

Corrosion Behavior of Welded Austenitic Stainless Steel Food Processing Equipment in Low pH Environments

Suresh Divi and Harbinder Pordal
Stress Engineering Services, Inc.
13800 Westfair East Drive
Houston, Texas, USA

ABSTRACT

The food industry uses various corrosion resistant alloys (CRA's) in the form of vessels, piping, mixers, etc. to process different types of foods. The physicochemical characteristics of processed foods permit various CRA grades depending on the type of food contents and its corrosivity (non-corrosive, mild, medium, and high corrosivity). Due to ease of availability and low cost 304 stainless steel (UNS S30400) is the most commonly used CRA in the food industry. If proper heat treatment is not performed on the 304 stainless steel food processing components, when subjected to low pH corrosive environments, the welds and heat affected zone (HAZ) show poor corrosion resistance.

In this study, the corrosion resistance of 304 stainless steel weld metal in low pH environments, involving a high viscosity, low pH (3.6) "food product" and lime juice was investigated via electrochemical corrosion tests. A series of electrochemical linear polarization resistance (LPR) corrosion rate measurements of sensitized 304 weld and non-sensitized 304 and 316 stainless steel welds in the above-mentioned environments are performed at room temperature and 40°C to determine the general corrosion behavior and pitting corrosion resistance. Metallographic examination and scanning electron microscopy (SEM) examination of the tested welds were performed. Sensitized areas of 304 stainless steel showed higher corrosion rates and poor pitting resistance. The study demonstrated that a non-sensitized weld of food processing equipment is very important to prevent corrosion in low pH foods.

Keywords: Stainless steel, low pH, food processing equipment, welds, pitting and electrochemistry.

INTRODUCTION

Food consists mainly of proteins, carbohydrates, and fats. Processed foods contain diverse aqueous solutions, syrups, and additives, used to improve food appearance, taste, quality and preservation. They have a wide pH range, components such as, salt, water, and vinegar impact food corrosivity.¹

Modern science and technology have enabled the development of an extended range of materials with increased corrosion resistance, improved mechanical strength, easier forming and fabrication, weldability, and health friendly features. The workhorses of food processing industry are stainless steels 304 (UNS S30400) and 316 (UNS S31600), but other austenitic and duplex SS are in useful service in food plants.²

Foods such as milk, meat, oil, and fish are non-corrosive to food processing equipment. Foods such as certain dairy products, fruits, wine, carbonated sweet drinks and syrups with pH 6-7 are mildly corrosive to food processing equipment. However, foods such as fruit juices, acidic canned fruits, hot gravies, certain sauces and dressings and fish pickled in brines with 1-3% salt are highly corrosive to the process and storage metal equipment.³

Water is considered as the universal solvent since all chemical substances have a finite solubility in water ranging from acids, bases, salts, sugars, alcohols, etc. Water is dissociated into ions: $\text{H}_2\text{O} \rightarrow \text{H}^+ + \text{OH}^-$ forming the hydronium ion H_3O^+ a bonding between a hydrogen ion H^+ and a water molecule, these are the ions involved in corrosion of metallic materials typically used for the construction of food processing equipment.

Acidic metallic salts undergo hydrolysis in water: $2\text{FeCl}_3 + 3\text{H}_2\text{O} \rightarrow 6\text{HCl} + \text{Fe}_2\text{O}_3$, forming an acidic and corrosive environment.⁴ The pH values associated with foods generally range from 3 to 8. A pH of 3 corresponds to a mildly acidic water and has an acceptable corrosive behavior for aluminum, stainless steel, and tin.

The corrosion resistance of stainless steel is due to the presence of a protective, passive oxide film on the surface, which is stable, tightly adherent, and very thin ($\sim 50 \text{ \AA}$). Due to good corrosion resistance, relatively lower cost, and availability 304 stainless steel is the most commonly used stainless steel grade in the food industry. However, the weld metal corrosion resistance can vary based on weld quality. A good weld without any deleterious effects is important in providing good corrosion resistance. Welds in stainless steel can corrode in certain environments due to a phenomenon referred to as weld sensitization. Weld sensitization in stainless steel is the precipitation of carbides at grain boundaries in the weld, resulting in the alloy being susceptible to intergranular corrosion.

