View from the Penthouse

The DNFM Technical News Letter

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Superheaters and reheaters operate at temperatures which may susceptible to creep failures in most of the commonly used alloys. Creep may be defined as a time-dependent strain or deformation at constant stress at elevated temperature. The temperature at which creep becomes an important design consideration depends on the particular alloy. For the low-carbon steels without any alloying elements besides manganese, grades similar to SA192, creep failures may be expected at metal temperatures as low as 800°F to 850°F. On the other hand, for the austenitic stainless steels similar to 304H, 321H, and 347H, the onset of creep occurs at temperatures above about 1000°F and is certainly a factor at 1100°F.

The grain boundary region exhibits atomic disorder, where individual atoms are less strongly bonded to their neighbors than are atoms within the crystal. At room temperature, this grain-boundary weakness may be seen in preferential corrosion along grain boundaries and is manifested by simple etching of metallographic samples. At elevated temperatures, the grain-boundary weakness may be seen in intergranular oxidation, and the strength of the grain boundary is less than the tensile strength of the individual grains. The temperature where the strength of the grain boundary equals the strength of the grain is known as the "equi-cohesive temperature". This temperature may be taken as the onset of creep.

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. This loss of creep ductility leads to premature failures that have the following characteristics:

- Failures are always intergranular
- Little gross distortion of the component
- The austenite grains will display evidence of cold work (deformation twins)
- Virtually no ductility on the fracture surface

Figure 1 illustrates the longitudinal cracking in ASME SA-213 TP310HCb stainless steel tube. It failed within 18 months of service. **Figure 2** is a macroscopic view of a metallurgical specimen removed from the tube bend. Note that the crack initiated at the tube ID where there was a "kink" formed during fabrication which acted as a stress raiser. The crack was intergranular and thick-edged as shown in **Figures 3** and **4**. At a higher magnification, in **Fig. 4**, deformation twins can be seen at the tip of the crack. These twins are from cold work during tube bending. Ring samples, **Fig. 5**, were sectioned from the tube for dimensional and hardness measurements. The ring section removed from the bend area had distorted. Note the significant difference in hardness between the rings removed from the bend and away from it. The higher hardness at the tube bend was due to strain hardening resulting from tube bending.

