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Metallographic Characterization of Thermal Damage in Boiler Tubes

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Failure of boiler tubes within systems such as fossil fueled power plants have long posed economic and operational challenges due to unscheduled down time. A proper failure analysis is critical to diagnose the root cause, recommend follow-on inspections for the extent of further damage, assess life expectancy, and monitor health throughout the remaining life cycle. Due to the hot and corrosive conditions, the most common damage mechanisms are primarily thermal and/or corrosion related. The focus of this talk will be the use of metallography in the assessment of thermally influenced failures, highlighted by case histories detailing each mechanism. Specific failure causes that will be discussed include long term overheating, short term overheating, and thermal fatigue, which are briefly described below. Finally, an overview of remaining life assessment will be related to a combination of metallographic interpretation, mechanical properties, dimensional inspection and temperature monitoring.

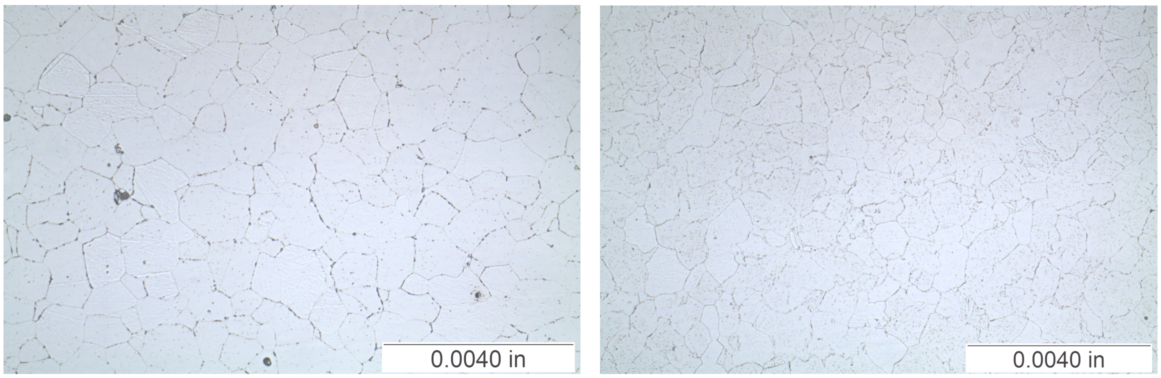
Long Term Overheating is implied in more boiler tube failures than any other mechanism, which occurs when local temperatures exceed the design limit for time scales ranging from days to years [1]. Long Term Overheating often manifests as creep and stress rupture, which can be diagnosed with metallographic examination. Stages of creep and stress rupture follow a predictable course including nucleation of creep voids at triple points, continued nucleation along grain boundaries, coalescence of voids, and eventual rupture. Thermal oxidation may also be involved, which lowers the effective wall thickness and therefore increases local stresses. Exposure to elevated temperatures for a prolonged period may also produce microstructural changes that aid in determining the peak temperature ranges. For example, spheroidization of pearlite lamellae implies long term exposure to elevated temperatures below the Ac1 temperature, whereas the observation of fresh pearlite and/or bainite is produced by heating above Ac1 and slow cooling.

Short Term Overheating (e.g. rapid overheating) occurs at temperatures in excess of approximately 850 degrees F and sometimes much higher, where the yield strength of the alloy is lowered sufficiently to permit relatively fast deformation and fracture. As opposed to long term overheating, cases with short term overheating are normally confined to a single or short series of process excursions [2]. When rupture occurs below the crystallization temperature, the microstructure near the fracture can exhibit severe plastic deformation. At higher temperatures, between Ac1 and Ac3, a microstructure of pearlite and/or bainite is formed due to the cooling conditions following failure [3]. Examination of adjacent tubes can aid in determining if the observed microstructures were localized or widespread.

Thermal Fatigue may refer to high or low cycle fatigue, where thermal cycling imposes mechanical stress on the tubes due to expansion and compression. Crack morphology is consistent with mechanical fatigue failure, and appears as straight unbranched cracks that propagate perpendicular to the maximum tensile stress. Depending on conditions within the tube, the cracks may exhibit oxidation as well as other symptoms of long term overheating damage.

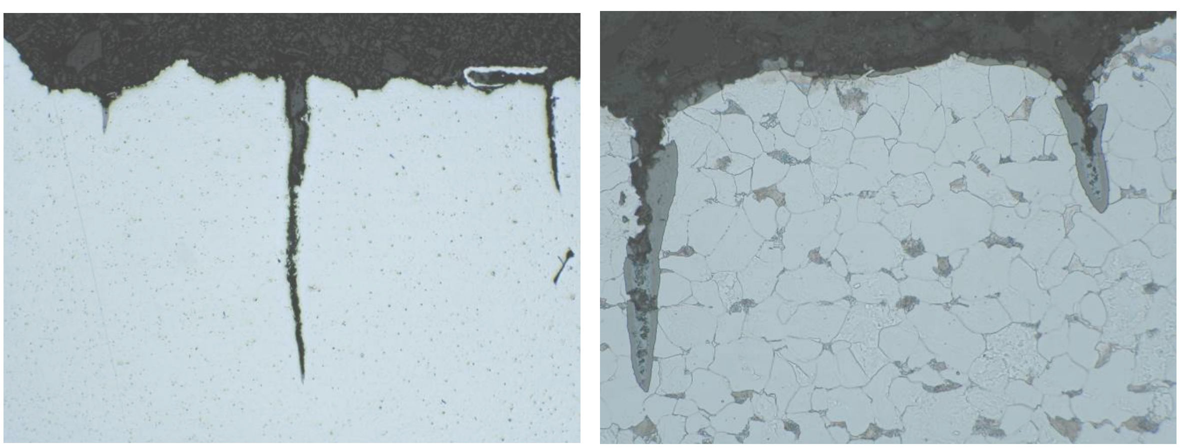
References:

[1] The NALCO Guide to Boiler Failure Analysis, Robert D. Port, Harvey M. Herro, McGraw Hill, New York.
[2] Damage Mechanisms and Life Assessment of High-Temperature Components, R. Viswanathan, ASM International, Metals Park, OH.
[3] ASM Handbook, Failure Analysis and Prevention, 8th Edition. Page 529.
[4] The author acknowledges Mark Lisin, P.E. for providing case histories within this talk as well as continued mentorship in the field of Metallurgical Failure Analysis.



Near Long Term Overheating Bulge Away from Long Term Overheating Bulge

Figure 1: Optical photomicrographs showing metallographic cross sections taken at (left) and away from (right) long term overheating damage. Both microstructures are ferritic, but creep void formation along grain boundaries is apparent in the overheated area. Fractography of the main fracture surface revealed a predominately intergranular pathway. 2% nital etch.



As-Polished 2% Nital Etch

Figure 2: Optical photomicrographs showing longitudinal sections through adjacent cracks. The straight, unbranched, wedge shaped cracks are characteristic of thermal fatigue. The microstructure of the tube consisted of lamellar pearlite in a ferrite matrix. Evidence of overheating damage was not revealed by the metallographic examination. As-polished (left) and 2% nital etch (right).