A View from the Penthouse

The DNFM Technical News Letter

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Under the Clean Air Act amendments, it is required to control the nitrogen oxides generally referenced as NOx (NO or NO_2) before releasing them into the atmosphere. NOx emissions have several adverse effects on human health and on the environment. NOx reacts with moisture to form nitric acid vapor, which causes acid rain. NOx reacts with volatile organic compounds in the presence of sunlight to form ozone. Ozone can cause adverse effects on human health such as lung disorders and respiratory issues. Ozone can also be transported by wind currents and cause health impacts in locations away from its origin. NOx is primarily divided into three groups in the combustion process: fuel NOx, thermal NOx and prompt NOx. Thermal NOx is highly dependent on temperature, and is the most relevant source when burning fossil fuels. It typically forms at about 2900°F. Thermal NOx refers to NOx formed through high temperature oxidation of the nitrogen found in combustion air. The formation rate is primarily a function of temperature and the residence time of nitrogen at that temperature. Fuel NOx forms when burning nitrogen-bearing fuels, such as coal and oil. The contribution of prompt NOx, which forms when atmospheric nitrogen reacts with radicals derived from the fuel, is normally considered negligible.

There are several strategies used in controlling the NOx emissions in fossil-fuel fired units during and after combustion processes. Staged combustion with or without over-fire air (OFA) and/or secondary over-fire air (SOFA) is a widely used and proven technology which reduces emissions during the combustion process. The idea behind staged combustion is to limit the amount of excess air (oxygen) in the air-fuel mixture so that the amount of free oxygen which ties up with nitrogen during combustion is limited. In this process, the peak temperatures are also reduced, resulting in further NOx reduction. Urea or ammonia is injected into the flue gas stream as a post-combustion emission control in selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR). These chemicals react with NOx to produce elemental nitrogen and water vapor.

There are several adverse effects on pressure parts when staged combustion is utilized. Oxygen starved combustion is highly susceptible to corrosion. The reducing conditions formed during staged combustion promote the formation of hydrogen sulfides and porous metallic sulfides on the pressure parts. Note that these sulfide scales are more porous and less protective than oxides. Reducing conditions also promote carburization of T91 (**Fig. 1**) and stainless steel, resulting in loss of corrosion/oxidation resistance.