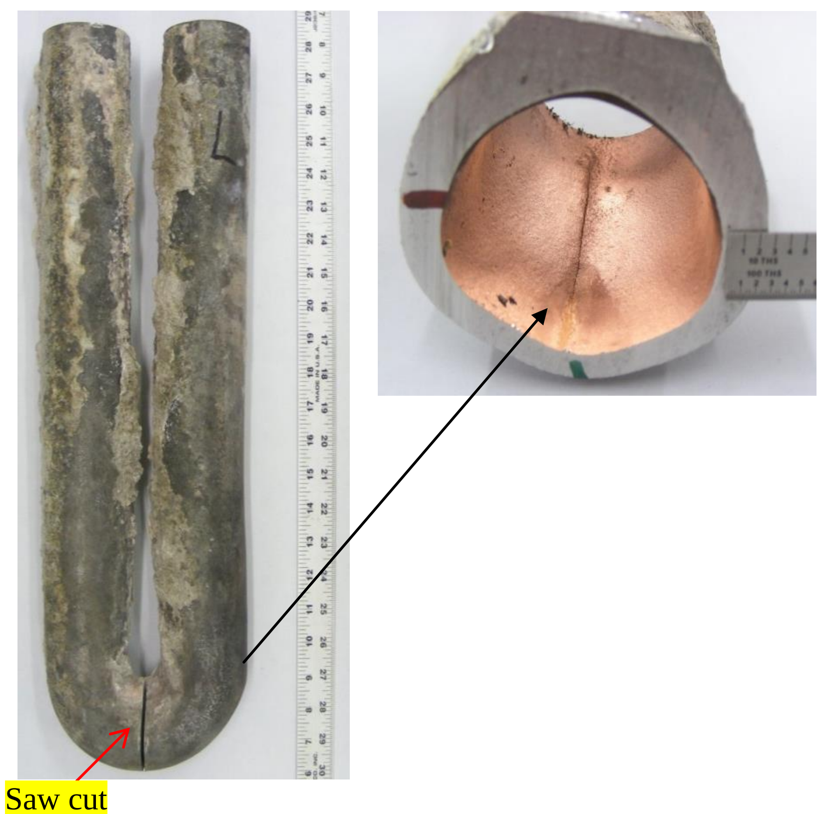

Figure 1. Longitudinal cracking at the tube bend and the ID view

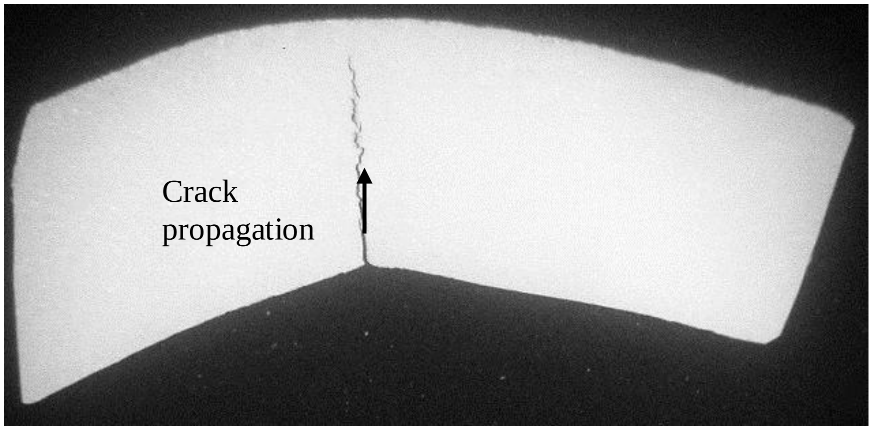

Figure 2. Macroscopic view

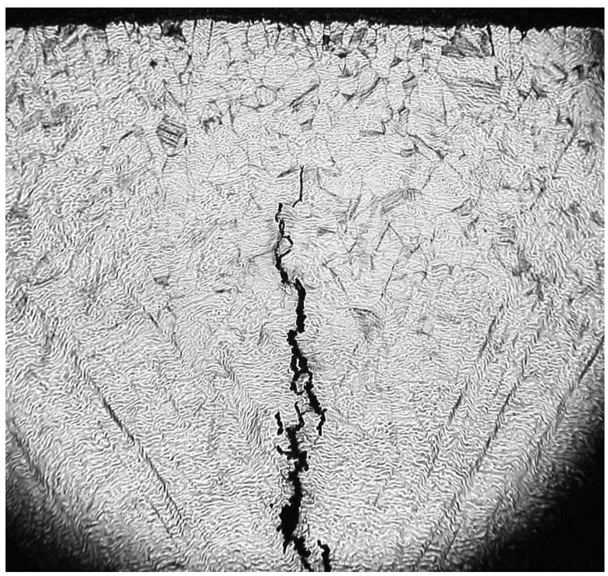

Figure 3. Intergranular cracking from the ID surface, 30x

The ASME Code (Section I PG-19) indicates the necessity of solution heat treatment in cold-forming components made with austenitic stainless steels used in the pressure part applications. The failures resulting from SIPH typically occur during initial periods of operation, usually within 5 years of operation when tubes are operating within the creep range. The SIPH failures usually do not occur after that threshold period. This is primarily due to grain relaxation and/or diffusion of grain boundary precipitates during that period. This is a slow rate of solution treatment; it occurs at a relatively low-temperature, but will take a prolonged time when compared to the solution treatment. Therefore, the failures from SIPH can be reduced by solution-treating after cold-working.

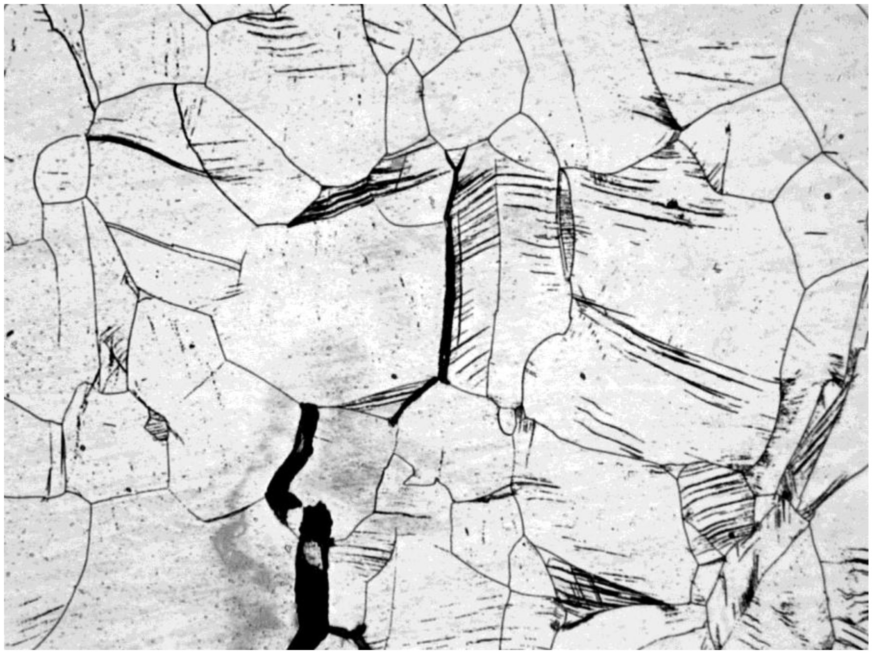

Figure 4. SIPH, deformation twins, intergranular cracking, 200x

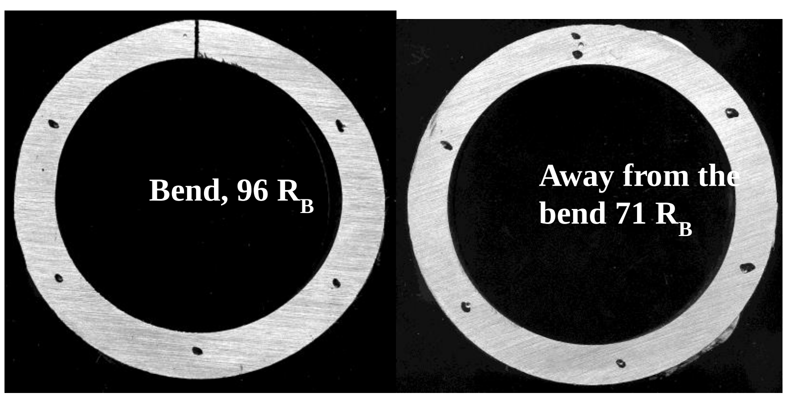

Figure 5. Removed rings from the tube, ~1x