concentration of boiler water chemicals. If combined with boiler water chemistry upsets of high pH, it results in a caustic condition which corrosively attacks and breaks down protective magnetite.

**Oxygen Pitting**

**Symptoms:** Aggressive localized corrosion and loss of tube wall, most prevalent near economizer feedwater inlet on operating boilers. Flooded or non-drainable surfaces are most susceptible during outage periods.

**Causes:** Oxygen pitting occurs with the presence of excessive oxygen in boiler water. It can occur during operation as a result of in-leakage of air at pumps, or failure in operation of preboiler water treatment equipment. This also may occur during extended out-of-service periods, such as outages and storage, if proper procedures are not followed in layup. Non-drainable locations of boiler circuits, such as superheater loops, sagging horizontal superheater and reheater tubes, and supply lines, are especially susceptible.

More generalized oxidation of tubes during idle periods is sometimes referred to as out-of-service corrosion. Wetted surfaces are subject to oxidation as the water reacts with the iron to form iron oxide.

When corrosive ash is present, moisture on tube surfaces from condensation or water washing can react with elements in the ash to form acids that lead to a much more aggressive attack on metal surfaces.

**Hydrogen Damage**

**Symptoms:** Intergranular micro-cracking. Loss of ductility or embrittlement of the tube material leading to brittle catastrophic rupture.

**Causes:** Hydrogen damage is most commonly associated with excessive deposition on ID tube surfaces, coupled with a boiler water low pH excursion. Water chemistry is upset, such as what can occur from condenser leaks, particularly with salt water cooling medium, and leads to acidic (low pH) contaminants that can be concentrated in the deposit. Under-deposit corrosion releases atomic hydrogen which migrates into the tube wall metal, reacts with carbon in the steel (decarburization) and causes intergranular separation.
Acid Attack

**Symptoms:** Corrosive attack of the internal tube metal surfaces, resulting in an irregular pitted or, in extreme cases, a “Swiss cheese” appearance of the tube ID.

**Causes:** Acid attack most commonly is associated with poor control of process during boiler chemical cleanings and/or inadequate post-cleaning passivation of residual acid.

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Stress Corrosion Cracking (SCC)

**Symptoms:** Failures from SCC are characterized by a thick wall, brittle-type crack. May be found at locations of higher external stresses, such as near attachments.

**Causes:** SCC most commonly is associated with austenitic (stainless steel) superheater materials and can lead to either transgranular or intergranular crack propagation in the tube wall. It occurs where a combination of high-tensile stresses and a corrosive fluid are present. The damage results from cracks that propagate from the ID. The source of corrosive fluid may be carryover into the superheater from the steam drum or from contamination during boiler acid cleaning if the superheater is not properly protected.

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Waterside Corrosion Fatigue

**Symptoms:** ID initiated, wide transgranular cracks which typically occur adjacent to external attachments.

**Causes:** Tube damage occurs due to the combination of thermal fatigue and corrosion. Corrosion fatigue is influenced by boiler design, water chemistry, boiler water oxygen content and boiler operation. A combination of these effects leads to the breakdown of the protective magnetite on the ID surface of the boiler tube. The loss of this protective scale exposes tube to corrosion. The locations of attachments and external weldments, such as buckstay attachments, seal plates and scallop bars, are most susceptible. The problem is most likely to progress during boiler start-up cycles.

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Superheater Fireside Ash Corrosion

**Symptoms:** External tube wall loss and increasing tube strain. Tubes commonly have a pock-marked appearance when scale and corrosion products are removed.

**Causes:** Fireside ash corrosion is a function of the ash characteristics of the fuel and boiler design. It usually is associated with coal firing, but also can occur for certain types of oil firing. Ash characteristics are considered in the boiler design when establishing the size, geometry and materials used in the boiler. Combustion gas and metal temperatures in the convection passes are important considerations. Damage occurs when certain coal ash constituents remain in a molten state on the superheater tube surfaces. This molten ash can be highly corrosive.

