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A VIEW FROM THE PENTHOUSE: USEFUL INFORMATION FOR THE WORLD OF BOILERS

The steam pressure and temperature of utility boilers have not changed in thirty years. Subcritical units operate at about 2400 psig and 1005°F; supercritical, at around 4000 psig and 1005°F. Thus as the boilers installed in the 1950's approach the end of their original design life, there is no thermodynamic efficiency gain in replacement. New power plants will not generate electricity with fewer tons of coal per MWH, the problems of siting new facilities are numerous, and the cost of money is dear. It seems prudent, then, to repair or rebuild. In any project to replace a portion of a boiler or piping, the question of how far to go is central. Where is it safe to continue to use the original components and where is it necessary to install new parts? Some metallurgical background may shed light on this important subject.

The pressure parts of utility boilers are made from carbon steel, low alloy chromium-molybdenum ferritic steels, and 18-8 chromium-nickel austenitic stainless steels. In a few unusual cases 5-9 % chromium-molybdenum steels have been used in SH and RH. The oxidation limits for these alloys are:

Carbon steel (SA210, SA106)	850°F
Carbon - ½Mo (SA209)	900°F
1¼Cr - ½Mo (T11, P11)	1025°F
2¼Cr - 1Mo (T22, P22)	1075°F
18Cr - 8Ni (304, 321, 347)	1300°F

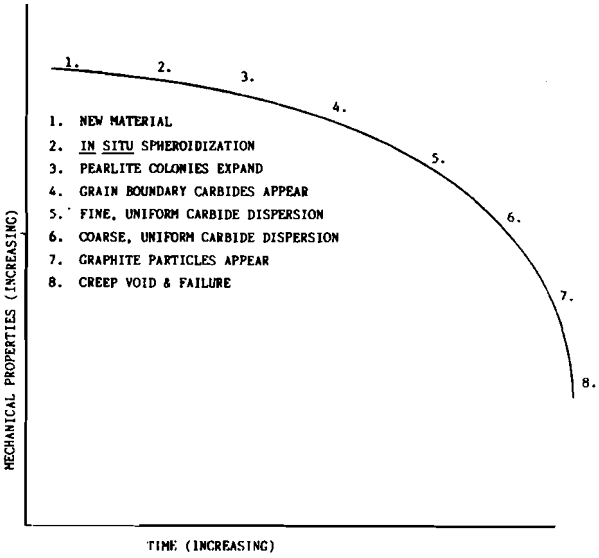
As part of the original design, changes in materials are made as estimated metal temperatures reach the oxidation limits given above. Thus waterwalls of sub-critical boilers are carbon steel, occasionally SA209; T11 or T22 is used for super-critical units. SH and RH alloys are T11, T22 and 18-8 stainless, depending on the temperature; and economisers are carbon steel. Downcomers are carbon steel and the main steam piping is usually 2¼Cr - 1Mo.

While it is obvious why oxidation limits exist for these alloys in elevated temperature service, there are less obvious but important microstructural changes that occur unseen by casual observation. Oxidation and corrosion of the fireside are easily observed; however even at temperatures below the specified oxidation limit, longterm microstructural degradation will affect the strength and fitness for continued service. Internal scale formation increases the tube metal temperature. Only careful metallurgical examination can determine the condition and suitability for further use of any particular component.

For plain carbon and low alloy ferritic steels that contain chromium and molybdenum, the expected microstructure for new materials is ferrite (nearly pure iron) and pearlite (a lamellar structure of alternating plates of ferrite and iron carbide). This normalized structure is made by slowly cooling the finished product from about 1650°F. In this condition the material is as strong as it will be. All microstructural changes that occur during service will decrease its strength.

From a thermodynamic view, a plate shape is unstable relative to a sphere. The internal energy of a phase is reduced by changing its shape to a sphere, the excess surface energy is the driving force for change. Other factors will promote the more rapid spheroidization of the carbide phase, for example high temperatures, applied stress, and the quenched and tempered microstructures in the heat-affected zones of welds. The result is a smaller surface to volume ratio and more stability. Thus ferrite and pearlite become ferrite and spheroidized carbides. For plain carbon and carbon + ½ molybdenum steels, the carbide phase, Fe_3C, is unstable and becomes graphite and ferrite. The addition of chromium as in T11 and T22 stabilizes the Fe_3C so that graphitization does not occur.

Concomitant with these microstructural changes is a decrease in mechanical properties, tensile strength, hardness, creep strength, etc; all are reduced. Schematically these changes may be represented by:



There are roughly eight stages to this degradation:

1. Ferrite + pearlite - new material
2. Ferrite + <u>in situ</u> spheroidization - the pearlite colonies are still well-defined but the plates of iron carbide have become spherical in shape.
3. Pearlite colonies retain their shape but expand in size.
4. Pearlite colonies are still visible but grain boundary carbides appear.
5. Ferrite + a dispersion of fine carbide particles uniformly spread throughout the structure.
6. The uniform dispersion of fine carbide particles agglomerate into a uniform dispersion of coarse particles.
7. Ferrite + graphite - the iron carbide decomposes into graphite. For alloys T11 and T22 this stage does not occur.
8. Creep voids - At elevated temperature, one of the longterm failure mechanisms of an alloy under stress is by creep, the slow deformation by sliding of one grain past its neighbors. As adjacent grains slip, voids form at the juncture of three grains. As deformation continues, these voids link along grain boundaries to form cracks, by grain boundary separation. By the time either creep voids or graphite are present in the microstructure, the safe useful life of the component is about over.

All of these transformations occur over a range of temperatures. However, what occurs in a short time at high temperature will occur in a longer time at a lower temperature. The Larson-Miller parameter P has been used to relate this time-temperature interchangeability for these microstructural changes:

$$P = T(20 + \log t)$$

where T is absolute temperature (°F + 460), "t" is time in hours and 20 is an empirical constant. Using this relationship it may be seen that what occurs in 20 years at 1050°F, will occur in just 8 years at 1075°F, a reduction of 60% for just 25°F increase in temperature. Thus any operating temperature increase over the design temperature will shorten the life of the component.

In doing life assessment, more than simple microstructural analysis is required. Since both stress and HAZ's promote graphitization, spheroidization, and creep cracking, MT or PT examinations should be done in the highly stressed welds of a header or piping. The design life is a function of the stress and temperature. A forty year old boiler whose actual operating stress is $\frac{1}{2}$ the ASME Code allowable stress is going to have a longer life than a thirty year old unit whose present operating stress is equal to the ASME Code allowable stress. While microstructural analysis is important it is not done without knowledge and understanding of the operating stresses, Code stresses, actual wall thicknesses, and present operating temperatures.

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