The Stainless Steel Family

A short description of the various grades of stainless steel and how they fit into distinct metallurgical families. It has been written primarily from a European perspective and may not fully reflect the practice in other regions.

Stainless steel is the term used to describe an extremely versatile family of engineering materials, which are selected primarily for their corrosion and heat resistant properties.

All stainless steels contain principally iron and a minimum of 10.5% chromium. At this level, chromium reacts with oxygen and moisture in the environment to form a protective, adherent and coherent, oxide film that envelops the entire surface of the material. This oxide film (known as the passive or boundary layer) is very thin (2-3 namometres). [1nanometre = 10-9 m].

The passive layer on stainless steels exhibits a truly remarkable property: when damaged (e.g. abraded), it self-repairs as chromium in the steel reacts rapidly with oxygen and moisture in the environment to reform the oxide layer.

Increasing the chromium content beyond the minimum of 10.5% confers still greater corrosion resistance. Corrosion resistance may be further improved, and a wide range of properties provided, by the addition of 8% or more nickel. The addition of molybdenum further increases corrosion resistance (in particular, resistance to pitting corrosion), while nitrogen increases mechanical strength and enhances resistance to pitting.

Categories of Stainless Steels

The stainless steel family tree has several branches, which may be differentiated in a variety of ways e.g. in terms of their areas of application, by the alloying elements used in their production, or, perhaps the most accurate way, by the metallurgical phases present in their microscopic structures:

- Ferritic
- Martensitic (including precipitation hardening steels)
- Austenitic
- Duplex steels, consisting of mixture of ferrite and austenite

Within each of these groups, there are several “grades” of stainless steel defined according to their compositional ranges. These compositional ranges are defined in European (and other e.g. USA) standards, and within the specified range, the stainless steel grade will exhibit all of the desired properties (e.g. corrosion resistance and/or heat resistance and/or machineability). More detail on standards and grades is given below.

Ferritic stainless steels (e.g. grades 1.4512 and 1.4016) consist of chromium (typically 12.5% or 17%) and iron. Ferritic stainless steels are essentially nickel-free. These materials contain very little carbon and are non-heat treatable, but exhibit superior corrosion resistance to martensitic stainless steels and possess good resistance to oxidation. They are ferromagnetic and, although subject to an impact transition (i.e. become brittle) at low temperatures, possess adequate formability. Their thermal expansion and other thermal properties are similar to conventional steels. Ferritic stainless steels are readily welded in thin sections, but suffer grain growth with consequential loss of properties when welded in thicker sections.

Martensitic stainless steels (e.g. grades 1.4006, 1.4028 and 1.4112) consist of carbon (0.2-1.0%), chromium (10.5-18%) and iron. These materials may be heat treated, in a similar manner to conventional steels, to provide a range of mechanical properties, but offer higher hardenability and have different heat treatment temperatures. Their corrosion resistance may be described as moderate (i.e. their corrosion performance is poorer than other stainless steels of the same chromium and alloy content). They are ferromagnetic, subject to an impact transition at low temperatures and possess poor formability. Their thermal expansion and other thermal properties are similar to conventional steels. They may be welded with caution, but cracking can be a feature when matching filler metals are used.

Austenitic stainless steels (e.g. grades 1.4301 and 1.4833) consist of chromium (16-26%), nickel (6-12%) and iron. Other alloying elements (e.g. molybdenum) may be added or modified according to the desired properties to produce derivative grades that are defined in the standards (e.g. 1.4404). The austenitic group contains more grades, that are used in greater quantities, than any other category of stainless steel. Austenitic stainless steels exhibit superior corrosion resistance to both ferritic and martensitic stainless steels. Corrosion performance may be varied to suit a wide range of service environments by careful alloy adjustment e.g. by varying the carbon or molybdenum content. These materials cannot be hardened by heat treatment and are strengthened by work-hardening. Unlike ferritic and martensitic stainless steels, austenitic grades do not exhibit a yield point. They offer excellent formability and their response to deformation can be controlled by chemical composition. They are not subject to an impact transition at low temperatures and possess high toughness to cryogenic temperatures. They exhibit greater thermal expansion and heat capacity, with lower thermal conductivity than other stainless or conventional steels. They are generally readily welded, but care is required in the selection of consumables and practices for more highly alloyed grades. Austenitic stainless steels are often described as non-magnetic, but may become slightly magnetic when machined or worked.