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High-temperature Oxidation

Similar in appearance and often confused with fireside ash corrosion, high-temperature oxidation can occur locally in areas that have the highest outside surface temperature relative to the oxidation limit of the tube material. Determining the actual root cause between the mechanisms of ash corrosion or high-temperature oxidation is best done by tube analysis and evaluation of both ID and OD scale and deposits.
Waterwall Fireside Corrosion
Symptoms: External tube metal loss (wastage) leading to thinning and increasing tube strain.
Causes: Corrosion occurs on external surfaces of waterwall tubes when the combustion process produces a reducing atmosphere (substoichiometric). This is common in the lower furnace of process recovery boilers in the pulp and paper industry. For conventional fossil fuel boilers, corrosion in the burner zone usually is associated with coal firing. Boilers having maladjusted burners or operating with staged air zones to control combustion can be more susceptible to larger local regions possessing a reducing atmosphere, resulting in increased corrosion rates.

Fireside Corrosion Fatigue
Symptoms: Tubes develop a series of cracks that initiate on the outside diameter (OD) surface and propagate into the tube wall. Since the damage develops over longer periods, tube surfaces tend to develop appearances described as “elephant hide,” “alligator hide” or craze cracking. Most commonly seen as a series of circumferential cracks. Usually found on furnace wall tubes of coal-fired once-through boiler designs, but also has occurred on tubes in drum-type boilers.
Causes: Damage initiation and propagation result from corrosion in combination with thermal fatigue. Tube OD surfaces experience thermal fatigue stress cycles which can occur from normal shedding of slag, sootblowing or from cyclic operation of the boiler. Thermal cycling, in addition to subjecting the material to cyclic stress, can initiate cracking of the less elastic external tube scales and expose the tube base material to repeated corrosion.

Short-term Overheat
Symptoms: Failure results in a ductile rupture of the tube metal and is normally characterized by the classic “fish mouth” opening in the tube where the fracture surface is a thin edge.
Causes: Short-term overheat failures are most common during boiler start up. Failures result when the tube metal temperature is extremely elevated from a lack of cooling steam or water flow. A typical example is when superheater tubes have not cleared of condensation during boiler start-up, obstructing steam flow. Tube metal temperatures reach combustion gas temperatures of 1600°F or greater which lead to tube failure.

Long-term Overheat
Symptoms: The failed tube has minimal swelling and a longitudinal split that is narrow when compared to short-term overheat. Tube metal often has heavy external scale build-up and secondary cracking.
Causes: Long-term overheat occurs over a period of months or years. Superheater and reheater superheater tubes commonly fail after many years of service, as a result of creep. During normal operation, alloy superheater tubes will experience increasing temperature and strain over the life of the tube until the creep life is expended. Furnace water wall tubes also can fail from long-term overheat. In the case of water wall tubes, the tube temperature increases abnormally, most commonly from waterside problems such as deposits, scale or restricted flow. In the case of either superheater or water wall tubes, eventual failure is by creep rupture.
**Graphitization**

**Symptoms:** Failure is brittle with a thick edge fracture.

**Causes:** Long-term operation at relatively high metal temperatures can result in damage in carbon steels of higher carbon content, or carbon-molybdenum steel, and result in a unique degradation of the material in a manner referred to as graphitization. These materials, if exposed to excessive temperature, will experience dissolution of the iron carbide in the steel and formation of graphite nodules, resulting in a loss of strength and eventual failure.

**Dissimilar Metal Weld (DMW) Failure**

**Symptoms:** Failure is preceded by little or no warning of tube degradation. Material fails at the ferritic side of the weld, along the weld fusion line. A failure tends to be catastrophic in that the entire tube will fail across the circumference of the tube section.

**Causes:** DMW describes the butt weld where an autenitic (stainless steel) material joins a ferritic alloy, such as SA213T22, material. Failures at DMW locations occur on the ferritic side of the butt weld. These failures are attributed to several factors: high stresses at the austenitic to ferritic interface due to differences in expansion properties of the two materials, excessive external loading stresses and thermal cycling, and creep of the ferritic material. As a consequence, failures are a function of operating temperatures and unit design.

