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Stain-Less

Dear Advice & Counsel,
I would like to have more information on the metallurgy passivation of stainless steel. We are having problems passing the salt spray test.

Signed,
One of your past students

Dear Student:
The term "stainless" as it applies to stainless steel is misleading, as many think that stainless steel can not corrode (because it is stainless). The correct term should be "stains-less but still may corrode steel". Another term used for stainless steel is CRES (corrosion-resistant steel).

The reality is that parts manufactured from stainless steel can readily corrode because they most often have "free" iron imbedded into the surface by whatever manufacturing processes such as stamping, grinding, welding and forging may have been used.

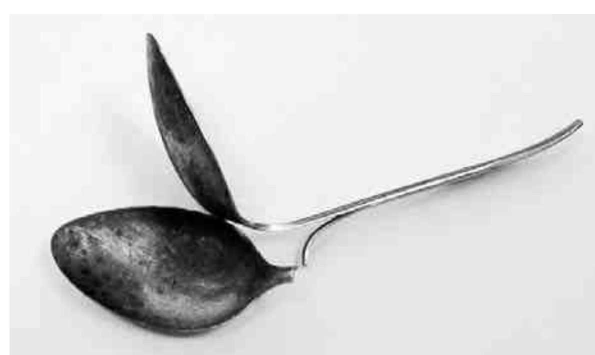
There also is the issue of "quality" of stainless steel, as there are numerous types of alloys, and compositional quality can vary greatly.

What makes steel "stainless" is the incorporation of at least 11.5% chromium into the iron-carbon (steel) alloy. The most corrosion-resistant stainless steels will also contain significant percentages of nickel, and some alloys contain additional alloying elements such as molybdenum and vanadium. A general rule is that the higher the chromium and nickel content, the higher the quality (corrosion resistance) of the stainless steel alloy. Chromium and nickel are metals that naturally form an oxide layer when exposed to air, and it is this oxide layer that acts as an effective barrier to many commonly encountered corrosive environments. However, this oxide layer can be compromised by acidic environments containing halogens such as fluoride, chloride and bromide. Stainless steel is typically not considered suitable for applications in which these ions are present. Hydrochloric acid, for example, is well known to cause intergranular attack and chloride ions are well known to cause stress corrosion cracking of stainless steel. There are some proprietary stainless steel alloys are designed to resist this type of corrosion.

When stainless steel is subjected to high temperature conditions such as a welding operation, the chromium may migrate to grain boundaries, forming carbides. The reduction of chromium due to the formation of carbides can make welds significantly lower in corrosion resistance. Alloys containing <0.03% carbon are preferred for welding, for this reason.

When stainless steel has free iron embedded into the surface, a galvanic cell is produced, in which the free iron is the anode and the stainless steel is the cathode. Depending on the alloy, the cell voltage is between 0.1 to 0.3 V (316 and 600 series stainless produce the higher voltages). When exposed to an electrolyte such as a salt spray mist, the battery is completed and the free iron quickly (often within minutes) begins to rust.

Consider the spoon in the accompanying photo. It was made by cladding two layers of 400 series stainless steel together, but a manufacturing defect caused the layers to split, creating a thin unnoticeable cavity (In the photo we have separated the layers to show the corrosion.). This thin cavity soaked up liquid as the spoon was used (by one of my friends to eat soup in a restaurant). The trapped liquid between the stainless steel layers acted as an electrolyte, completing the battery. In addition, the thin crevice produced an oxygen concentration cell. The end result was severe corrosion between the layers of stainless steel, and bad tasting soup which my friend asked me to investigate (he refuses to eat there again).



Let's delve deeper into some of the more commonly encountered stainless alloys:

200-300 (Austenitic) grade stainless steel

The vast majority of stainless steel manufactured is of the 300 series variety. These alloys contain nickel and or manganese to stabilize the austenitic crystal structure. These alloys are non-magnetic and contain a minimum of 16% chromium. The carbon in these alloys adds strength and hardness. The alloys can be heat treated to yield additional hardness. 300 series alloys offer excellent service under very low temperature conditions.

These steels exhibit superior corrosion resistance in a wide range of environments. The properties can only be modified by cold work. They are also significantly more expensive than the 400 series stainless grades. The thermal expansion of 200-300 series stainless steel is close to copper, but the thermal conductivity is extremely low.

Some popular alloys in this grade are:

303 (<0.15% C, 17-19% Cr, 8-10% Ni, <2% Mn, <1% Si, <0.2% P, >0.15%S)
This alloy typically contains enough sulfur and phosphorus to make it easier to machine vs. 304. It is a commonly used alloy in screw machine applications.

The high sulfur content also contributes to resistance to galling (cold welding of stainless steel when mated to itself using fasteners). The 303 alloy is less corrosion resistant than the 304 alloy.

