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304L Stainless Steel Failures – Case Study

By

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Introduction

Typically, 304L stainless steel has very good corrosion resistance. Over the years we have come across numerous situations where 304L stainless steel has become sensitized and lost its corrosion resistance. It is very difficult to sensitize 304L stainless steel, requiring prolonged heating at temperatures between 480° and 815° C. "L" grades of 3XX series stainless steels are not sensitized by normal heat treating or welding processes unless carbon based materials, such as forming oils or coolants, are present. Chemical analysis of the failed parts has shown that the carbon levels in the sensitized parts have been below 0.03 percent, the upper limit for carbon in "L" grade stainless steels.

Sensitization of Stainless Steels

The corrosion resistance of stainless steel is the due to the presence of chromium oxide on its surface. The chromium oxide forms an adherent self-healing film on the surface of stainless steels. Stainless steels are sensitized when grain boundary chromium/iron carbides are formed. The formation of chromium/iron carbides depletes the chromium in the grain boundaries, which can result in intergranular and/or pitting corrosion. The carbides can be formed by prolonged heating at temperatures in the range of 480° to 815° C. The higher the carbon content, the shorter the heating time required. "L", low carbon, at 0.03% or less, stainless steels require long periods of time, much longer than found in the typical welding or heat treating process. To insure complete immunity to sensitization the carbon content must remain below 0.015%. One spot of oil or machining coolant on a part being welded is enough to cause localized sensitization. Forming oils that are not completely removed from parts prior to annealing will likely result in sensitization of the entire part.

Detecting Sensitization

The method that we find most useful and reliable is electrolytic etching of a metallographically prepared sample with a saturated solution of oxalic acid. This testing corresponds to ASTM A262 Practice A.

Figure 1 shows the etched microstructure of a sample of 304L stainless steel which had not been sensitized. This is a very good example of high quality 304L stainless steel.

Figure 2 shows sensitized grain boundaries in 304L stainless steel. This sample was lightly electrolytically etched with saturated oxalic acid. The round and oval etch pits indicate the presence of chromium carbides. Tubing formed from this lot of 304L stainless steel failed by stress corrosion cracking after being in service for a few months.

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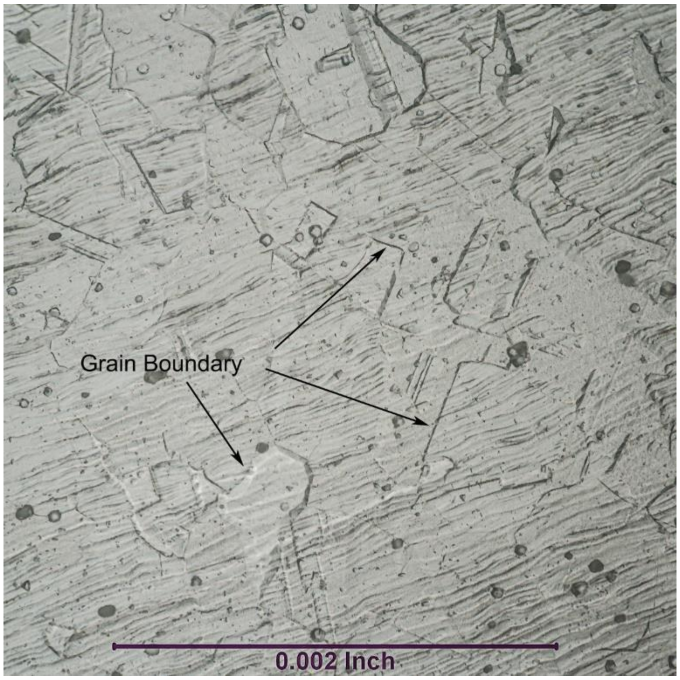

Figure 1 – 1500X Grain Boundaries Free of Chromium Carbides

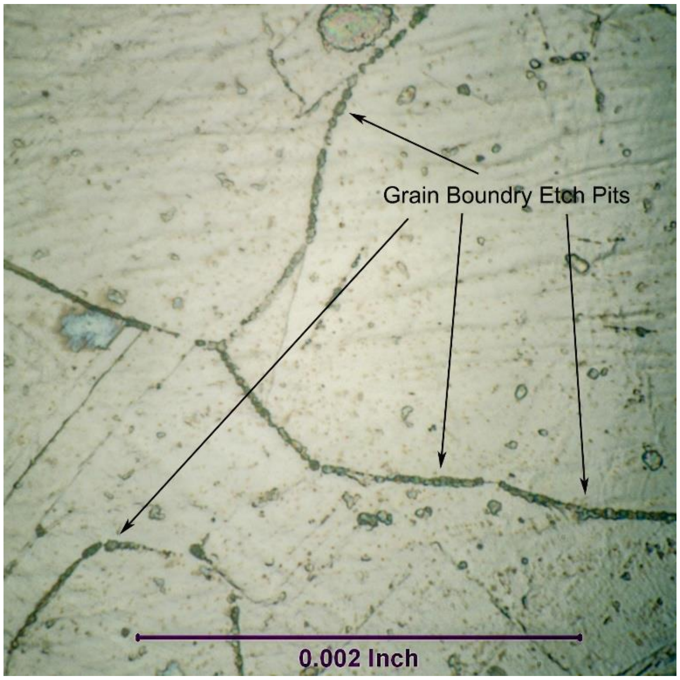

Figure 2 – 1500X Sensitized Grain Boundaries with Chromium Carbides Present

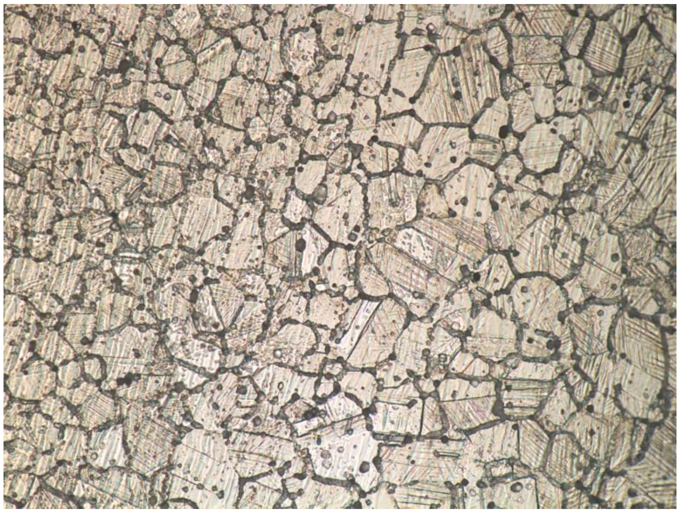
Figure 3 – 400X Sensitized Return Bend

Figure 3 shows the electrolytically etched microstructure of a highly sensitized annealed 304L return bend. This return bend failed by pitting corrosion after being in service for a few weeks.

It has been my experience that, any time there has been a corrosion failure of 304L stainless steel that had not been in a highly corrosive environment, the 304L stainless steel was sensitized to some degree.