Stainless Steel - Introduction

Stainless steel is not a single material but the name for a family of corrosion resistant steels. Like many scientific discoveries the origins of stainless steel lies in a serendipitous accident. In 1913 Sheffield, England, Harry Brearley was investigating the development of new steel alloys for use in gun barrels. He noticed that some of his samples didn't rust and were difficult to etch. These alloys contained around 13% chromium.

The first application of these steels was in cutlery for which Sheffield subsequently became world famous. Simultaneous work in France led to the development of the first austenitic stainless steels.

Worldwide demand for stainless steel is increasing at a rate of about 5% per annum. Annual consumption is now well over 20 million tonnes and is rising in areas such as the construction industry and household appliances. New uses are being continuously found for the attractive appearance, corrosion resistance, low maintenance and strength of stainless steel. Stainless steel is more expensive than standard grades of steel but it has greater resistance to corrosion, needs low maintenance and has no need for painting or other protective coatings. These factors mean stainless steel can be more economically viable once service life and life-cycle costs are considered.

Properties of Stainless Steels

The advantageous properties of stainless steels can be seen when compared to standard plain carbon mild steel. Although stainless steels have a broad range of properties, in general, when compared with mild steel, stainless steels have:

- Higher corrosion resistance
- Higher cryogenic toughness
- Higher work hardening rate
- Higher hot strength
- Higher ductility
- Higher strength and hardness
- A more attractive appearance
- Lower maintenance

Corrosion Resistance

All stainless steels are iron-based alloys that contain a minimum of around 10.5% Chromium. The Chromium in the alloy forms a self-healing protective clear oxide layer. This oxide layer gives stainless steels their corrosion resistance. The self healing nature of the oxide layer means the corrosion resistance remains intact regardless of fabrication methods. Even if the material surface is cut or damaged, it will self heal and corrosion resistance will be maintained.

Conversely, normal carbon steels may be protected from corrosion by painting or other coatings like galvanising. Any modification of the surface exposes the underlying steel and corrosion can occur.

The corrosion of different grades of stainless steel will differ with various environments. Suitable grades will depend upon the service environment. Even trace amounts of some elements can markedly alter the corrosion resistance. Chlorides in particular can have an adverse effect on the corrosion resistance of stainless steel.

Grades high in Chromium, Molybdenum and Nickel are the most resistant to corrosion.

Cryogenic (Low Temp.) Resistance

Cryogenic resistance is measured by the ductility or toughness at sub zero temperatures. At cryogenic temperatures the tensile strengths of austenitic stainless steels are substantially higher than at ambient temperatures. They also maintain excellent toughness.

Ferritic, martensitic and precipitation hardening steels should not be used at sub-zero temperatures. The toughness of these grades drops significantly at low temperatures. In some cases this drop occurs close to room temperature.

Work Hardening

Work hardenable grades of stainless steel have the advantage that significant increases to the strength of the metal can be achieved simply through cold working. A combination of cold working and annealing stages can be employed to give the fabricated component a specific strength.

A typical example of this is the drawing of wire. Wire to be used as springs will be work hardened to a particular tensile strength. If the same wire was to be used as a bendable tie wire, it would be annealed, resulting in a softer material.

Hot Strength

Austenitic grades retain high strength at elevated temperatures. This is particularly so with grades containing high levels of chromium and/or high silicon, nitrogen and rare earth elements (e.g. grade 310 and S30815). High chromium ferritic grades like 446 can also show high hot strength.

The high chromium content of stainless steels also helps to resist scaling at elevated temperatures.

Ductility

Ductility tends to be given by the % elongation during a tensile test. The elongation for austenitic stainless steels is quite high. High ductility and high work hardening rates allows austenitic stainless steels to be formed using severe processes such as deep drawing.

High Strength

When compared with mild steels, stainless steels tend to have higher tensile strength. The duplex stainless steels have higher tensile strengths than austenitic steels.

The highest tensile strengths are seen in the martensitic (431) and precipitation hardening grades (17-4 PH). These grades can have strengths double that of TYPES 304 and 316, the most commonly used stainless steels.

Magnetic Response

Magnetic response is the attraction of steel to a magnet. Austenitic grades are generally not magnetic although a magnetic response can be induced in the low austenitic grades by cold working. High nickel grades like 316 and 310 will remain non-magnetic even with cold working.

All other grades are magnetic.

Stainless Steel Families

Although the corrosion resistance of stainless comes from the presence of Chromium, other elements are added to enhance other properties. These elements alter the microstructure of the steel.

Stainless steels are grouped into families based on their metallurgical microstructure. The microstructure may be composed of the stable phases austenite or ferrite, a “duplex” mix of these two, martensite or a hardened structure containing precipitated micro-constituents.

Austenitic Stainless Steels

Austenitic stainless steels contain a minimum of 16% chromium and 6% nickel. They range from basic grades like 304 through to super austenitics such as 904L and 6% Molybdenum grades.

