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

ERUMPENT FAILURES

The dynamic balance between heat generation and fluid flow when in proper equilibrium leads to safe metal temperatures that assure long boiler-tube life. When the fluid flow is interrupted by a partial or total blockage tube-metal temperatures can rise to 1600°F or so in a few minutes. At this temperature failures follow in very short order. Failures of this type are usually referred to as "short-term overheating."

These failures are characterized by a wide-open burst with fracture edges drawn to near knife-edge condition. There is considerable ductility to the rupture, and the appearance is referred to sometimes as a "fishmouth failure." (See Figure 1)

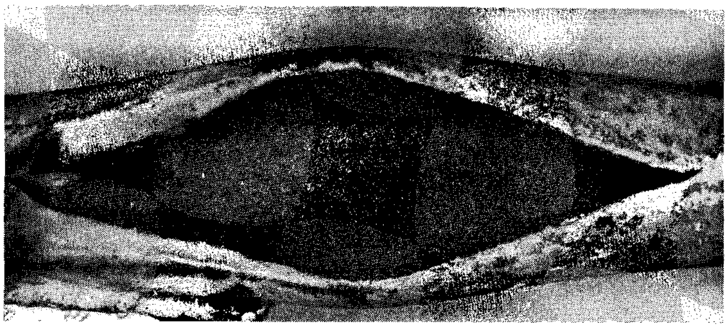

Figure 1. A fishmouth failure

In order to fully explain these erumpent failures, two features to carbon and low-alloy steels need to be discussed. First, as temperature increases, the tensile strength decreases. When the hoop stress from the steam pressure is approximately equal to the high-temperature tensile strength, failure follows. Equation 1 gives the hoop stress.

$$S = \frac{P(D-W)}{2W} \qquad \text{EQ 1}$$

where S = hoop stress, psi
P = steam pressure, psi
D = tube diameter, inch
W = tube wall, inch

Table I lists the elevated temperature strengths of carbon steel (SA-210), $1\frac{1}{4}$Cr-$\frac{1}{2}$Mo (T-11) and $2\frac{1}{4}$Cr-1Mo (T-22) materials commonly used in boilers.

TABLE I. ELEVATED TEMPERATURE STRENGTHS

TEMP, °F	TENSILE STRENGTHS, KSI		
	SA-210	T-11	T-22
500°	63.8	70.0	67.0
700°	57.0	68.0	64.2
900°	44.0	64.0	60.0
1100°	25.2	44.0	41.0
1300°	9.0	18.0	22.0

The second important feature is the alletropic transformation inherent to low-alloy and carbon steels. At room temperature the crystallographic structure of ferritic steel is body-centered cubic (BCC). The individual atoms of iron arrange themselves on a cubic lattice with an atom at the corner of each cube and one at the center of the cube. The BCC form of iron is called "ferrite." At high temperatures the crystallographic arrangement is face-centered cubic (FCC). In this case, individual atoms of iron arrange themselves on the corner of a cube with additional atoms in the middle of the 6 faces of the cube. The FCC form of iron is called "austenite."

Further, the solubility of carbon in these two forms is different. At high temperature, the FCC lattice will dissolve up to 2% carbon, while the BCC lattice will dissolve less than 0.02% carbon. During steel making and fabrication of these materials, the cooling rate from the high-temperature crystallographic form of FCC to the room temperature crystallographic form of BCC is slow enough to give the carbon atoms adequate time to un-mix. Since the BCC lattice will accomodate only 0.02%C, another constituent forms of higher carbon content. This other phase is iron carbide, Fe_3C, called "cementite." The normal appearance of mixtures of ferrite and iron carbide is lamellar pearlite, see Figure 2. The amount of pearlite in the microstructure depends on the %C. High-carbon steels have more pearlite than low-carbon steels. As cooling rates from austenite to ferrite and