In this study, corrosion behavior of two 304 stainless steel welds (sensitized and non-sensitized) was investigated via electrochemical corrosion study in a high viscosity, low pH, food product. The corrosion characteristics in lime juice are also studied for reference purposes. For comparison, 316 stainless steel welds (non-sensitized) were also exposed to the same environments and used as the reference material.

CORROSION TESTING

Electrochemical test electrodes were prepared from the sensitized and non-sensitized 304 stainless steel welds and non-sensitized 316 stainless steel welds. Approximately 1 cm² area was exposed to the test solution and rest of the electrode was masked with high temperature, acid resistant, epoxy. A schematic of the test setup is shown in Figure 1.

Free corrosion potential (E_{corr})

Free corrosion potential (E_{corr}) of 304 stainless steels welds (sensitized and non-sensitized) and 316 stainless steels welds (non-sensitized) was measured at two temperatures (room temperature and 40°C) in food product and lime juice until a stable potential was observed.

Linear Polarization Resistance (LPR) Corrosion Rates

Linear polarization resistance (LPR) scans were then performed. The LPR scans were run from -20 mV to +20 mV with respect to E_{corr} at a scan rate of 0.167 mV/sec. Polarization resistance (R_p) of the corroding electrode was obtained from the slope of the potential versus current density plot. Based on a Stern-Geary coefficient⁵ of 0.12 V/decade, corrosion rates were then calculated using Gamry¹ software per the ASTM G 59 standard.⁵ Note that the Stern-Geary equation describes the relationship between the Polarization Resistance (R_p) and the Corrosion Current (i_{CORR}) from which corrosion rate is calculated.

Potentiodynamic Polarization Scans

A potentiodynamic polarization test was performed at 40°C in the above-mentioned test solutions by scanning from -0.5 V to +1 V (SCE) with respect to E_{corr} at 0.167 mV/sec scan rate. Note that these tests were conducted under naturally aerated conditions; no inert gas was purged for any of the tests.

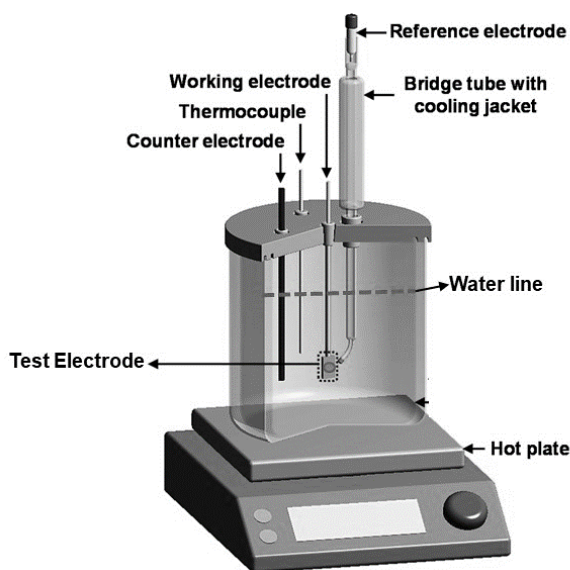


Figure 1: Schematic of the electrochemical corrosion cell with test electrode.

¹Trade name.

RESULTS

Free corrosion potential (E_{corr}) & Linear Polarization Resistance (LPR) Corrosion Rates

Stable E_{corr} and LPR corrosion rates measured in both test solutions at room temperature (RT) and at 40°C are provided in Table 1. E_{corr} values measured in food product and lime juice are plotted in Figures 2 and 3, respectively. Similarly, calculated corrosion rates from LPR scans in food product and lime juice are plotted in Figures 4 and 5, respectively. A dramatic increase in corrosion rate is seen for the sensitized welds with increase in temperature from room temperature to 40°C.

