Stainless Steels *Part 1*

by Guy Avellon

There are hundreds of different types, or alloys, that make up stainless steels. Each is developed to produce its own unique properties. Originally called 'rust-less' steel, it is an alloy of a very low carbon steel that contains a minimum of 12% chromium. This alloy has the ability to form a thin, but tenacious film of passive chromium oxide at the surface in the presence of oxygen. This invisible film is what provides the basis for its resistance to atmospheric corrosion and to most oxidizing agents.

Since iron exists in steel in different crystalline structures, the defining difference is the amount of carbon they can absorb. The higher the amount of carbon, the harder and more brittle it becomes. Therefore, stainless steels generally contain very low amounts of carbon. Crystals form when molten steel cools through multiple temperature ranges. Austenite is created by heating ferrite to 912° C (1,674° F), at which point the BCC (Body Centered Cubic) structure transforms into a FCC (Face Centered Cubic) structure which can absorb up to 2% carbon. Austenite retains its structure (stabilizes) from the addition of nickel and manganese.

Elements, such as nickel, manganese, copper, molybdenum, columbium, etc. may be added to further increase corrosion and oxidation resistance, increase its tensile strength or enhance its heat resistance. These alloying elements have led to the formation of five main classes of stainless steels; austenitic, martensitic, ferritic, precipitation hardening and duplex steels.

Austenitic stainless steels are the chromium-nickel chromium-nickel-manganese based stainless steels. These products are essentially nonmagnetic in the annealed condition. They can be hot worked but will cold work rapidly. Cold working may produce a slight magnetic condition, which can be differentiated from a strong magnetic attraction. The austenitic steels exhibit the best high-temperature strength, corrosion resistance and resistance to heat scaling than the martensitic and ferritic steels. Austenitic stainless steels are also susceptible to intergranular corrosion at temperatures between 425 and 870° C (800 - 1,600° F) because of carbide precipitation in the grain boundaries.

Typical austenitic stainless steels are represented by AISI (American Iron and Steel Institute) Types 301, 302, 309, 314, 316, 317, 321, 330, 347 and 384. Due to the shortage of nickel during World War II, using manganese as a substitute for nickel led to the development of AISI Types 201 and 202. The 200 series are a chromium-nickel-manganese stainless steel. The type 201 has a nominal composition of 17% chromium, 4.5% nickel and 6.6% manganese. This was found to be a suitable replacement for type 301 (17% Cr and 7% Ni). Where formability or machining was needed, type 202 was developed with a nominal composition of 18% Cr, 5% Ni and 8% Mn. The addition of manganese reduced the rate of work hardening, so it is used for washing machine tubs and structural applications. The atmospheric corrosion resistance is comparable with 301 and 302, though the chemical resistance is somewhat lower.

Martensitic stainless steels are primarily straight chromium steels containing between 11.5 and 18% chromium. Martensitic steel is a BCT (body-centered tetragonal) crystalline structure which is created when heated austenite is rapidly cooled by quenching. This rapid cooling prevents brittleness. The martensitic group of stainless steels are ferromagnetic and can be hardened by heat treatment. They can be cold worked without any difficulty due to the low carbon content, can be machined and they can be hot worked. This series shows good toughness and good corrosion resistance to weather and some chemicals. Their best chemical resistance is obtained when hardened from room temperature.

Typical martensitic stainless-steel types are; 403, 410, 414, 416, 420, 431 and 440. Types most commonly used are: 403 for turbine blades; 410 for general purpose; 414 for springs, knife blades and tempered rules; 416 for automatic screw machine parts; 420 for surgical instruments and ball bearings; 431 for high strength parts, pumps and valves; 440 for instruments, valves and flat ware.

Ferritic stainless steels are also a BCC structure which is magnetic and can be hardenable by cold working or hot working. They develop maximum softness, ductility and corrosion resistance in the annealed condition. These are straight chromium stainless steels which are not hardenable by heat treatment. The ferritic stainless steels have a lower strength at elevated temperatures than the martensitic type, but their resistance to scaling and corrosion is generally better.

Typical ferritic stainless-steel types include: 405 for quenching racks and annealing boxes; 409 for automotive exhausts and heat exchangers; 429 for chemical processing equipment, especially for handling nitric acid; 430 for automotive trim, kitchen equipment; 434 for automotive trim and fasteners; 446 for high temperature service for glass molds, furnace parts and chemical processing equipment. Type 446 is one of the most oxidation resistant steels commercially available.

Precipitation hardening stainless steel is a form of hardening by having impurities or additions of copper, aluminum, titanium, niobium and / or molybdenum. The metal is heated to very high temperatures to dissolve all elements and alloys into a single-phase solution and remains in this condition during rapid cooling. Rapid cooling prevents diffusion. When reheated to 650 - 760° C (1,200-1,400° F) the precipitation occurs. The precipitate particles of alloy material and undissolved carbides disperse into the grain structure of the steel to fill voids and help the crystalline structure become stronger by resisting any movement against the lattice structure.

The precipitation hardening, or age hardening alloys, have much higher tensile strengths and hardnesses, excellent fatigue properties and heat resistance to 900ºF (482ºC). They lack the chemical resistance of the 300 series but are still superior to other hardenable chromium alloys. Typical precipitation hardened alloys are designated by the suffix of 'PH', such as 15-5 PH, 17-4 PH, 17-7 PH. The 17-4 PH has a composition of 17% chromium, 4% nickel, 4% copper and 0.3% niobium.

In the next series, we will discuss the particular properties, available physical treatments, specification numbering systems and uses and limitations. Remember, most of these stainless steels are only a little better than a Grade 2 fastener in strength, but have very sophisticated metallurgical alloying for corrosion and heat resistance. Some are very costly, but choosing the correct alloy will be a cost savings in the long run. ■