Bulletin Board

DNFM is pleased to announce a new addition to our team. Nathan Huster, a recent graduate from the University of Kentucky, has come aboard. Nathan holds a Bachelor of Science degree in Materials Science and Engineering. Prior to joining DNFM, he served as a research assistant at the University of Kentucky's Center for Applied Energy Research, contributing to various materials projects. To gain valuable hands-on experience, Mr. Huster has assisted in sample preparation in the lab, as well as traveled with UDC Field Inspection Teams training in the area of boiler inspection.

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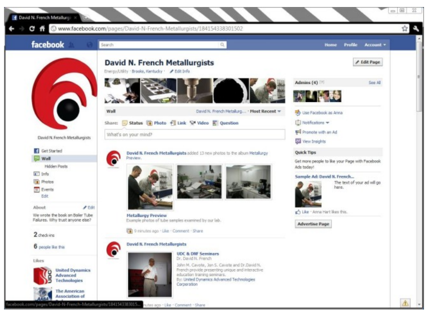

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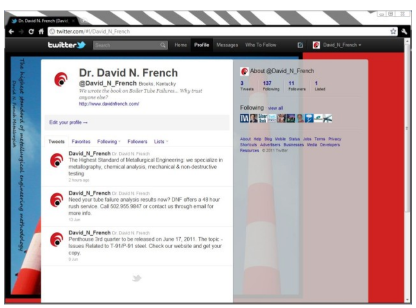

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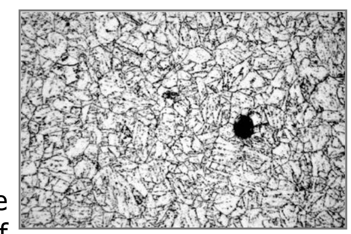
SUMMER 2011

Issues Related to T-91/P-91 Steel

P-91 Boiler Tubing

T-91 and P-91 are the oldest of a new class of high-strength ferritic steels approved for use in boilers and pressure vessels. These newer alloys develop high strength through heat treatment, a rapid cooling or quenching to form martensite, followed by tempering to improve ductility. As a result, these alloys offer much higher allowable stresses so that thinner sections provide adequate strength for high-temperature service. The thinner sections, such as 2 ½" vs. 4" for high pressure piping, mean less welding during fabrication and lighter dead weight loads to support. Most of the applications thus far have been in substituting for P-22/T-22. The primary advantages of the T91 materials over conventional low-alloy steels are the higher allowable stress values for a given temperature and improved oxidation, corrosion, creep and fatigue resistance. Creep strength of T91 steel is obtainable via a quenching process followed by controlled tempering treatment. Elements such as niobium and vanadium in the steel precipitate at defect sites; this is known as the "pinning effect".



Tempered Martensitic Microstructure
3 yr-old T-91 SH division wall tube. (not a concern at such a high magnification. 800x)

Now that T-91 and P-91 have been in service for nearly 30 years, some shortcomings have become apparent. A perusal of the allowable stress values for T-91 shows a drop off in strength above about 1150 ^{o}F. Thus, start-up conditions where superheaters, and especially reheaters, may experience metal temperatures above 1200 ^{o}F, lead to over-tempering and loss of

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Issues Related to T-91/P-91 Steel (continued)

creep strength. The break down of a tempered martensite microstructure into ferrite and spheroidized carbide begins at about 1110 °F, after an extended time.

Welding for these heat treated, high-strength ferritic alloys requires both a preheat (300 to 500 °F depending on section thickness) and a post-weld heat treatment (PWHT) at a minimum temperature of 1350 °F. The time-at-temperature is determined by the weld thickness (for example, the components less than or equal to five inches thick, 1 hour per inch) with a minimum time of 30 minutes. The pre-heat prevents cracking in the martensitic heat-affected zone (HAZ) and the PWHT tempers the weld metal and HAZ to regain the "pinning effect".