The corrosion rates of 304 sensitized weld showed higher corrosion rates than non-sensitized 304 and 316 stainless steel welds. The corrosion rate of sensitized 304 weld at 40°C in both test solutions is much higher than non-sensitized 304 and 316 welds. The corrosion rate in lime juice is also higher compared to food product due to lower pH.

Table 1
Free corrosion potential (E_{corr}) and Linear Polarization Resistance (LPR) Corrosion Rates for 304 and 316 Stainless Steel Welds.

Test Material	Temperature (°C)	Food Product (pH 3.6)	
		Corr. Potential Vs. SCE (mV)	LPR-Corrosion Rate (µm/year)
Sensitized 304 Weld	RT	110	0.83
Non-Sensitized 304 Weld		200	0.08
Non-Sensitized 316 Weld		250	0.08
Sensitized 304 Weld	40	67	10.30
Non-Sensitized 304 Weld		30	0.23
Non-Sensitized 316 Weld		137	0.15
Test Material	Temperature (°C)	Lime Juice (pH 2.9)	
		Corr. Potential Vs. SCE (mV)	LPR-Corrosion Rate (µm/year)
Sensitized 304 Weld	RT	95	2.42
Non-Sensitized 304 Weld		111	1.29
Non-Sensitized 316 Weld		212	0.15
Sensitized 304 Weld	40	141	25.76
Non-Sensitized 304 Weld		40	9.09
Non-Sensitized 316 Weld		195	5.23