304 (17.5-20% Cr, 8-11% Ni, <2% Mn, <1% Si, <0.45%P, <0.03%S, <0.08%C)
This is the most commonly encountered stainless steel and is also known as "18/8" stainless steel. The crystal structure allows this alloy to be deep drawn without intermediate annealing. Commonly manufactured parts include kitchen sink tubs, hollow-ware and saucepans (304DDQ). This alloy can readily be welded. Post-weld annealing is required when welding heavy sections of the 304 alloy, but is not typically required with the 304L (low carbon) version. 304 also comes in a high carbon version (304H) for high temperature applications.

316 (16-18.5% Cr, 10-14% Ni, 2-3% Mo, <2% Mn, <1% Si, <0.45%P, <0.03%S, <0.03%C)
The main difference between 316 and 304 stainless is the molybdenum content. Molybdenum increases the resistance of the alloy to attack by corrosives such as chloride. The 316 alloy is considered to be superior to 304 in most any corrosive environment. This alloy can readily be welded. Post-weld annealing is required when welding heavy sections of the 316 alloy but is not typically required with the 316L (low carbon) version. This alloy is commonly found in food contact and in many medical applications.

400 (Ferritic) grade stainless steel

These alloys can easily be differentiated from 300 series by their magnetic properties. They contain between 10 and 27% chromium and only 0 to 2% nickel. Some ferritic alloys contain molybdenum (*e.g.*, 29Cr - 4Mo). While some alloys may be highly corrosion resistant, the lower chromium alloys typically are poor in all but the most benign environments. Commonly encountered 400 series alloys include:

420 (<0.15% C, 12.0-14.0% Cr, <1.0% Mn, <1.0% Si, <0.04% P, >0.03% S)
This alloy contains just enough chromium to improve the corrosion resistance vs. non-stainless steel. It can be heat treated to very high hardness (Rockwell C 50). The most common use is cutlery. This alloy is poor in weldability. It turns brittle at subzero temperatures.

430 (<0.12% C, 16-18% Cr, <0.75% Ni, <1.0% Mn, <1.0% Si, <0.040% P, <0.030% S)
This is a non-heat treatable alloy offering good formability and better corrosion resistance than 420. The most common application for this alloy is decorative trim on consumer items such as appliances and automobiles.

400 (Martensitic) stainless steel

These stainless steels are heat treatable due to their higher carbon content. The martensitic 400 series stainless steels are less corrosion resistant than the ferritic 400 series alloys. These alloys offer good strength and corrosion resistance at high temperatures (up to around 750°C) contain enough carbon to make them heat treatable as a consequence of the higher carbon content, and are known as martensitic stainless steels (e.g. 410, 416). They do, however, exhibit lower corrosion resistance due to chromium depletion of the oxide film. They exhibit good strength and oxidation resistance up to 750°C. Creep resistance above 600°C is poor.

440 (0.65-1.0% C, 16-18% Cr, <1.0% Mn, <1.0% Si, <0.040% P, <0.030% S)
The higher carbon 440 alloys can attain the highest level of hardness, after heat treatment, of all stainless alloys, reaching a Rockwell C hardness of nearly 60. This stainless is commonly used for razor blades and other utensils requiring a sharp edge. The alloy comes in four grades (A, B, C and F). The A, B and C grades are in order of increasing carbon content, while the F grade is a free machining alloy. The lower carbon alloys are more corrosion resistant, while the higher carbon alloys are harder after heat treatment.

600 (Martensitic) grade stainless steel

These alloys are also magnetic. They are typically heat treated to yield high tensile strength and are popular in aerospace applications. The chromium content is 12 to 14%. Other alloying elements include carbon (0.1 to 1.0%) and nickel (0 to 2%). These alloys are typically less corrosion resistant than the 300 and some 400 series alloys.

These alloys contain elements such as copper, aluminum and/or titanium which form finely dispersed alloy precipitates during ageing (storage for many hours at specific high temperatures). A desirable feature of these alloys is that they can be hardened at low enough temperatures to allow for hardening after forming/machining, without scale formation. Common alloys in this group include 17-4PH (17% chromium-4% nickel) and 15-5PH stainless steel.

There are numerous other alloys, including mixtures of austenitic and ferritic alloys (duplex stainless steels), but the above are the most commonly encountered.

Next month we'll cover the passivation process. *P&SF*

***Editor's Note:** The reader will notice that, by happy coincidence, two of our columnists, Frank Altmayer and Steve Rudy, have both written on stainless steels this month. They have provided both complementary supplementary and most valuable information on this important topic.–Ed.*

Answers to I.Q. Quiz #440

1. Vibration frequency and amplitude.
2. The action of the media against the part surfaces occurs throughout the load.
3. (a) Open-topped tub; (b) bowl (round or toroidal).
4. (a) By a vibratory motor, (b) a rotating shaft with an eccentric load or (c) electromagnets operating at an alternating frequency.
5. Faster; rougher