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CORROSION IN 316 STAINLESS STEEL VERSUS 316 LOW CARBON STAINLESS STEEL

Barbara Feldhacker Hudson

JMS Southeast, Inc.

Statesville, NC

BACKGROUND:

When 316 stainless steel is welded it is exposed to temperatures in the range of 1000°F to 1600°F and carbon readily diffuses toward the grain boundaries in this temperature range. This excess carbon in these areas adjacent to the grain boundaries combines with the chromium in the steel to form chromium carbides. This action depletes the effective chromium content near and at the grain boundaries, leaving this area of the metal susceptible to corrosive attack. When welding occurs and this phenomenon occurs, the chromium from within these grains cannot replenish this shortage rapidly enough to overcome this susceptibility. This is called “sensitization.”

Stainless steel loses its resistance to corrosion when the chromium content drops below 10.5-11%. Intergranular corrosion occurs when the chromium content along the grain boundaries drops below this amount. The less chromium present the more rapid the attack that could ensue.

Corrosion also occurs more readily in austenitic stainless steels that contain more than .03% carbon due to the fact that complex chromium carbides precipitate along grain boundaries when the chromium ties up with this carbon. After the metal is cooled from the 1000°F-1600°F temperature range, any areas that experienced that temperature and are depleted of chromium are very susceptible to corrosion. In the manufacture of resistance temperature detectors, approximately the last 3 inches of the probe and the weld area experience these temperatures. Therefore, they are prime candidates for corrosion.

CORROSION PREVENTION:

There are a number of ways to combat the susceptibility of corrosion in 316 stainless steel. We have investigated a number of options. Water quenching of the entire susceptible area would avoid this corrosive property due to the fact that this cooling would dissolve the chromium carbides and the chromium content would be again uniform throughout the metal. Water quenching cools the metals rapidly enough to prevent the combination of chromium with carbon. We, at JMS, felt this option was not as feasible due to the problem of quenching every probe in manufacturing. This could not be done to an RTD assembly due to the fact that it would cause thermal shock to the probe and a sudden strain to the RTD bulb. RTD's are susceptible to strain and thermal shock and this could be detrimental to the sensor.

A second method of avoiding the corrosion phenomenon in 316 stainless steel is to add carbide forming elements to the stainless steels. If the carbon in the metal is tied up with other elements, it can not tie up with chromium and the free chromium present could not form chromium carbides and migrate to the grain boundaries. Some elements added to stainless steels for this purpose are titanium, columbium and tantalum. These elements have greater affinity for carbon than chromium so they stabilize the steel against chromium depletion. An example of this is Monel. This is a

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more expensive option than what JMS Southeast decided upon.

A third method to avoid this possibility of corrosion of 316 stainless steel is to keep the steel in the “sensitizing” temperature range (1000°F-1600°F) for a long enough time for thermal stabilization to take place. The chromium carbides do form at the grain boundaries; however, after additional time, the chromium can diffuse into the area of impoverished grain boundaries.

The option was not feasible however, due to the fact that this thermal stabilization usually takes four hours. This is difficult to impossible to accomplish during welding. The method that JMS Southeast decided upon to combat corrosion in 316 stainless steel is to keep the carbon content so low in the metal that there is not adequate carbon present to form detrimental amounts of chromium carbide. If there is not enough carbon to tie up with the chromium then the chromium does not become depleted and corrosion is much less likely to occur. This type of protection is accomplished by using 316 low carbon stainless steel (316L) which has a maximum carbon content of .03%.

In an environment containing chlorides, the 316 stainless steel probe is at an even greater risk due to the fact that chlorides promote the formation of active/passive electrolytic cells. This can be explained by the fact that all stainless steels are passive under most conditions; however, if the probe is exposed to the “sensitization” temperature range and this molecular transformation occurs it forms anodic area (opposite the passive area). The oxygen around these two areas serves as a depolarizer and corrosion proceeds at an accelerated rate at the point the two areas meet.

Chlorides also have a higher valence state. Any chloride in an appreciable concentration is a source of trouble in promoting corrosion. Therefore, the use of 316 low carbon stainless steel becomes even more necessary in a chloride atmosphere if the metal is to endure a satisfactory lifetime. This occurs in an area that has been welded and is adjacent to the non-affected area.

Another problem of chlorides is that deposits may occur in crevices on the probe. In a crevice, oxygen supply is limited and cannot repair the passive oxide film. A crevice stays damp longer than a fully exposed surface. Salts are likely to accumulate in crevices particularly if the area around the crevice is alternately wet and dry. If the oxygen concentration decreases below a level necessary to maintain passivity in the anodic area, there is a double electrolytic effect. The difference in oxygen concentration alone will tend to promote attack on the anodic area and the potential between the passive and active area is already quite high, so corrosion becomes even more aggressive. Chlorides, being electrolytes will not contribute to passivity and will become very acidic thus accelerating the corrosive attack even more.

It is difficult to predict the corrosion rate of 316 stainless steel or 316 low carbon stainless steel due to the environmental variables; however, our experience has shown an increase of up to twice the life in a low carbon stainless steel probe versus a standard stainless steel probe. The problem with pitting corrosion and crevice corrosion in an RTD probe is that through these openings in the metal sheath, the RTD bulb can become contaminated and fail. If quantified specimen tests are needed, the ASTM lists some approved corrosion testing procedures.

In the ASTM A262-64 Standard two widely used intergranular corrosion susceptibility tests are described. They include the Huey test, which test subject samples to five 48 hours boils in 65% nitric acid solutions. A weight loss after each boil is noted and translated to a corrosion rate in inches per month. This test, however, indicates overall corrosion not grain boundary corrosion.

A second test is the oxalic acid etch test which involves etching a polished specimen then examining the appearance under a microscope. Comparisons are then made to some ASTM photographs.

Two other tests listed in A262 are the boiling sulfuric acid-ferric sulfate solution test and the nitric acid-hydrofluoric acid test at room temperature. These are not as widely used, however.

In conclusion, corrosion of 316 stainless steel in a chloride environment is a definite problem. To minimize this problem, low carbon stainless steel metal should be used in this environment as the encapsulation for RTD probes. If this is not done, the RTD longevity will be substantially reduced. JMS Southeast recommends the use of 316 low carbon stainless steel to all our customers who are using RTD's for temperature measurement in a process that contains chlorides.

REFERENCES:

1. Zak, C.A., “Intergranular Corrosion of Austenitic Stainless Steels” Metallurgy of Tubing/Volume 8
2. American Society for Metals, “Metals Handbook” Volume 8, No. 1, 1961