A View from the Penthouse

The DNFM Technical News Letter

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Stainless steels are commonly used in boilers for their high-temperature strength and excellent corrosion resistance. However, there are a few drawbacks with stainless steel tubing when burning high-chlorine coal. Chlorine plays two major roles in the damage and failure of stainless steel components: stress-corrosion cracking (SCC), and fireside corrosion. SCC requires a presence of threshold tensile stresses, electrolyte and corrosion species. However, the occurrence of SCC in boiler tubes is not common.

SCC can be intergranular (along the grain boundaries), transgranular (across the grains) or both, depending on the operating conditions. Since they resemble each other, intergranular SCC failures in high-temperature superheater/reheater tubes should not be confused with creep failures. With creep failures, intergranular creep voids are present at higher magnification; this is not so with intergranular SCC. Another clue is that intergranular SCC typically exhibits missing grains from the affected area after polishing. When superheater/reheater tubes in a high-chlorine fuel environment are water washed, the chlorides dissolve in the water, run down the pendants, and collect at the bottom. Residual stresses from the cold work during tube bending and/or unintentional stresses from sagging or defective support system/restraints may initiate SCC failures. **Figure 1** illustrates OD-initiated SCC in a reheater tube. Corrosive species were from offline water washing and stresses were from residual stresses due to cold work during tube bending. SCC is also a concern at the ID of austenitic high-temperature superheater/reheater tubes. The contributing sources can be carryover of volatile chemicals from the boiler, contamination from chemical cleaning, and/or upstream attemperator sprays to control the steam temperatures. In **Figure 2**, some grains seem to have fallen out during polishing, typical for intergranular SCC.

