Subject: Eight Forms of Corrosion

This is the fifth of eight primers which introduce the forms of corrosion likely to be encountered in the petrochemical, refining, fertilizer, and other industries. The eight forms have been used for decades to describe, by appearance, the common degradation mechanisms in metals and alloys.

5. Intergranular Corrosion

Intergranular corrosion or attack (IGA) occurs in, or adjacent to, grain boundaries of corrosion resistant alloys such as stainless steel. In advanced cases, IGA causes grain dropping due to complete degradation of the grain boundaries. IGA is most often related to sensitization (carbide formation) but can also result from grain boundary related impurities or the precipitation of other deleterious phases along grain boundaries.

Sensitization can be caused by welding, heat treatment, or high temperature service. Sensitization can also occur because of carbon pickup during the casting of stainless steel and other corrosion resistant materials. Knife-line attack is form of IGA in weld heat affected zones due to the thermal cycles of welding and the carbides or other precipitates formed at the grain boundaries.

During sensitization, elements with a strong affinity for carbon such as chromium, niobium, and titanium, form carbides. Around the carbides are regions which have been partially stripped (denuded) of the carbide forming elements. The loss of chromium is especially harmful as chromium is added to increase the corrosion resistance of an alloy.

Sensitization of 300 series stainless steel occurs in the 370-815°C (700-1,500°F) range. Longer times are required at lower temperatures while only brief exposure time is necessary near the top of the sensitization range. For workhorse alloys like 300 series stainless steels, owner-operators specify low carbon or “L” grades (304L or 316L), dual certified grades (304/304L or 316/316L) which have L-grade carbon levels and purposeful nitrogen additions for strength retention, or stabilized grades (321 or 347) with additions of titanium and niobium respectively. Each of these options improve sensitization resistance by reducing the amount of available carbon or use of a strong carbide former.

Though improvements in sensitization resistance are attained with L, dual certified, and stabilized grades, they are not immune. Sensitization of 304L and 316L will still occur at temperatures >400°C (>750°F), at temperatures >455°C (>850°F) for 321, and at temperatures >482°C (>900°F) for 347. Further improvements in sensitization resistance can be obtained on 321 and 347 via a thermal stabilization treatment at 900°C (1,650°F) at the mill and again as a post weld heat treatment.

Solution annealing can also be performed to dissolve the carbides prior to service. The annealing temperature range is 1,040-1,100°C (1,900-2,000°F) for most grades of stainless steel and is followed by rapid cooling to avoid reprecipitation of carbides. Given the required temperature and cooling rates it may not be feasible to anneal a fabrication due to distortion or other limitations such as size.

An alloys susceptibility to IGA can be determined through standardized corrosion tests. ASTM A262 covers the testing of 300 series stainless steel, ASTM A763 covers ferritic (400 series) stainless steels, and ASTM G28 covers nickel-rich, chromium bearing alloys.

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