The Basics of Stainless Steel

by Laurence Claus

Introduction

In 1913 English metallurgist Harry Brearley was working on a project to develop an improved steel for gun barrels that was more erosion resistant than the current steel of the day. He was experimenting with Chromium alloy steels and happened to try one that had 12.8% Chromium and 0.24% Carbon. As often happens, what begins with one goal in mind results in an entirely different outcome. In this case, Mr. Brearley's erosion resistant experiments would result in a steel far more corrosion resistant than normal steel. Stainless steel was born.

Today stainless steels are a part of everyday life and are used in a wide variety of applications from appliance coverings, pots and pans, marine components, automotive components, and even fasteners. Stainless steels are a logical choice when the primary goal of the designer is corrosion resistance, although other properties such as appearance and strength may be determining factors in a choice to use them. There are over 300 different iron based alloys containing a minimum of 11.5% chromium that comprise those materials considered stainless steels.

Stainless steel achieves its corrosion resistant properties through the formation of a chromium rich oxide (Cr2O3) film. This oxide naturally forms in the presence of oxygen and is self-healing when scratched or abraded. This means that the oxide will reform and heal itself when it gets damaged because of a scratch, nick, or bump.

Stainless steels can be categorized into one of five different families. These are distinguishable from one another by their crystalline structure which defines their properties and determines certain fundamental behavior, such as magnetism and heat treatability. The five different families of stainless steel are Austenitic, Ferritic, Martensitic, Precipitation Hardening, and Duplex stainless steels. This article will explain the characteristics and compare and contrast each of these five families of stainless steel.

Austenitic Stainless Steel

When people think about stainless steel, it is Austenitic stainless steel that they most frequently associate with. Austenitic stainless steels generally contain about 18% Chromium and 8% Nickel. For this reason, these are often referred to as 18-8 stainless. Unfortunately, this description is not specific enough to truly designate the exact composition, and should not be used for purchasing or design purposes. In the North American designation system, these stainless steels are identified as the 200 and 300 series alloys. The most common Austenitic stainless steel varieties used for fasteners are 304, 302HQ (HQ means Heading Quality), 204-Cu, 316 and 321. Internationally, the common designation is A2 for a 304 equivalent and A4 for a 316 equivalent.

Austenitic stainless steels have the best corrosion resistance of all the stainless families. They are usually non-magnetic, and have an attractive appearance and luster. This family of stainless steels is not heat treatable but can work harden at a rapid pace during cold working. For this reason, these materials can be extremely challenging to cold head, especially on parts with complicated geometries, heavy extrusions, and large upsets. Although these materials cannot be strengthened through heat treatment, they can be annealed to restore ductility in instances where significant cold work is performed. Otherwise, these materials have good ductility and toughness.

One of the desirable properties of Austenitic stainless steels is that they are not magnetic. However, it is not uncommon for a user to be confounded by Austenitic stainless steel parts that exhibit a mild level of magnetism. How can this be?

Magnetism is gauged by a material's Magnetic Permeability or degree to which it can form a magnetic field within itself. Magnetic Permeability, like many material properties, is a function of the metal's internal structure. In the case of Austenitic stainless steel the atoms take a structure known as Face Centered Cubic, which is not magnetic. Another gross structure in stainless steel is Martensite which has an atomic crystal structure that is Body Centered Tetragonal in orientation which is magnetic. Under normal conditions Austenitic stainless steel should contain either no or very minute levels of Martensite. However, under conditions of extreme cold working or slow cooling from high temperatures, Austenitic stainless steel can experience what is known as Martensitic Stress Induced Transformation (MSIT), or the formation of some Martensite. The degree to which Martensite is formed will determine whether the parts exhibit some mild level of magnetism. The lower the alloy content (Ni, C, and N) the more susceptible they are to Martensitic Stress Induced Transformation. Therefore, 304 stainless steel will be more susceptible to MSIT after cold working than 316 stainless steel. The non-magnetic form can be stored through a simple thermal stress relief process.

Ferritic Stainless Steel

One of the ways that Ferritic stainless steels are different from Austenitic stainless steels is their absence of Nickel in any greater than trace concentrations. In North America, these steels are designated with a 400 series number. Great caution must be exhibited, however, because Martensitic stainless steel also is described with a 400 series number. Therefore, to get the right family for classification the Chromium and Carbon content is important to know as it is the determining factor between these two families of stainless steel.

Ferritic stainless steels provide moderate corrosion protection, are magnetic, and are not heat treatable.

Unlike Austenitic grade stainless steel these materials have only a moderate work hardening rate during cold work. For this reason they form pretty well but result in parts relatively low in strength. Relative to the other stainless steel options, these materials are low cost. For this reason they are favored by users that want better than average corrosion protection but are unwilling to pay the price for the better performing Austenitic stainless steel. Common Ferritic stainless steel fastener grades include 409Cb and 430 stainless steels.