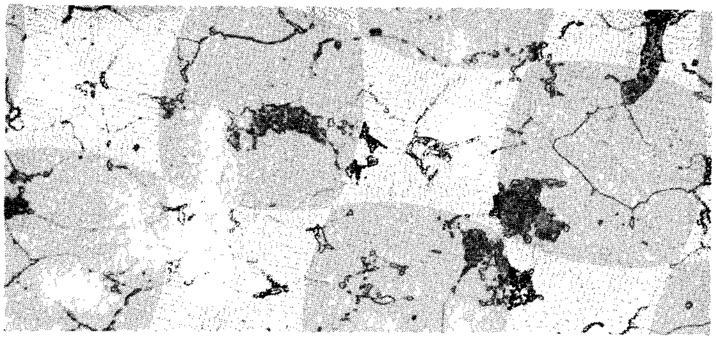

Figure 2. Lamellar pearlite and ferrite

pearlite are increased, there is inadequate time for carbon un-mixing. Thus the microstructure at room temperature will be a quenched or rapidly cooled structure, either bainite or martensite.

The temperature at which the BCC lattice transforms to the FCC lattice is known as the "lower-critical transformation temperature" (LCTT). This particular temperature is a function of the alloy content of the steel, as shown in Table II.

TABLE II. LOWER CRITICAL TRANSFORMATION TEMPERATURE, LCTT

MATERIAL	TEMP., °F
Carbon steel	1340°
C + $\frac{1}{2}$Mo	1350°
T-11, T-12	1430°
T-22, T-3	1480°
T-5	1505°
T-7	1520°
T-9	1490°

When failures occur at temperatures above the LCTT, the microstructure will reflect this peak temperature. When the tube finally fails the eruption of steam or water through the failure rapidly cools the steel to the temperature of the steam or water. When the temperature is above LCTT, the microstructure will be rapidly cooled from the FCC lattice configuration to bainite as shown in Figure 3.

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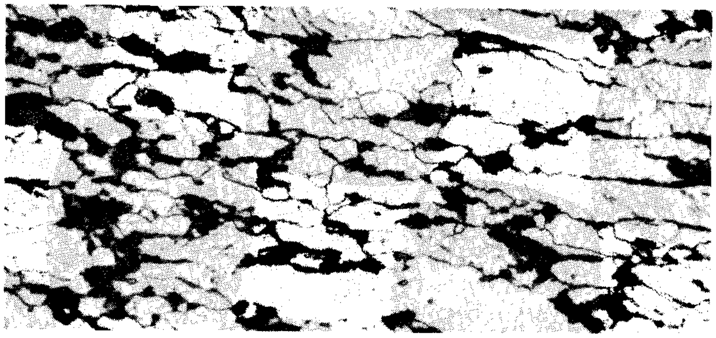

Figure 3. Bainite and ferrite

Thus there are a couple of ways to estimate the peak metal temperature at the moment of failure. A) The hoop stress is about equal to the strength. Thus a calculation of stress from EQ 1 is equated with the tensile strength given in Table II. B) For temperatures above the LCTT the mixtures of ferrite and bainite will indicate that the temperature was above LCTT.

The causes of erumpent failures are relatively simple to enumerate. Any circumstance that totally or partially blocks the flow of fluid will lead to a rapid increase in metal temperatures. During start-up, condensate in a pendant superheater or reheater, for example, will allow little or no steam flow through that particular tube. Since there are many tubes within a superheater or reheater, steam will flow through all but the tube with condensate. That tube will be rapidly heated toward the flue-gas temperature and an erumpent failure will follow. For waterwall tubes, flame impingement will lead to an excessive heat-flux which will cause the formation of steam blankets on the water side. The steam blanket is an effective insulator and the tube temperature will rise to failure in a short period of time. Corrosion wastage will lead to a thin-wall tube which will be able to tolerate less of a temperature rise. During start-up, for example erumpent failures will follow because the wall thickness has been reduced substantially. (See VOL. II, No. 3 of this newsletter.) On rare occations there may be a defect in the electric resistance weld that would lead to reduced effective wall thickness and a wide-open burst would follow. Finally, foreign material may be left in the tube that effectively blocks the steam flow and leads to these high-temperature, erumpent failures.

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