

The Effect of Electropolishing on SS Welds and Heat Affected Zones

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INTRODUCTION

Austenitic stainless steels (300 series) are used extensively in many industries (chemical, electronic, pharmaceutical, thermal, nuclear and food). The extensive use of these materials comes from their excellent corrosion behavior, good mechanical properties, easy fabricability, including welding, and good cleanability. These excellent responses to many corrosion mediums are attributed to a 20 to 40 Å thick passive protective film consisting mainly of Cr_2O_3 .¹

During welding, high temperature oxides are produced on filler and adjacent heat affected zones. The thickness and chemical composition of these oxides are dependent upon the temperature of exposure, welding time and welding environment (inert gas shielding) and differ from natural oxides.

The main post welding procedure used to remove these oxides and restore passivity is pickling followed by passivation. This study shows that electropolishing seems to be (from both a theoretical point of view and experimental results) the best method for restoration and upgrading of corrosion resistance of welds and heat affected zones.

EXPERIMENTAL

WELDING PROCEDURE:

Specimens 1" x 1.5" were cut from the same 1/8" thick 308 stainless steel plate. Edge preparation was conducted for single V-groove joints as shown in Fig 1. Filler rod was commercial 308 stainless steel 1/16" in diameter. The parameters for tungsten inert gas (TIG) welding are shown in Table I.

PICKLING:

Welded coupons were submerged for 15 minutes in an industrial scale remover recommended for stainless steel and rubbed off with a rubber glove.

Table I. TIG Welding Parameters

Current, A	Voltage, V	Argon flow, in%/
150	15	25-30

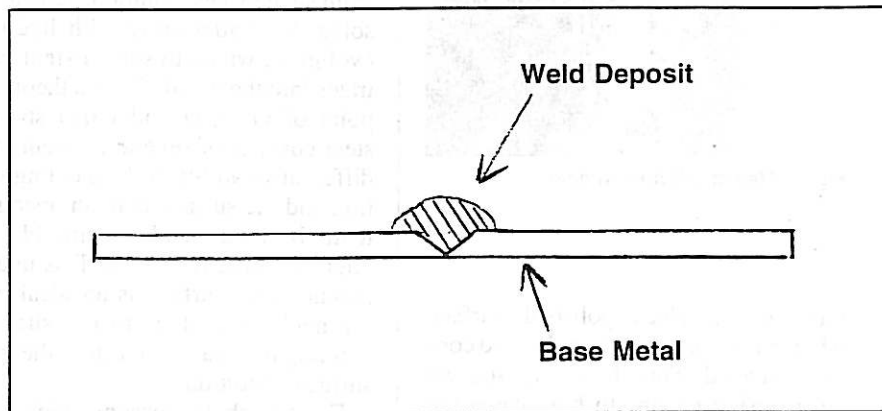


Fig. 1. Schematic of a weld pad.

After all welding scale and discoloration came off, test coupons were rinsed off in tap water, neutralized in a dilute solution of soda ash, again rinsed off in tap water, ultrasonically cleaned in distilled water and dried.

PASSIVATION:

The welding coupon was passivated in accordance with Federal Specification QQ-P-35A, Type I.

ELECTROPOLISHING:

Electropolishing was performed in a proprietary electrolyte for five minutes to a bright finish. Material removal was 0.002" per side.

CORROSION TEST:

Resistance to pitting was assessed using the ASTM Standard G-48-76 method involving immersion in 6% FeCl_3 solution at room temperature (23°C) for 72 hours. The coupons were positioned at a 45° angle in PVC racks with welds facing upwards.

RESULTS OF THE CORROSION TEST

During the tests, bubbles of gas were spotted on the surface of the test solution. While many of them were visible all over the passivated coupon, only a few were noticed on the electropolished sample. After three days of exposure

to the test solution, the coupons were removed, rinsed off, dried and visually examined. The coupons did not show many signs of damage (only some pits were visible on both samples), until they were dried by pressurized air.

The air pressure collapsed the surface which revealed pits. The passivated sample was so severely damaged (Fig 2.), that in three areas pits changed into holes passing right through the whole thickness of the coupon. Corrosion attacked mainly the heat affected zones. In these areas pits were arranged almost in rows. They were elongated and parallel to the weld. Weld metal showed some pits, but not as many. The electropolished sample revealed two large pits and some smaller ones in the heat affected zones (Fig 3.). Filler metal was pitted in some places. Worthy of notice is the shape of the

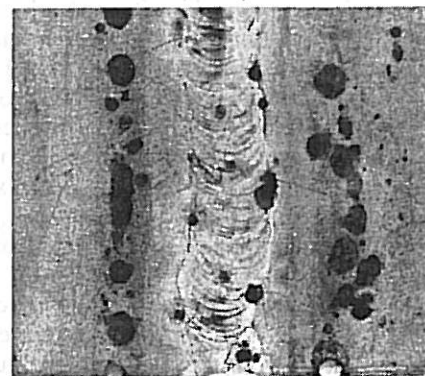


Fig. 2. Passivated sample.

