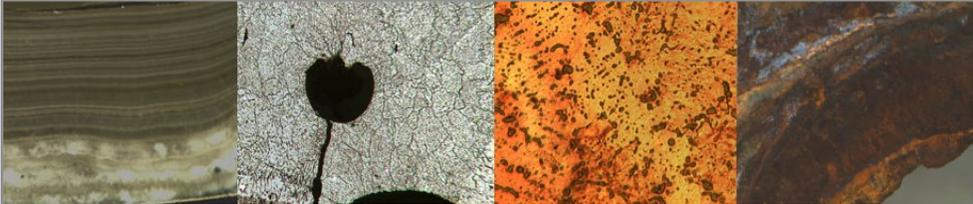


NU S & B L S



New Hampshire
MATERIALS
LABORATORY, INC.
Your Problem Solving Partner

FAILURE IN THE FOOD INDUSTRY

MAY 2014 ISSUE 13

Welcome to New Hampshire Materials Laboratory

First, everyone here at NHML would like to thank all of our customers who have been sending us an incredible amount of work this year so far. Your loyalty has allowed 2014 to begin with a great start and hopefully to a great year. We continue to look forward in being “Your Problem Solving Partner” for all your mechanical and chemical testing needs.

One of the more complex yet intriguing types of testing that we do here at NHML is a “Failure Analysis”. This analysis can be performed on a variety of products that vary in the types of failures that can occur during production, testing or in actual use. In this month’s Nuts & Bolts supplement, we will discuss a case study in regards to a product that many of you see on a day to day basis, a drop-in hot food well. This specific product is used in company cafeterias, fast food restaurants and in many local franchise and corporate restaurants.

For more information or to find out more on how we can be “Your Problem Solving Partner”, please visit our website at www.nhml.com or call our toll free number 800-334-5432.

Tim Kenney
Laboratory Director

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Food Industry Stainless Steel Corrosion Case Study

by Fred Hochgraf

NHML was inquired about a problem that a customer was having with their heated food well pans. The pans that were in question are built into a heated food warmer where they would be filled with water then heated to warm containers of food. They provided us with 2 stainless steel well pans to evaluate for a failure analysis. One of the pans provided had failed with signs of corrosion and the other was new and in good condition to be used for comparison. The failed pan was leaking water at the area of corrosion and our job was to find out why it had failed in the first place.

GOT A PROBLEM? 

1. **What's going on?**
2. **What could we do?**
3. **How did it go?**

Upon receiving the samples, NHML provided the customer with an intended course of action. We planned on providing a report that included a chemical analysis of the steel, identification of the corrosion mechanism and any microstructural abnormalities. We are usually able to identify elements participating in pitting corrosion and/or stress corrosion cracking. Following the results of our analysis, we usually include recommendations for steps that can be taken to avoid any future problems.

Steps NHML took to find the problem:

Chemical Analysis

Chips were taken from the failed pan for chemical analysis. Carbon and sulfur was analyzed with our spectrometer and the remaining elements were analyzed through ICP all using NIST traceable standards. The alloy composition was found to have been in specification for 302 and 304 stainless steel.

Microstructure

Metallographic samples were prepared in accordance with ASTM E3. Cross sections were taken through various pits, intact metal adjacent to a pit and from the rim of the intact pan (non-failed pan). The segments that were taken and mounted in epoxy, wet ground through successively finer grades

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of silicon carbide abrasive paper, rough polished on a lap that was charged with 6 micrometer diamond and finally polished on a lap with 0.05 micrometer alumina. The sections were electrolytically etched in 10% oxalic acid. Each section was then examined with a metallograph and selected sections were examined in the SEM.

As seen in Figure 1, through examination we found there was only pitting corrosion. There was no evidence of stress corrosion cracking, general corrosion or galvanic attack. No crevice corrosion was found either; however, crevice corrosion is related to pitting attack as noted below in the Discussion section. Figure 2 was the elemental analysis showing that the contents of the pit were principally carbonaceous food debris. There was a trace amount of chlorine that was found as well. The sensitivity of the EDS analytical technique suggested that the amount of chlorine in the pit was of the order of 0.1%, which is more than enough to sustain the pitting reaction.