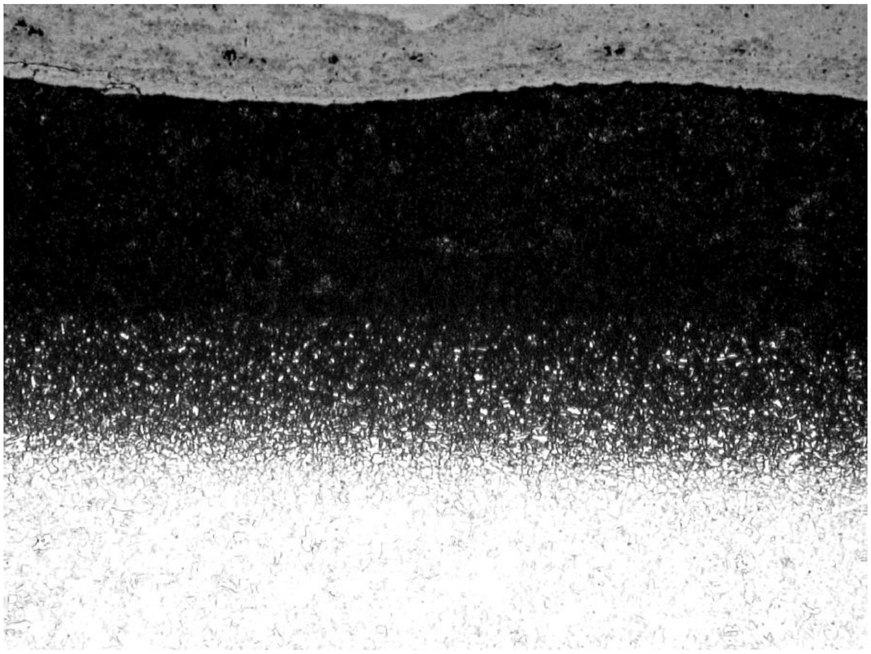

Figure 1. Carburization of T91 steel tube, 200x

The addition of OFAs and SOFAs likely promote flame impingement and secondary combustion issues, resulting in localized overheating issues and higher furnace exit-gas temperature (FEGT). The rise in FEGT may lead to several issues such as plugging of vertical pendants with ash deposits (**Fig. 2**), hotash corrosion, sagging and bowing of pendants, over tempering of creep-strength-enhanced ferritic steels, or reducing creep life of the superheater/reheater tubes and dissimilar-metal welds (DMWs). In pressure parts, a metallurgical joint between the austenitic steels and ferritic steels is known as dissimilar-metal weld (DMW), as shown in **Fig. 3**. DMWs are frequently used in high temperature SH and RH circuits due to the material transitions. The DMW is one of several locations subjected to creep fatigue damage. The finite life of a DMW is further reduced with increasing FEGTs. Although creep life is a function of time, temperature and stress, temperature plays a major role in the remaining creep life.

Figure 2. Plugging of pendant sections in a coal-fired boiler

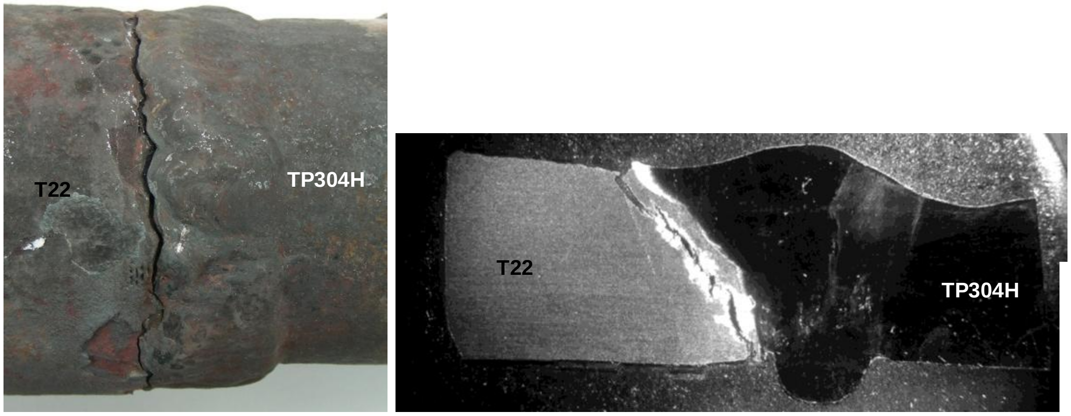

Figure 3. DMW failure in the heat-affected zone of T22 steel

Modern plants are fabricated with creep-strength-enhanced ferritic (CSEF) steels because of their superior properties over their ancestor grades such as T22 and T11. Note that metal temperatures above about 1200°F lead to over-tempering and loss of creep strength in CSEFs. Higher FEGTs may cause over tempering in CSEF steels, resulting in premature failures. Fireside corrosion increases with higher superheater and reheater temperatures. Fireside corrosion is also referred to hotash corrosion. The low-melting species which form on the tube surface dissolve the protective oxides, resulting in severe tube wastage. High temperatures (about 1000°F) in the superheater/reheater favor the formation of these low-melting compounds. In coal fired-units, the corrosion rate continues to increase as the temperature increases (up to about 1250°F). The secondary combustion also increases the tube metal temperatures, promoting hotash corrosion.

The typical microstructure of carbon steel is ferrite and perlite. In carbon or carbon-molybdenum steels, the iron carbides are unstable when exposed to temperatures beyond

800°F for a prolonged period and therefore decompose into ferrite and graphite. Carbon diffuses from pearlite to form graphite particles, **Fig. 4**. These graphite particles reduce the strength of the steel and make the material susceptible to brittle failures, as shown in **Fig. 5**. These materials are typically used in primary superheaters where the temperatures are expected to be below 800°F. However, it is likely that secondary combustion pushes the temperature in those regions beyond the sweet spots, causing premature failures. Note that an operating temperature of 50°F beyond the design temperature reduces the creep life significantly.