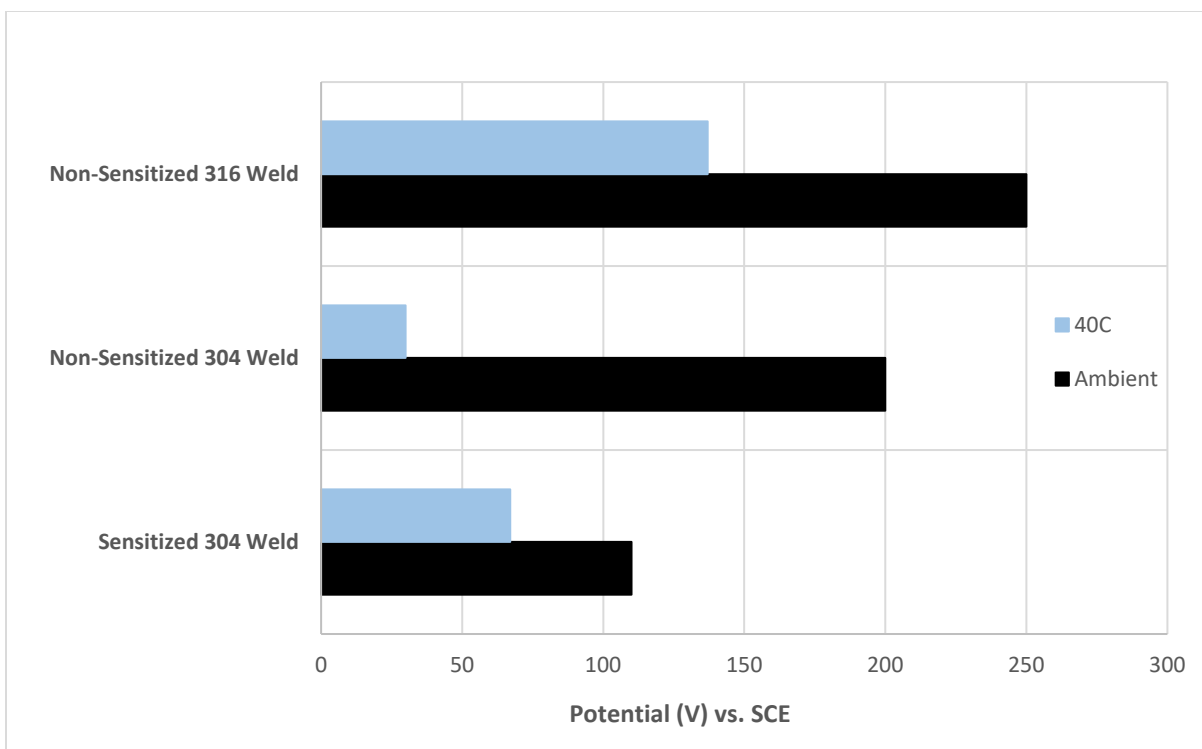


Figure 2: Bar graph showing the free corrosion potential of 304 and 316 Stainless Steel welds in Food Product.

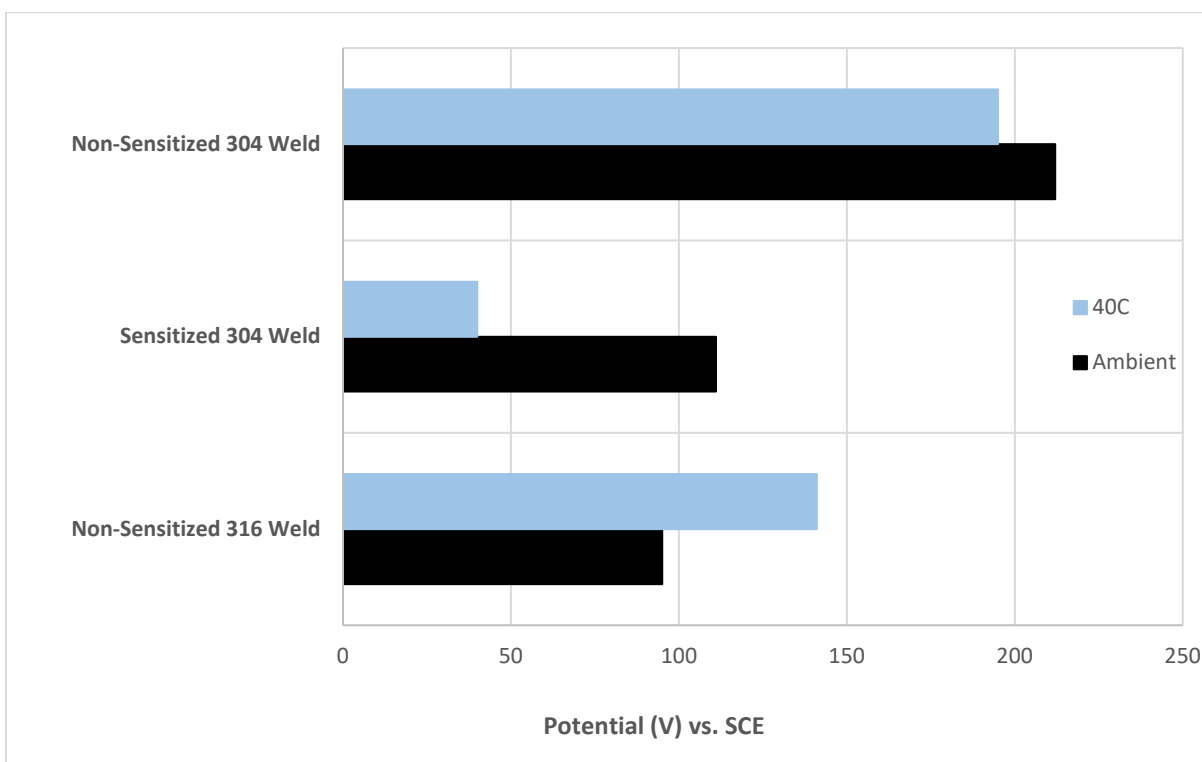


Figure 3: Bar graph showing the free corrosion potential of 304 and 316 Stainless Steel welds in Lime Juice.