**Erosion**

**Symptoms:** Tube experiences metal loss from the OD of the tube. Damage will be oriented on the impact side of the tube. Ultimate failure results from rupture due to increasing strain as tube material erodes away.

**Causes:** Erosion of tube surfaces occurs from impingement on the external surfaces. The erosion medium can be any abrasive in the combustion gas flow stream, but most commonly is associated with impingement of fly ash or soot blowing steam. In cases where soot blower steam is the primary cause, the erosion may be accompanied by thermal fatigue.

**Mechanical Fatigue**

**Symptoms:** Damage most often results in an OD initiated crack. Tends to be localized to the area of high stress or constraint.

**Causes:** Fatigue is the result of cyclical stresses in the component. Distinct from thermal fatigue effects, mechanical fatigue damage is associated with externally applied stresses. Stresses may be associated with vibration due to flue gas flow or sootblowers (high-frequency low-amplitude stresses), or they may be associated with boiler cycling (low-frequency high-amplitude stress mechanism). Fatigue failure most often occurs at areas of constraint, such as tube penetrations, welds, attachments or supports.
We can help you detect, analyze and correct the problems leading to tube failures. B&W has developed a line of tube inspection services to aid you in evaluating your boiler’s tubing. These patented techniques have a proven track record of success in helping you identify tubes that may lead to failures.

**NOTIS®**
Nondestructive Oxide Thickness Inspection Service
An ultrasonic NDE test coupled to a computer model enables the calculation of remaining creep life for steam cooled superheater and reheater tubes.

**FHyMES**
Furnace wall Hydrogen damage Nondestructive Examination Service
This ultrasonic test utilizes multiple transducers to scan tubes for attenuation due to hydrogen damage.

**MANTIS®**
Modular Automated Nondestructive Thickness Inspection Service
The marriage of electronically acquired ultrasonic thickness measurements with computer-aided data management and analysis makes evaluation of wall thickness straightforward and efficient.

**FST-GAGE™**
Fast-Scanning Thickness Gage
Our newest testing service uses technology developed by B&W on a project sponsored by the Electric Power Research Institute (EPRI). The FST-GAGE is an EMAT-based (ElectroMagnetic Acoustic Transducer), nondestructive examination technique that enables rapid scanning of boiler tubes to detect wall loss and internal tube damage.

**Cleaning Your Boiler**
When the elimination of tube damage requires chemical cleaning, B&W’s water chemistry and deposit removal expertise can help. The chemistry section at the Alliance Research Center can perform cleaning tests to determine the best chemicals and methods to clean your boiler tubes without harming the tubes themselves. Our water chemistry field specialist then can provide the expert, on-site project management capability to ensure a successful cleaning.

**Corrosion Assessment**
If the conditions leading to corrosive damage are not clear, then the corrosion section of the ARC can be called in to help. Extensive laboratory facilities are available to simulate boiler conditions and identify causative conditions. These simulations can be performed for both fireside and steamside applications.
B&W is Committed to Helping You Keep Your Plant On-line

B&W's goal is to meet your evolving needs in helping to keep your steam production on-line and available when you need it. Through innovation and teamwork, we are committed to delivering the latest inspection technologies, as well as providing full-scope design, manufacturing, construction and service expertise. When needed, B&W’s research center can support in-depth analyses and testing to determine the root cause of your problem. These capabilities include expertise in many diverse disciplines, including:

- Analytical metallurgy
- Chemical cleaning and preservation
- Chemical engineering
- Chemistry
- Combustion
- Corrosion
- Dynamics and flow-induced vibration
- Fluid mechanics and heat transfer
- Fuels and fuels analysis
- Materials performance and mechanical testing
- Measurements
- Mechanical design
- Nondestructive methods and diagnostics
- Pollution control
- Quality control
- Stress analysis/finite element analysis
- Water chemistry
- Welding or other manufacturing technology

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