Martensitic Stainless Steel

As already explained above with respect to Ferritic stainless steel, the Martensitic stainless steels also are identified with a 400 series number and have little or no Nickel in their composition. In the same way as with Ferritic varieties, the Chromium and Carbon content is the determining factor which family they will be included in. Martensitic stainless steel contains anywhere from about 12% to 17% Chromium by weight.

Of the three families considered to this point, they have the lowest corrosion resistance. They are magnetic, have moderate work hardening rates, and are heat treatable by Bright Hardening. Bright Hardening is accomplished in a vacuum furnace and improves the surface to a bright, shiny luster. In addition to the excellent appearance, these parts exhibit high strength after heat treatment. Common grades of Martensitic stainless steel used for fasteners include 410, 431, and 420.

Precipitation Hardening Stainless Steels

These materials offer the best combination of strength and corrosion resistance of all the varieties. In general their corrosion resistance is a little less than the Austenitic stainless steels but when considering the ratio between achievable strength and corrosion resistance they are superior. They are magnetic.

Precipitation Hardening stainless steel uses a completely different strengthening mechanism than quenched and tempered steel. They harden by a mechanism of solution heat treating and aging. In this process the material is sufficiently heated so that all the constituents go into solution like sugar dissolves into hot tea. The material is then quenched to "fix" everything in solution. As time goes by the constituents start to form precipitates, which are new harder structures formed by chemical reactions of the dissolved constituents in solution. These newly formed precipitated structures are harder and stronger than the constituents prior to heat treating. The process of allowing time to precipitate these new structures is known as aging. This hardening process results in moderate to high strength parts and because of the way the process is conducted results in only minimal size change or distortion.

Precipitation Hardening stainless steels can be difficult to form or machine. Often they have high yield and tensile strengths and are not as ductile as Austenitic stainless steels. For these reasons only fastener manufacturers experienced with these materials usually choose to be suppliers. Commonly used Precipitation Hardened fastener grades include 17-4PH, 15-7PH, and PH13-8Mo®.

Duplex Stainless Steels

Duplex stainless steels are relatively new in the market. They seek to combine the best attributes of Austenitic and Ferritic stainless steels and are usually about a 50/50 combination of the two. They are stronger than either Austenitic or Ferritic stainless steels on their own. They also exhibit improved resistance to localized corrosion, especially pitting and crevice corrosion, and they increase the resistance to stress corrosion cracking.

Duplex stainless steels are high in Chromium and Molybdenum but low in Nickel. They are magnetic. They are not heat treatable, but can be strengthened through cold work. Common Duplex stainless steel fastener grades include Alloy 2205 and Alloy 255.

Passivation

Users are often surprised to find small spots of rust on the surface of stainless steel parts. This can lead them to believe that they have not been supplied the correct material. This is not an uncommon situation as parts are exposed to carbon steel or iron sources during processing, usually during part collection which is often done in steel pans or tubs. Contact with these steel pans or tubs can transfer trace amounts of iron onto the surface of the parts. These iron particles, in turn, oxidize making it appear that the part is rusting when, in fact, it is not.

To prevent this, stainless steel parts are often passivated. Passivation is the process of immersing the parts in a heated acid solution, usually either citric acid or nitric acid. This process serves to clean the parts of any iron contamination, remove any copper that may still be present from a coating on the wire, and make the parts more galvanically passive.

Selecting the Proper Stainless Steel

Proper selection hinges on a number of factors, but is primarily a function of what kind of performance and properties are needed. The most common influencers of choice are:

- Corrosion resistance required
- Environment the part will be used in (Special care must be taken when the application is subject to crevice corrosion attack, stress corrosion cracking, hydrogen embrittlement, and sulfide stress cracking.)
- Strength required especially if at elevated or depressed temperatures
- Formability
- Weldability
- Machinability
- Cost

Excellent resource materials exist that assist the designer in choosing the right material. These resources show all sorts of relationships of factors such as headability relative to corrosion resistance or the effects on Tensile Strength as a result of the percent of cold work. Collectively the designer should be able to narrow down a choice of stainless steel that best fits their needs.

Conclusion

Stainless steels can be exceptional materials to use on fasteners that must perform in severe environments such as food processing applications and where chlorides are present such as paper mills, ink production, textiles and rubber. In addition to such demanding applications, stainless steels fasteners are used in many everyday applications where the designer simply does not want the parts to corrode, or is seeking a specific appearance or look. Although stainless steel fasteners may not be needed in many applications, Harry Brearley's accidental discovery over a hundred years ago is still welcomed today for those that do. ■