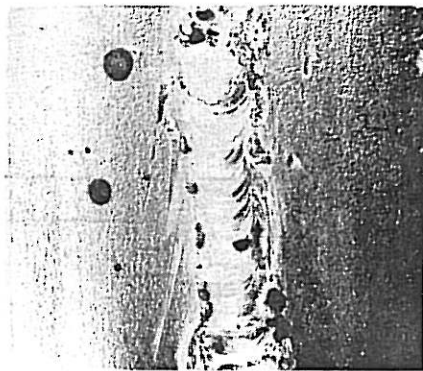


Fig. 3. Electropolished sample.

pits on the electropolished surface which in all cases was rounded and conically shaped. This shape may suggest an inclusion origin. In both cases the corrosion product was black powder.

DISCUSSION

The reduced corrosion resistance of welds and heat affected zones in the post welded state is attributed to depletion of the chromium content of the oxide and matrix alloy immediately beneath the oxide. During TIG welding, elevated temperature forces chromium out of the matrix alloy to the matrix-oxide interface, therefore the matrix alloy layer becomes depleted in chromium. The chromium which was forced out of the matrix alloy, and also from the freshly created oxide, in this elevated temperature diffuses constantly to the oxide-gas interface, where it reacts with oxygen. In ideal conditions (the number of oxygen atoms balances the number of chromium atoms) the oxide should be stoichiometric² and therefore very stable, but in actual TIG welding conditions the number of oxygen atoms exceeds the number of chromium atoms making it nonstoichiometric. Additionally, after the chromium supply is depleted, iron and nickel start to be oxidized. In effect, the oxide originated during TIG welding does not consist of very pure, stoichiometric Cr_2O_3 , but most probably is a mixture of nonstoichiometric Cr_xO_y , Fe_xO_y , and Ni_xO_y and is thus strongly depleted in chromium atoms.

The loss of some percentage of chromium atoms is attributed to direct evaporation from the oxide surface due to the elevated temperature.² To remove these mixtures of oxides (welding scales, discoloration) a pickling proce-

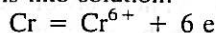
dures is widely used as a post weld treatment. The high temperature oxide which is not homogenous in composition has a different solubility in the pickling solution, therefore some areas are dissolved preferentially to others. When the oxide is already removed from such places, solution starts to dissolve the matrix-alloy with hydrogen evolution, which to some extent penetrates into the metal. From a theoretical point of view, consider that stainless steel consists of several elements with different solubility in the pickling solution and the surface is in an unequipo-tentialized state and remains like this after the process is over. This unequipo-tentialized surface is an ideal place for nucleation of corrosion sites and pickling is not able to restore the initial surface condition.

For the above reasons, pickling is followed by a passivation treatment in order to make the surface more passive. Due to its preferential dissolution of iron during the process, the passivating solution enriches the outermost layer in chromium. The chromium in this enriched layer is oxidized to Cr_2O_3 , which gives excellent corrosion resistance to the stainless steel. On the other hand, passivation does not completely remove the degenerated and hydrided layer originated during the pickling process.

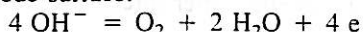
Electropolishing is an anodic metal dissolution process which is controlled by a great variety of parameters (electrolyte composition, temperature, current density, metal or alloy composition, agitation, etc). The process by its electrolytic dissolution action restores the true properties of the bulk metal and improves corrosion resistance by creating a very dense, stable oxide layer, which mainly consists of Cr_2O_3 .

Considering the complexity of the electropolishing process, it is impossible to include all the chemical reactions which take place, but following the basic rules of an ideal electropolishing process³ and keeping in mind the conclusive role which chromium plays in electropolishing of stainless steel,⁴ a simplified model can be written down as follows.

1. Dissolution and transfer of chromium ions into solution.

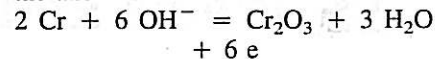


2. Evolution of oxygen from the anode surface.



3. Formation of a passive film on

the anode surface.



The passive oxide film originates during the electropolishing process and is more stable and corrosion resistant than the one originated by passivation in nitric acid or by a chemical polishing process.^{5,6}

CONCLUSION

Considering that the Cr_2O_3 layer originated by the passivation process is built on a very electrochemically unstable and to some extent a hydrided underlayer, no one can expect from it the same corrosion resistance as from the Cr_2O_3 layer created by electropolishing, where this underlayer is removed during the process and hydriding is completely ruled out.

In the first case, the passive oxide film is endangered from both sides, by two factors:

1. The corrosive environment from outside directed towards the film.
2. Migration of hydrogen from the hydrided layer beneath the passive film in the opposite direction.

Note:

At the conclusion of this article, I would like to share my observation concerning the utilization of the electropolishing process in the electronics-semiconductor industry. Almost all components of a gas installation (process tubing, flowmeters, regulators, gas cylinders, etc.) in this industry are internally electropolished to decrease particulates, but in my opinion one very important matter is overlooked, namely not re-electropolishing welds and heat affected zones during assembly of the installation. These places not only can become potential sources of corrosion, but they are actual sources of particulates due to chipping off of high temperature oxide exposed to the pressure and flow velocity of the gas. MF

References

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