View From The Penthouse

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CREEP FAILURES

A creep failure is the final step in a long sequence of metallurgical changes as a high-temperature ferritic steel superheater or reheater tube comes to the end of "life". In 15 or 20 years or more in service, the tube metal temperature gradually rises as steam-side scale forms by reaction of steam with steel. Steam-side scale thicknesses average 1-1½ mils (0.001"-0.0015") per year. The oxide has a thermal conductivity of 5% that of the metal, and the net effect of this ID insulating layer is higher metal temperatures than the original design. These higher temperatures increase oxidation and corrosion rates and hasten the microstructural degradation.

Newly installed, carbon steel (i.e. SA210, SA178, SA192), carbon-molybdenum steels (all SA209 grades), or chromium-molybdenum alloy steels of SA213 T-2, T-11, T-12, or T-22, have a microstructure that is usually ferrite and pearlite. These alloys are often used in the normalized or normalized and tempered condition, although other heat-treatments are permitted. In this condition, these ferritic steels start life with a microstructure of ferrite and pearlite. Ferrite is iron with the alloying elements of chromium and/or molybdenum, among others, dissolved in the iron. That is, individual atoms of the alloying metals substitute for iron within the atomic arrangement of solid iron. This mixture of different metals with iron is called ferrite. The pearlite constituent is a sandwich structure made up of alternating layers of ferrite (the nearly pure iron) and iron carbides. Some of these alloying elements, mainly chromium, become part of the carbides, and effectively become an iron-chromium carbide. Thus, the shape of the carbide is that of a platelet or a blade, large in two dimensions and small in the third. For carbon steels similar to SA210 A-1, and the carbon-molybdenum steels (SA209), the as-new hardness will be in the Rockwell B mid-70's range, and in the chromium-molybdenum alloys of T-2, T-11, T-12, and T-22, the hardness is in the low 80's range, perhaps 82 or 83.

For carbon steels, microstructural degradation and creep failures occur at temperatures above about 800°F. For the carbon-molybdenum alloys, that temperature is higher, about 850°F. For the chromium-molybdenum alloys, the temperature is still higher, perhaps 900° to 1000°F, depending on the alloy content, lower for T-2 and higher for T-22. At these temperatures, the blade-like appearance of the iron carbide changes to a spherical shape, a process called *"spheroidization"*. For carbon and carbon-molybdenum steels, the iron carbide is also unstable relative to the decomposition into ferrite and graphite, a process known as *'graphitization"*. The addition of about 0.5% chromium to carbon steel, T-2 for one example, stabilizes the iron carbide. These chromium-containing steels do not graphitize.

Concomitant with these changes in microstructure is a decrease in the mechanical strength and hardness. For example, by the time an SA210 A-1 or SA209 steel is fully graphitized, the hardness has dropped from the mid 70's Rockwell B, to perhaps 40 or 50. Hardnesses below 40 have been measured on carbon steels erroneously used where T-22 was specified. In one recent example, a reheater stub tube was made of carbon steel similar to SA192. In this case, the design stress appears to be correct for the 1000°F temperature (based on the tube size, OD, and wall, and reheater pressure). It failed, however, after 30 years of service with the usual creep-rupture mechanism, perhaps exacerbated by differential expansion and thermal fatigue. The microstructure was essentially pure ferrite, and the failure of intergranular cracking is characteristic of creep failures. Since reheaters operate at very low pressure, the hoop stress within this sample was quite low, and the carbon steel gave satisfactory service for three decades. It was however, a near classic, end-of-life failure: the hardness measured less than Rockwell B 40, and the micro-structure contained essentially no visible carbide particles. The structure was not graphitized, which suggests 30 years, perhaps 225,000 hours, at 1000°F was long enough to decarburize the tube.

CREEP FAILURES (*Continued*)

Similar failures would occur for the chromium-molybdenum steels at elevated temperatures; that is, for these steels above 900 to 1000°F. The microstructures become fully spheroidized, a microstructure of ferrite and iron-carbide spheroids; and the strength and hardness decrease as with carbon steels, but not to the same ultimate low level. The lowest hardness measured in areas of these "old" tubes without visible creep damage is in the low 60's, Rockwell B. Chromium and molybdenum harden and strengthen the ferrite, witness the difference in the lowest hardness measure, high 30's vs low 60's RB. The microstructural appearance to the failures is also similar, intergranular cracking. Creep failures are characteristically similar, regardless of the alloy, as the grain-boundary strength is less than the strength of the ferrite grains at elevated temperatures. Thus the grain boundaries separate, starting as small voids, where three or more ferrite grains come together, and grow to become intergranular cracking and ultimately failure. These end-of-useful life failures all have low hardness: for the chromium-molybdenum steels in the mid 60's range, and fully spheroidized microstructures.

In all these microstructural changes, time and temperature are interconnected. Changes that occur over a few years at low temperatures will develop over a few hundred or thousand hours at high temperatures. For these reasons operating temperatures above the design condition decrease life dramatically. An increase of only 50°F will shorten expected life by up to 80%.

However, there is a class of creep failures that come about not because of long-term operation at elevated temperature, but relatively short-term, high-stress conditions at temperature or times that leave the microstructures and hardnesses only slightly changed from the initial condition. The most obvious case of this nature is soot-blower erosion. Over a relatively short period of time the wastage rates are high enough to change the stress conditions and the local hoop stress may double, or more, from the design conditions.

Table I below gives some approximate strength data for SA213 T-11 material. Similar changes in the stress to cause creep failures occur for all the steels under discussion. The data provides the stress at which failure will occur in 100, 1,000, 10,000, and 100,000 hours at 1000°F. (For a comparison, the ASME Code Allowable stress for T-11 at 1000°F is 6,300 psi.)

TABLE I (T-11 Material)

TIME TO FAILURE, Hrs.	STRESS, PSI
100	40,000
1,000	28,000
10,000	15,000
100,000	9,000
TEST TEMPERATURE = 1,000°F	

Under a circumstance with rapid wastage rates, either from erosion or severe fuel-ash corrosion, the wall thickness will be reduced, or the stress will increase until failure occurs. These failures will be by a creep (or stress rupture) mechanism, and the microstructures at the failure edge will show that evidence. Intergranular cracking and creep voids near the fracture lip are prevalent. However, the balance of the tube away from the localized wastage will have mechanical properties, particularly hardness, that may be only slightly less than as installed. Thus, it is imperative that the root cause of the failure be identified. A metallurgical report that simply says that the failure is by creep may miss the most significant feature, and that is, localized wastage at the root cause.