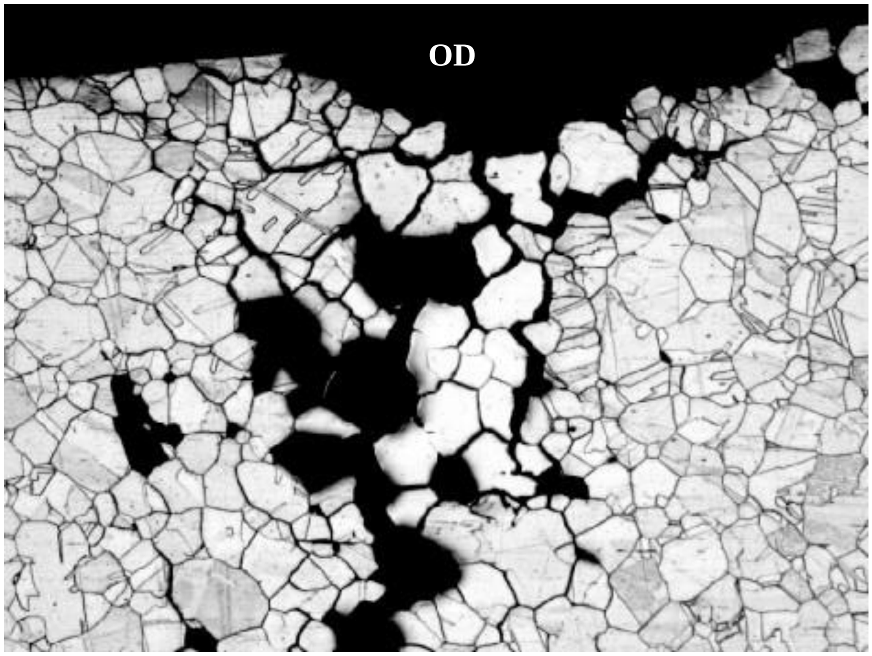

Figure 1. Intergranular SCC and missing grains, OD. 87x

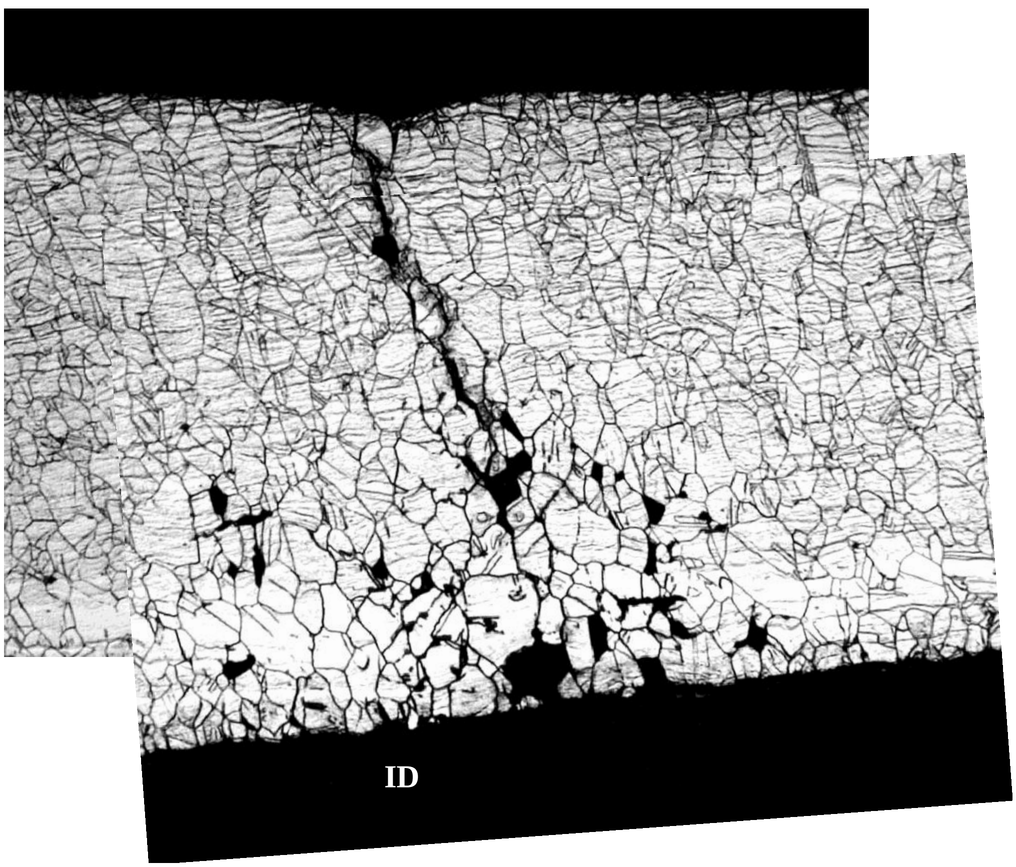

Figure 2. Intergranular SCC, black voids where grains were removed, ID-initiated SCC. 50x.

Low-melting point species of Zn, Pb and Fe chloride will dissolve the protective oxide scales, which will promote fireside corrosion. This iron chloride has a relatively low boiling point, and therefore iron chloride vapors form in the superheater/reheater temperature range, and the corrosion is due to loss of iron as a vapor. With reducing conditions, a mixture of chromium/iron oxides and sulfides forms on the OD surface, which exacerbates the wastage rates.

Another problem associated with cold-working (bending and swaging) of austenitic stainless steel tubes during fabrication is that this can lead to premature failure when the tube operates within the creep range. Cold-forming, such as bending and swaging of austenitic stainless steels during fabrication, can lead to premature failures when tubes operate within creep range. The reduced ductility due to precipitation is known as strain-induced precipitation hardening (SIPH). During cold-work, the alloying elements such as Cb/Nb, Ti and N precipitate at the grain boundaries, resulting in reduced ductility. The cold work of these materials increases both the strength and hardness, but reduces the ductility. At low temperatures, the reduced ductility is compensated by the improved strength/hardness. As operating temperatures rise into the creep regime, premature cracking in the cold-worked material may occur. These conditions are exacerbated by notches, attachments, and other stress-concentrating factors. SIPH adversely affects the creep ductility. In solution-treated materials when a grain-boundary creep crack develops, the growth or extension of the crack is slowed or blunted by the soft and ductile neighboring austenite grains. The deformation energy of the movement of the grain boundary crack is converted into plastic deformation in the crystals preceding the crack. In cold-worked material, the ability of the austenite grains to blunt the crack growth by energy absorption is diminished. Cold-worked grains are less ductile and can no longer "bend" to prevent further crack movement. Characteristics of these failures are intergranular cracking, no significant plastic deformation, deformation twins in the austenitic grains and no significant wall loss. **Figures 3** and **4** illustrate the fracture morphology of a SIPH failure. At a higher magnification of the crack tip in **Figure 5**, deformation twins can be seen. These are from cold work during tube bending.