Duplex stainless steels (e.g. grade S31803) consist of chromium (18-26%) nickel (4-7%), molybdenum (0-4%), copper and iron. These stainless steels have a microstructure consisting of austenite and ferrite, which provides a combination of the corrosion resistance of austenitic stainless steels with greater strength. Duplex stainless steels are weldable, but care must be exercised to maintain the correct balance of austenite and ferrite. They are ferromagnetic and subject to an impact transition at low temperatures. Their thermal expansion lies between that of austenitic and ferritic stainless steels, while other thermal properties are similar to plain carbon steels. Formability is reasonable, but higher forces than those used for austenitic stainless steels are required.

Effect of Alloying on Structure and Properties

CHROMIUM

Chromium is by far the most important alloying element in stainless steel production. A minimum of 10.5% chromium is required for the formation of a protective layer of chromium oxide on the steel surface. The strength of this protective (passive) layer increases with increasing chromium content. Chromium prompts the formation of ferrite within the alloy structure and is described as ferrite stabiliser.

NICKEL

Nickel improves general corrosion resistance and prompts the formation of austenite (i.e. it is an austenite stabiliser). Stainless steels with 8-9% nickel have a fully austenitic structure and exhibit superior welding and working characteristics to ferritic stainless steels. Increasing nickel content beyond 8-9% further improves both corrosion resistance (especially in acid environments) and workability.

MOLYBDENUM (AND TUNGSTEN)

Molybdenum increases resistance to both local (pitting, crevice corrosion, etc) and general corrosion. Molybdenum and tungsten are ferrite stabilisers which, when used in austenitic alloys, must be balanced with austenite stabilisers in order to maintain the austenitic structure. Molybdenum is added to martensitic stainless steels to improve high temperature strength.

NITROGEN

Nitrogen increases strength and enhances resistance to localised corrosion. It is austenite former.

COPPER

Copper increases general corrosion resistance to acids and reduces the rate of work-hardening (e.g. it is used in cold-headed products such as nails and screws). It is an austenite stabiliser.

CARBON

Carbon enhances strength (especially, in hardenable martensitic stainless steels), but may have an adverse affect on corrosion resistance by the formation of chromium carbides. It is an austenite stabiliser.

TITANIUM (AND NIOBIUM & ZIRCONIUM)

Where it is not desirable or, indeed, not possible to control carbon at a low level, titanium or niobium may be used to stabilise stainless steel against intergranular corrosion. As titanium (niobium and zirconium) have greater affinity for carbon than chromium, titanium (niobium and zirconium) carbides are formed in preference to chromium carbide and thus localised depletion of chromium is prevented. These elements are ferrite stabilisers.

SULPHUR

Sulphur is added to improve the machinability of stainless steels. As a consequence, sulphur-bearing stainless steels exhibit reduced corrosion resistance.

CERIUM

Cerium, a rare earth metal, improves the strength and adhesion of the oxide film at high temperatures.

MANGANESE

Manganese is an austenite former, which increases the solubility of nitrogen in the steel and may be used to replace nickel in nitrogen-bearing grades.

SILICON

Silicon improves resistance to oxidation and is also used in special stainless steels exposed to highly concentrated sulphuric and nitric acids. Silicon is a ferrite stabiliser.

Stainless Steel Grade Designations

In Europe, stainless steel types are usually defined by designations given in Euronorm EN 10088 – Stainless Steels (for general purposes). These designations follow the Werkstoff numbering system for steels originally developed in German (e.g. 1.4301). Common US designations are also widely known, the most popular being the AISI series (e.g. AISI 303) and the ASTM series (e.g., ASTM S41050).

Under the appropriate application headings in this section of the website http://worldstainless.org/applications tables can be found which list the most common stainless steel types used in those particular applications. In the case of medical (non-implant) devices, both EN 10088 and US designations are provided but in addition reference is made to specific standards applicable to medical devices (e.g. ISO 7153-1). Medical implants have specific material specifications (e.g. ISO 5832-1 and ISO 5832-9), which do not have an equivalent EN 10088 grade.

Footnote: The above information has been extracted from a document prepared by Tony Newson of Eurofer, Brussels, whose objective was to provide a summary of the basic grades of stainless steel commercially available and to indicate which grades are most commonly used in some of the principal application categories.

Broad categories of use (e.g. transport, consumer goods etc) are defined, along with the stainless steel grades most commonly used for those applications. This extract deals mainly with the principal grades and the alloying elements contained in them. Specific information related to the main categories of use may be found under the following library headings:

- What can stainless steel do for - Transport
    - Automotive
    - Shipbuilding/Marine
    - Railway
    - Aerospace
- Home & Office
    - Consumer applications