View From The Penthouse

The DNFM Quarterly Newsletter

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Creep and Remaining Life

The high-temperature components, superheater and reheater tubes, fail by a creep or stress-rupture mechanism, at the end of their service life. Fuel-ash corrosion may have reduced the wall thickness so the onset of creep failures occurs sooner than expected. In any event, a determination of the useful remaining life or material condition assessment is made to assure replacement before failures begin to occur. The question is, “What are the metallurgical features that indicate the initiation of creep damage well before potential failures are likely?”

Creep is defined as time-dependent deformation at elevated temperatures. The ASME Boiler and Pressure Vessel Code provides allowable stresses for all boiler materials used in the creep range. One of the criteria used for determination of these allowable stress values is 1% creep expansion or deformation in 100,000 hours of service. Thus, the Code recognizes that over the operating life some creep deformation will occur.

Fuel-ash corrosion or oxidation may reduce wall thickness and increase hoop stress. Steam reacts with steel, forming iron oxide, and covers the ID surface of all boiler tubes. Since the thermal conductivity of iron oxide is less than steel, these steam-side scales act as an insulating barrier to heat flow. The net effect is to raise tube metal temperatures. The combination of increased metal temperature and reduced wall thickness promotes early tube failures. The local heat flux also plays a significant role as the metal temperature is a function of heat flux. Thus, there is a wide variation in the metallurgical condition of a superheater or reheater. A tube close to the roof seldom fails by creep and often contains no ash corrosion wastage; the same tube at the bottom of the radiant superheater pendant usually fails first and shows the most serious corrosion wastage.

In any material-condition assessment, the most distressed tubes and the highest heat-flux region should be examined first. Any single tube can show wide differences in metallurgical features. There are subtle changes within microstructure that occur during the creep deformation process. However, the first sign of creep damage is often the appearance of longitudinal cracks within the steam-side scale, see Fig. 1. Since the ductility of the steel is greater than the ductility of the steam-side magnetite layer, longitudinal cracks within this steam-side scale form as the oxide cannot expand with the steel.

Once a longitudinal crack forms in the ID oxide, the path between steam and steel is shortened. Continuing tube expansion due to creep deformation, the ID scale reforms at the crack. Locally, a cusp forms at the scale/metal interface, see Fig. 2. The sharp point acts as a stress raiser and intensifies the hoop stress at the cusp point. The stress is also slightly higher because the wall thickness is slightly less at the cusp. Depending on the circumstances on the fireside, similar longitudinal cracks may appear in the fireside scale. These OD cracks are more noticeable in gas-fired units, as fuel-ash corrosion may obscure these effects.

Often the first signs of creep damage within the steel microstructure are creep voids at these cusps. Less than 1/10 inch away from this damage, the microstructure shows no visible signs of distress. As the creep deformation continues, these OD cracks, ID cracks and creep damage fan out toward each other, see Fig. 3. Creep failures may then initiate at the ID as the stress intensification at the cusp tip is a greater factor than the higher temperature at the OD surface.

Ultimately, effective cross reduction or thickness of the tube wall is reduced to the point where the strength of the material is inadequate to contain the internal steam pressure and failure occurs. The time between the appearance of the first longitudinal cracks within the ID scale and final failure is, of course variable. It depends on the tube- metal operating temperature and whether there is OD tube wastage from ash corrosion or fly-ash erosion. The time is quite sensitive to actual operating temperature. Heat flux will be variable along the length of an individual tube. Thus one portion of the tube may show well-advanced creep damage; while 20’ away in the same tube, the microstructure shows no evidence of creep damage, not even longitudinal cracks in the ID scale.

Thus the estimation of remaining life and determination of creep damage is sensitive to the location within the boiler. Samples for evaluation should be removed from the highest heat flux regions of a superheater or reheater. If failures have occurred, samples from similar locations known to be “hot” should be included in the selected samples. Thermocouple measurement of steam temperature in individual tubes is helpful in evaluating the “hot” circuits. Steam-side scale-thickness measurements by ultrasonic techniques that do not require the removal of tubes may also be useful. However, to accurately assess the overall metallurgical condition, it is imperative to remove tube samples for careful metallurgical evaluation. Only by metallography can these steam-side scale cracks, cusps, and creep damage be accurately evaluated. Depending on the results, partial replacement of seriously degraded tubes rather than a complete replacement may be the best course of action.

Fig. 1

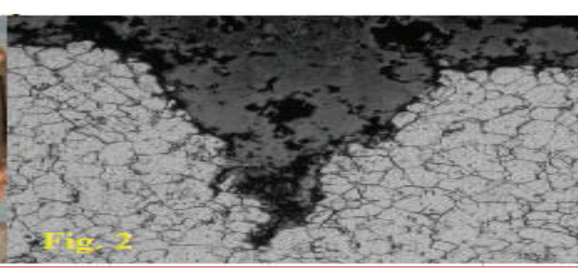

Fig. 2

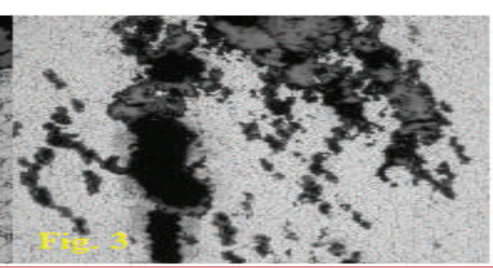

Fig. 3

If you have other ideas for topics, please email inquiries@davidnfrench.com