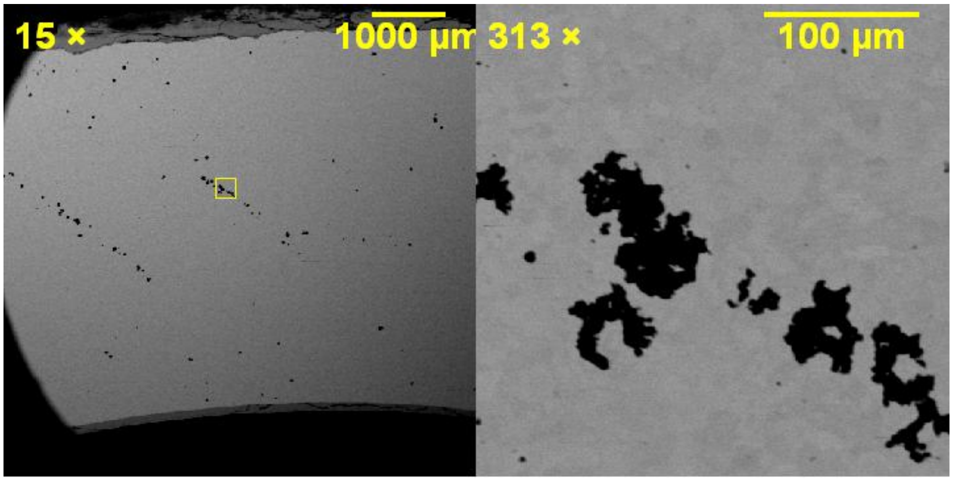

Figure 4. Chain graphitization in C-Mo steel, SEM image

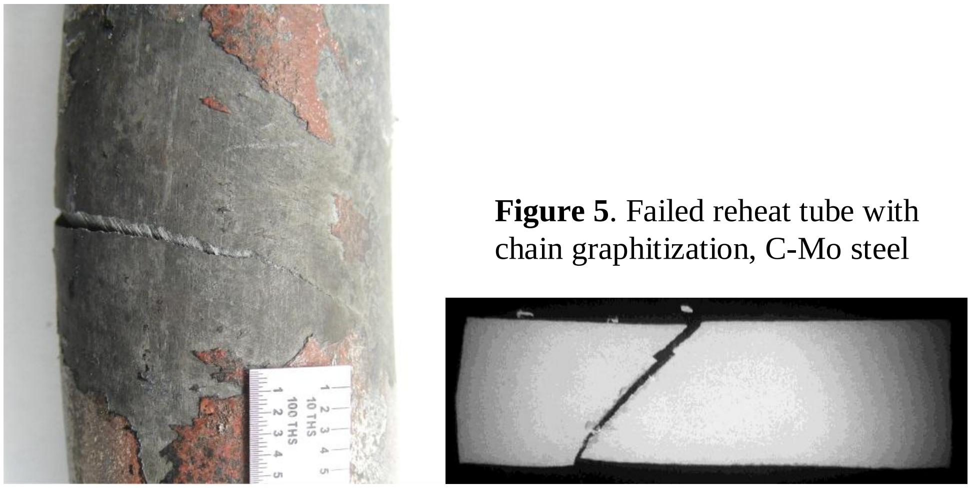

Figure 5. Failed reheat tube with chain graphitization, C-Mo steel

It is evident that secondary combustion causes several issues in the water walls as well as in the superheat/reheat circuits. Inconel overlays, specifically Inconel 622, provide satisfactory life on water walls, resulting in reduced tube wastage. Better mixing of coal and increasing coal fineness reduce carbon carryover, which minimizes the secondary combustion issues. According to the modern standards in coal-fired units, the following coal fineness is required: at least 75% of weight should pass through Sieve #200 (0.0029" opening) and 0-0.2% weight may remain in Sieve #50 (0.0117"). Coarse coal tends to increase carbon carryover and loss-of-ignition (LOI). Reducing the coal particle size increases the surface area to mass ratio, effectively making the coal more reactive. Consequently, improved coal fineness will improve a plant's efficiency as well as reduce emissions. The DMW joints can be relocated to a position where they are exposed to lower temperatures. Also, the use of DMWs made with nickel-based filler metal (P87 or Inconel) is recommended, specifically in CSEFs. Nickel-based filler metal compromises the differences in thermal expansion between stainless steel and ferritic steel. Sootblowers are often used heavily when higher FEGT exists. Therefore, sootblower retrofits and "intelligent" sootblowing systems may be adopted to increase efficiency and reliability. Along with this long list of operational and maintenance strategies it may be necessary to consider material upgrades to mitigate long-term issues.