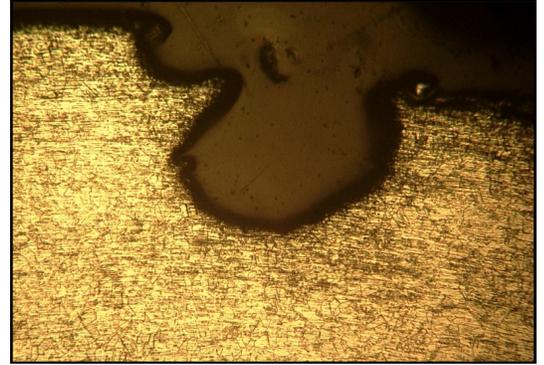


Figure 1: Metallographic section through the center of a pit

Figure 3 shows the microstructure of metal adjacent to a pit. The metallographic sample taken from the rim of the intact pan showed microstructure that is indistinguishable from figure 3. The following information was derived from figures 3 and 4:

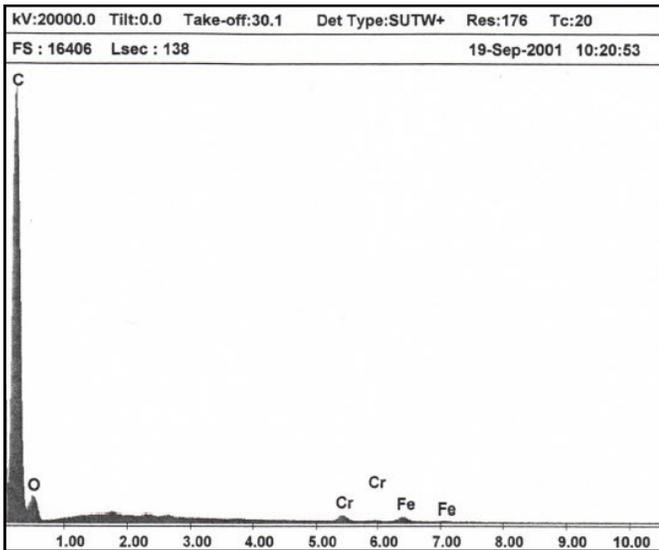


Figure 2: Elemental analysis results using the EDS accessory of the SEM within the pit in figure 1. The trace element emissions are unlabeled on the spectrum. Major-Carbon, Minor-Oxygen Chromium and Iron, Trace-Silicon, Sulfur and Chlorine

The metal was slightly cold worked, which is consistent with the samples' locations in lightly deformed areas in the pan's bottom and rim.

The metal was briefly annealed after it was rolled into sheet form. It was not annealed after being formed into the actual pan.

A minor phase was allowed to precipitate in the grain boundaries. We believed that the minor phase contained carbides. Their presence indicates the metal was in a sensitized condition making it more susceptible to pitting. The cause of the precipitation was too slow cooling from the annealing temperature.

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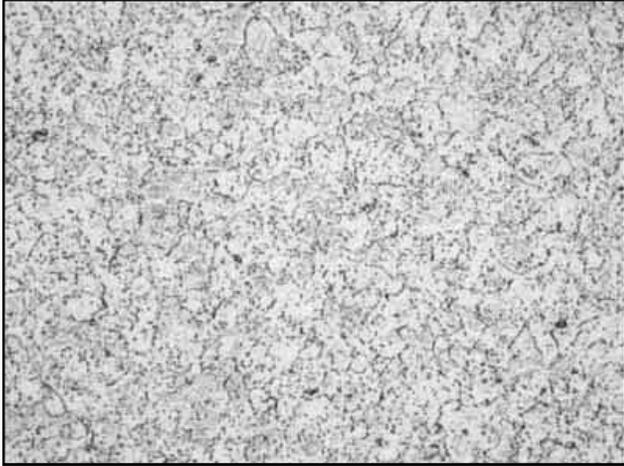


Figure 3: Microstructure of the metal adjacent to a pit. Area is on the pan's flat bottom, slightly deformed during cold forming. 400x

