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

STAINLESS STEELS

Stainless steels have been used for pressure parts since the 1950's. These alloys have excellent high temperature strength and resistance to flue gas or ash corrosion. Since there are significant differences between the 304, 321 or 347 grades used and the T-22, T-5, and T-9 materials they replace, some discussion is in order.

The first stainless steels were invented nearly 100 years ago. They were a result of research on iron-chromium alloys. Systematic studies on the effects of increasing amounts of chromium on the rust resistance of iron revealed that at about 12 - 13% Cr, the alloys would not show the red-brown iron oxide when left out in the weather. Hence they were stain-free and referred to as stainless steels. In fact, many corrosion problems of stainless steel may be explained by this early experimental observation, the abrupt change in corrosion resistance at about 12% Cr. Above 12% Cr, alloys show excellent corrosion resistance and below 12% Cr, the corrosion resistance is more ordinary.

To better understand some of the differences between carbon and low alloy steels and the stainless grades, we begin our explanation with the arrangement of metal atoms in a solid crystal. In the temperature range of interest, up to about 1800°F, there are two crystallographic arrangements for the low alloy and plain carbon steels. At low temperatures, below about 1340°F, the metal atoms arrange themselves on the 8 corners of a cube with one more atom at the cube center. Such an arrangement is called "body centered cubic" BCC. In steels the BCC atomic arrangement is called ferrite. Steels that contain mainly ferrite at room temperature are referred to as ferritic alloys. At temperatures above about 1600°F, the metal atoms are arranged on the 8 corners of a cube with additional atoms in the center of the 6 cube faces. Such an arrangement is called "face centered cubic", FCC. In between these two temperatures, 1340° - 1600°F, both crystal forms co-exist. For steels, the FCC lattice arrangement is called austenite.

All alloys used in boiler construction with less than approximately 12% Cr, are ferritic. These include all carbon steels and low alloy steels, T-11, T-22, etc. At chromium contents greater than 12% (12.7% to be exact), iron-chrome alloys are BCC over all temperatures and are referred to as ferritic stainless steels. The common grouping is the 400 series stainlesses, 410, 420, 430, etc. However these FeCr alloys are not widely used in this country for pressure parts. They do have excellent weldability and corrosion resistance, and are extensively used for duct work where dew point corrosion by sulfuric acid may be a problem. They are also used for support clips in SRE elements.

The addition of about 8% nickel to alloys with 18% chromium retains the high temperature FCC lattice arrangement to room temperature. Since the FCC crystallographic form in steels is called austenite, these 18Cr - 8Ni materials are known as austenitic stainless steels. The most commonly used are the 300 series, 304, 316, 321 and 347 grades.

There are other austenitic materials used in some pressure parts and high temperature attachments that are not, strictly speaking, steels. Steel, by definition is an alloy or iron and other elements, but must contain at least 50% iron. These non-steel austenitic alloys are nickel-chromium-iron materials. Since they were first developed by the International Nickel Co./Huntington Alloys, they are commonly referred to by the INCO trade name of Incoloy® or Inconel®. Some of these nickel base alloys are just beginning to find use in some boiler tubing applications, mainly Incoloy 800 or 800H®. For severe corrosion service, weld overlays of Inconel 625® on ferritic steels of SA-210 A-1, or SA-213 T-11 have been used.

Under normal boiler operational temperatures, there are two microstructural changes that occur in austenitic stainless steels of the 300 series. Neither change is detrimental to the performance of these alloys. Service temperatures between about 1000° - 1400°F lead to the formation of chromium carbide at the austenite grain boundaries. (A grain boundary, by the way, is the region of atomic mismatch and disarray between adjacent individual crystals or grains). Chromium distributed throughout the austenite at a concentration of more than 12% gives the alloy superior corrosion resistance. Once chromium carbide forms, the austenite surrounding the carbide particle is depleted of chromium and its corrosion resistance becomes poorer. Such a structure is said to be <u>sensitized</u>. In certain corrosive environments, not usually found in boilers, rapid corrosion occurs along the chromium depleted grain boundaries. In these service environments the performance is destroyed by intergranular attack. The failures that result would be described as "intercrystalline" or "intergranular".

In order to prevent the formation of sensitized structures, either reduce the carbon content or encourage the formation of a more stable carbide than chromium carbide. The extra low carbon grades of 304L or 316L have been designed for this purpose. The carbon content is limited to 0.03% maximum. At this concentration there is too little carbon to form a continuous network of carbide particles along the grain boundaries. Thus the corrosion resistance remains excellent and intergranular attack does not occur.

The addition of titanium or columbium to austenitic stainless steels gives rise to the 321 and 347 grades. When these grades are given heat treatments in the temperature range of 1650°F the carbon is combined with titanium to form titanium carbide (or with columbium, to form columbium carbide). In either case there is no free carbon available to form harmful chromium carbide at the austenite grain boundaries. Thus 321 and 347 grades given a stabilization heat treatment at 1650°F are immune to intergranular attack.

However, in pressure part applications no superheater or reheater is given such a stabilization heat treatment. The high temperature components do not fail by intergranular attack. Thus for fossil fired boiler uses there is no need to use the more expensive 321 or 347 grades when 304 has the same excellent corrosion resistance in boilers.

There is one other microstructural change that stainless steels suffer when subject to prolonged exposure to elevated temperatures, the formation of sigma phase. Sigma phase is an intermetallic compound with a formula approximately FeCr. The appearance of sigma phase within the microstructure occurs over the service temperature range of 1000°F - 1600°F. There are usually no adverse effects. The tensile strength and yield strength are virtually unaffected; if anything, the strength increases. Ductility, however, is reduced. The loss of ductility is from about 50% for new material to about 20% for alloys with about 5 - 7% sigma present. Note, though, an alloy with 20% elongation is still quite ductile. Some castings used for SRE supports or spacers will have no more than 20% ductility and are considered satisfactory. Only rarely do boiler pressure parts fail due to loss of ductility.

For comparison, the corrosion rate of T-22 is about six to ten times faster than 304, 321, or 347 in liquid ash corrosion environments. Steam side scale resistance is similarly improved when T-22 is replaced by 304. Scale thickness on 304 will be about 1/5 that of T-22 for equal temperature and time of operation. Thus exfoliation and erosion damage to turbine blades will be less. All in all, the microstructural changes inherent in the austenitic stainless steels are not of serious concern to users in boiler pressure part applications.

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