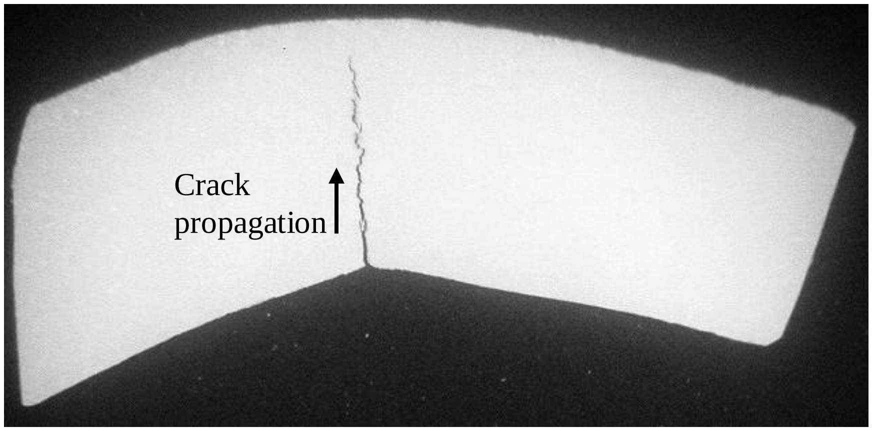

Figure 3. Macroscopic view

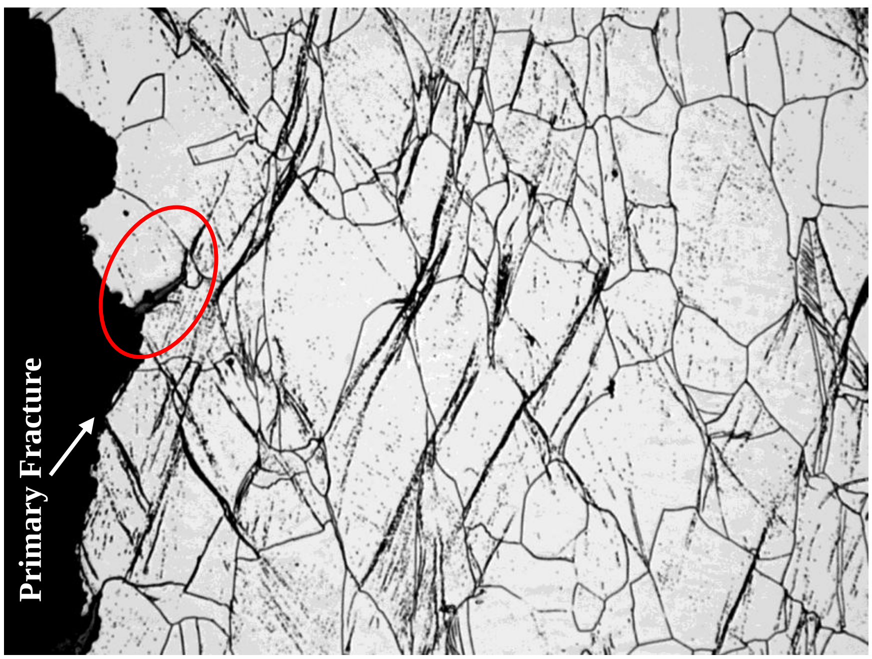

Figure 4. SIPH, primary fracture face, mid-wall. 200x.

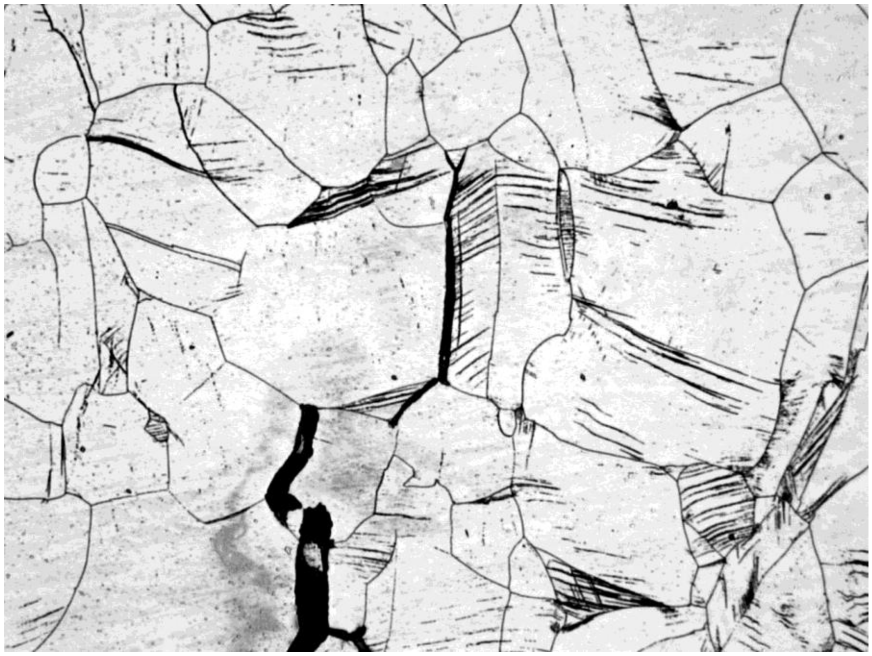

Figure 5. Deformation
twins, crack tip. 400x.

Drum levels and the condition of attemperator sprays should be checked periodically to reduce contamination. Higher drum levels may cause corrosive species to enter the high-temperature superheaters. Attemperators should spray high-quality, chlorine-free mist, and not spray water like a fire hose, which often results in thermal fatigue cracking at the ID surface. Periodic visual inspections are required to eliminate unintentional loading due to sagging, restraints or defective support systems. ASME PG-19 indicates austenitic tubes shall be heat treated if the forming strain is 10% or more, dependent on the tube design temperature, to reduce the risk associated with SCC and SIPH in the high temperature environment.