By adding elements such as Molybdenum, Titanium or Copper, the properties of the steel can be modified. These modifications can make the steel suited to high temperature applications or increase corrosion resistance. Most steels become brittle at low temperatures but the Nickel in austenitic stainless makes it suited to low temperature or cryogenic applications.

Austenitic stainless steels are generally non-magnetic. They are not able to be hardened by heat treatment. Austenitic stainless steels rapidly work-harden with cold working. Although they work harden, they are the most readily formed of the stainless steels.

The principal alloying elements are sometimes reflected in the name of the steel. As an a common name for 304 stainless steel is 18/8, for 18% chromium and 8% nickel. ▶

Austenitic Stainless Applications

Applications for austenitic stainless steels include:

- Kitchen sinks
- Architectural applications such as roofing and cladding
- Roofing and gutters
- Doors and Windows
- Balustrading
- Benches and food preparation areas
- Food processing equipment
- Heat exchangers
- Ovens
- Chemical tanks

Ferritic Stainless Steels

Ferritic stainless steels include grades like 430 and contain only chromium as a major alloying element. The quantity of chromium present ranges from 10.5 to 18%.

They are known for their moderate corrosion resistance and poor fabrication properties. Fabrication properties can be improved by alloy modifications and are satisfactory in grades such as 434and 444. Ferritic stainless steels cannot be hardened by heat treatment and are always used in the annealed condition.

Ferritic stainless steels are magnetic. They are also not susceptible to stress corrosion cracking. Weldability is acceptable in thin sections but decreases as section thicknesses increase.

Ferritic Stainless Applications

Ferritic stainless steels are typically used in:

- Vehicle exhausts
- Fuel lines
- Cooking utensils
- Architectural trim
- Domestic appliances

Martensitic Stainless Steels

High carbon and lower chromium content are the distinguishing features of martensitic stainless steels when compared with ferritic stainless.

Martensitic stainless steels include 410 and 416. Hardened martensitic steels cannot be successfully cold formed. They are magnetic, have moderate corrosion resistance and poor weldability.

Martensitic Stainless Applications

Martensitic stainless steels are typically used for:

- Knife blades
- Cutlery
- Surgical instruments
- Fasteners
- Shafts
- Springs

Duplex Stainless Steels

Duplex stainless steels have high chromium and low nickel contents. This gives duplex stainless steels microstructures that include both austenitic and ferritic phases. They include alloys like 2304 and 2205. These alloys are so named due to their respective compositions - 23% chromium, 4% nickel and 22% chromium, 5% nickel.

By having both austenite and ferrite in the microstructure, duplex stainless steels feature properties of both classes. Although a compromise between the two 'pure' types, duplex grades can offer some unique property solutions. Duplex grades are resistant to stress corrosion cracking, but not to the same level as ferritic grades. The toughness of duplex grades is superior to that of the ferritic grades – but inferior to that of the austenitic grades.

Most importantly, the corrosion resistance of duplex steels is equal, or superior to 304 and 316 stainless steel. This is particularly so for chloride attack.

Duplex grades are readily welded. They also have high tensile strengths.

Duplex Stainless Applications

Duplex stainless steels typically find application in areas like:

- Heat exchangers
- Marine applications
- Desalination plants
- Food pickling plants
- Off-shore oil & gas installations
- Chemical & petrochemical plant

Precipitation Hardening Grades

Precipitation hardening grades contain both Chromium and Nickel. They develop very high tensile strengths with heat treatment. Precipitation hardening grades are usually supplied in a “solution treated” condition that allows the steel to be machined. After machining or forming, the steel can be aged in a low temperature heat treatment process. As the heat treatment is performed at low temperatures, no distortion is induced in the work piece.

630 is the most common precipitation hardening grade This grade is also known as 17-4 PH due to a composition of 17% chromium, 4% nickel, 4% copper and 0.3% niobium.

Precipitation Hardening Applications

Precipitation hardening stainless steels are typically used for:

- Pulp and paper industry equipment
- Aerospace applications
- Turbine blades
- Nuclear waste casks
- Mechanical components

Standard Classifications

The old AISI three digit stainless steel numbering system (e.g. 304 and 316) is still commonly used. New grades are defined under the SAE and ASTM system that uses a 1-letter + 5-digit UNS number. An example of this is the new term for 304, which is S30400. Other designations include old BS and EN numbers like 304S31 and 58E.

Some grades are not covered by standard numbers and could be proprietary grades or be named using standards for specialist products like welding wire.

Grade Selection

The grade selection process for stainless steels is a compromise between the desired properties of the finished product.

When selecting a particular grade of stainless steel, it is essential to consider the primary properties required, such as corrosion resistance and heat resistance. Important consideration must also be given to the secondary properties, like physical and mechanical properties. These properties will determine other factors such as the ease of fabrication of any candidate grades.

If the secondary properties are not adequate, it may not be possible to viably and economically produce the required product.

An example of this is 303 stainless steel. It has excellent machinability due to an addition of Sulphur. However, the Sulphur also gives 303 poor weldability, corrosion resistance and formability.

Selecting the correct grade will ensure the product will have a long trouble-free life combined with cost-effective fabrication and installation.

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