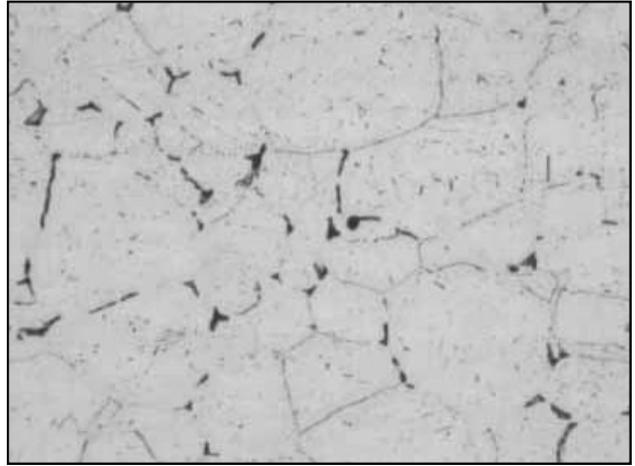


Figure 4: SEM photo of minor phase particles in the austenite grain boundaries.

Discussion

About Pitting

The pitting reaction relied on the quality and durability of the passive film that protects stainless steels as well as chemical reactions within a pit. The following quotations are from Peckner and Bernstein, Handbook of Stainless Steels, McGraw-Hill, 1977, p17-66 et seq.

“Pitting is an extremely localized attack resulting in holes in the metal. This type of corrosion is very dangerous, since the steel may quickly be fully penetrated despite the fact that its general corrosion rate is often very low...halogens (chiefly chloride ions) can penetrate the passive film...and destroy it at weak points. This produces very small anodes of active steel surrounded by a large cathodic area consisting of the passivated surface. This provides the conditions necessary for a rapid dissolution of the metal in the microanodes, provided that the chloride ions are able to remain in the anodes and prevent repassivation and that the electrolyte contains a sufficient quantity of oxidizing agent to maintain the passivity of the cathodic surface.”

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In the present application the surface area of the water assures ample dissolved oxygen. The chloride detected in the pits indicated that the second condition for pitting was also satisfied.

We concluded that the sensitivity to pitting was extremely marginal. Small shifts in one or several of the following factors would have either put the alloy into the pitting regime or would have given it immunity:

Temperature

Pitting corrosion of the 302/304 stainless steel is most rapid at 80°C. Both higher and lower temperatures reduce the amount of dissolved oxygen in the water. The oxygen is required to maintain the passive film over most of the area of the metal.

Pit Initiation

Given the somewhat sensitized condition of the metal and the presence of chlorides in the water, a particle of food stuck to the surface would suffice to initiate pitting. (The pits are at the lowest parts of the pan, where food particles would be most likely to be found).

Water Velocity

At water speeds above a few feet per second, particles tend to be carried away before they remain in one place long enough to initiate a pit. The present application of the pan had quiescent water which allowed the particles to remain and initiate corrosion.

Alloy Composition

Pitting sensitivity decreases markedly as nickel content is increased. The present alloy was on the low side in regards to nickel.

Carbon in excess of the limits specified for 304L, less than 0.03%, made the alloy liable to sensitization unless it was rapidly cooled through the critical range. The present carbon of 0.05 made it susceptible.

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Molybdenum is very effective in reducing the susceptibility to pitting. The present 0.07% was insufficient to offer much help.

Our Suggestions to Client

Alloy 304 often demands no premium price over 302. We suggested that they specify 304 rather than 302 to take advantage of 304's higher chromium and nickel content along with a lower carbon.

Applications that customarily have high chlorides in the water may have to use type 316 in spite of its greater expense.

Specifying a sensitization acceptance test may price the product out of competitive range. We suggested they explore the available options with their metal supplier.

The present application of the product is marginal for pitting. We suggested avoiding softened water because of its higher chlorine and advised that the water should be changed before residuals could become concentrated due to evaporation. Changing included wiping out the parts of the pan where foreign matter could be collected and daily wiping out/water change would probably be sufficient. Any particles reluctant to be dislodged should be removed with abrasive powder; however, ordinary steel wool should not be used since it implants particles that promote corrosion. Stainless steel wool should be used instead.