During welding, the temperature varies from the melting point of the steel to room temperature. The HAZ is defined as the zone next to the fusion line at the edge of the weld metal that has been heated high enough to form austenite, i.e., above the lower critical transformation temperature. Upon cooling the austenite transforms to martensite. Next to the region of microstructural transformation, there is an area heated to just below the austenite formation temperature, but above the tempering temperature of the tube when manufactured. This region suffers, in effect, over-tempering by the welding. The over-tempering softens the tempered martensite and results in the associated loss of both tensile and creep strength. This region of low strength is subject to failure during service.

This over-tempered region is an especially serious problem next to a longitudinal weld.

In recent months, our lab has investigated several failures in T-91 tubes which highlight the problem.

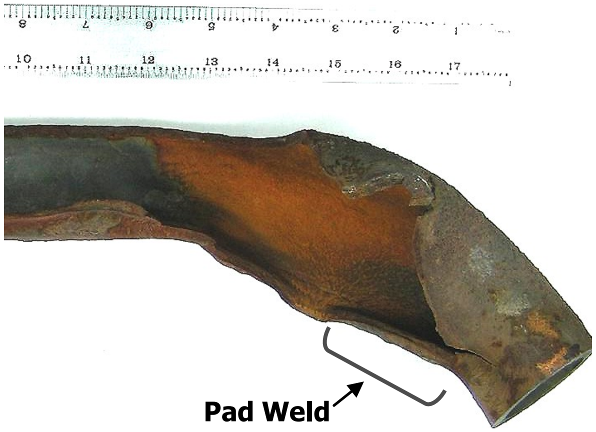

Figure 1

Figure 1 - Illustrates a failed T-91 tube which had been pad welded to repair erosion wastage. The failure occurred a short distance from the fusion line.

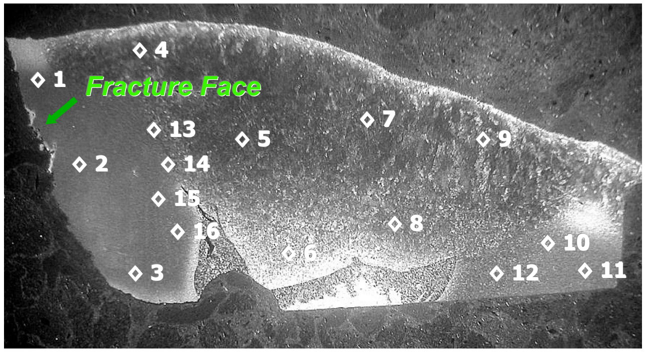

Figure 2

Figure 2 - Displays the fusion line exactly where the over-tempered zone would be expected. The hardness measurements are reasonably uniform confirming proper pre-weld and post-weld heat treatment of the material.

Figure 3

Other problems were noted on T-91 at welds between alignment clips and the tube. **Figure 3 -** Refers to this problem providing an example of how the space between the clip and tube can become filled with oxide or ash, and the clip forced off the tube. **Figure 4** below is the micro where the oxide wedge acts as a stress raiser to separate the clip from the tube.

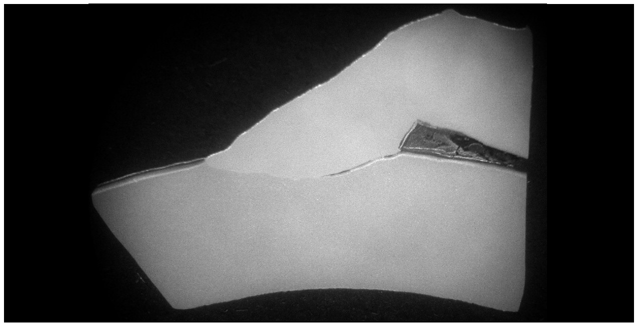

Figure 4

These failures are particularly difficult to repair because of the ASME Code requirement for both preheat and a 1350 °F PWHT.

As more of these long-term problems with T-91 tubing develop and are repaired, the use of 304H stainless steel for corrosion resistance and the return to T-22 may become the norm once again.