Stainless Steel was the descriptive term given to the new “rust resisting” steels discovered by essentially four persons in the early 1900’s. It has continued to be used as a generic term applied to an ever-increasing number of different grades of stainless steel.

What is “stainless steel” as compared to a large, somewhat confusing, number of different stainless steels?

Why are different stainless steels sometimes referred to by ‘strange’ names, eg Martensitic, Ferritic, Austenitic?

Some stainless steels are described as, for example, super alloys, exotic materials or high performance alloys - how do they fit in?

Are stainless steels indestructible materials and therefore a solution to all corrosion problems?

In this chapter, by reference to the more commonly used grades of wrought product (ie plate, sheet and bar), stainless steel is explained regarding the different classifications, together with an outline of the associated properties and typical applications.

The COMMON GRADES given are the American AISI grade numbers together with the similar New European Standard (EN) grade number in [     ]. The open {     } are to allow the reader to insert any grade number or designation with which they are more familiar.

The COMMON USES given are typical for the Classification as a whole. It does not mean that any one, or all, of the COMMON GRADES are suitable for any one, or all, such COMMON USES.

Stainless steels are based on alloying iron (Fe) with chromium (Cr).

Additional alloying elements include, amongst others, carbon (C), nickel (Ni), molybdenum (Mo), titanium (Ti), manganese (Mn), nitrogen (N) and copper (Cu).

Control of the chemical composition of each individual grade of stainless steel affects its:
- crystal structure (atomic arrangement)
- corrosion resistance
- mechanical properties (eg strength, ductility)
- physical properties (eg thermal conductivity)
- fabricational properties (eg weldability, formability).

The primary property of stainless steels is corrosion resistance.

They also exhibit a wide range of secondary properties, the scope of which renders them exciting and versatile materials.

The Classification of Stainless Steels

Metals are crystalline solids, ie the atoms of the elements that make up the chemical composition arrange themselves in a definite regular pattern, viz the crystal structure.

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Classification, Typical Properties and Applications

by David P. Rowlands, BSc Eng (Witwatersrand), MIM, CEng.

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its chemical reactivity and becomes inert to many corrosive solutions.

- The Cr content of stainless steels renders them **passive** due to the formation of a Cr rich oxide film (termed the **passive film**) on its surface. Refer Fig 2.
  - This passive film is
    - extremely thin \(\approx 3-5 \times 10^{-6}\) mm thick
    - uniform & continuous
    - stable & tenacious
    - smooth
    - self repairing.

![FIGURE 2:
Schematic illustration of the formation of a passive film on the surface of stainless steel by oxygen or an oxidising environment](image)

**Martensitic Stainless Steels**

These were the first stainless steels industrially developed, viz for knife blades.

They are plain chromium stainless steels that can be hardened and strengthened by heat treatment.

**BASIC COMPOSITION**

Plain chromium stainless steels
- Cr in the range of \(\approx 12-18\)%Cr
- Relatively high to high C contents of \(\approx 0.2-1.2\)%C.

**COMMON GRADES**

- 410
- 420
- 431
- 440A, B & C

**BASIC PROPERTIES**

- High strength and hardness
  - which *must* be developed by heat treatment (viz quenching & tempering)
- Moderate corrosion resistance (ie in relative ‘stainless steel’ terms)
- Magnetic
- Very poor weldability
  - due to their hardenable nature.

**COMMON USES**

Applications that require high strength and/or hardness
- knife blades, scissors
- surgical instruments
- springs
- shafts, spindles and nozzles
- impellers
- fasteners.

**FORMS COMMONLY AVAILABLE**

- bar, strip & forgings

- castings (as similar cast grades).

**Ferritic Stainless Steels**

There are three sub-classifications
1. Conventional Ferritic Stainless Steels
2. Utility Ferritic Stainless Steels

**CONVENTIONAL FERRITIC STAINLESS STEELS**

These are plain chromium stainless steels. At first glance they may appear similar to the martensitic stainless steels, but they have low C contents and therefore cannot be hardened or strengthened by heat treatment. Due to their poor weldability, they are mostly used as thin gauge material.

**BASIC COMPOSITION**

Plain chromium stainless steels
- Cr in the range of \(\approx 12-18\)%Cr
- Relatively low C contents of \(\approx 0.08\)%C
- the grades as indicated * and ** below contain titanium (Ti)*, and titanium + niobium (Ti + Nb)** respectively.

**COMMON GRADES**

- 430
- S40910**
- 439*
- [1.4016]  
- [1.4512]*  
- [1.4509]**

**BASIC PROPERTIES**

- Moderate to good corrosion resistance (ie in relative ‘stainless steel’ terms)
  - increased Cr contents improve the corrosion resistance
- Good strength and low hardness
  - always used in the annealed (ie fully softened) condition
- Magnetic
- Poor weldability
  - in general this limits their application as welded components to those made from thin gauge material.

**COMMON USES**

- As thin gauge material
  - builders hardware: eg sinks, troughs, urinals
  - cutlery and kitchen utensils
  - architectural (only in non-aggressive environments)
  - exhaust components: eg catalytic converters (‘catcons’).
- As thicker gauge material (generally not welded)
  - in materials handling applications; eg chute and silo linings, chain conveyors, weirs and penstock gates, spillways, dust and fume extraction.
- As tube
  - evaporator tube, automobile exhaust tube.

**FORMS COMMONLY AVAILABLE**

- sheet and coil, (seldom as plate)
- welded tube.

**UTILITY FERRITIC STAINLESS STEELS**

The initial breakthrough discovery of 3CR12™ in the early 1980’s has lead to the development of these stainless steels. Their good weldability is the significant property that differentiates them from all other plain chromium stainless steels. They contain the minimum amount of Cr to render them “stainless” (preferably considered as corrosion resisting as opposed to corrosion resistant).

**Page 1.2**

Their main application has been as a cost-effective material to replace un-coated and coated plain carbon steels in applications where these steels have inadequate corrosion resistance due to the environmental or operational conditions.
**BASIC COMPOSITION**
Plain chromium stainless steels
- 11-12% Cr
- Extra low C & N (both <0.03%),

**COMMON GRADES**
3CR12™ [1.4003] { }

**BASIC PROPERTIES**
- Good weldability
- in thicknesses of up to ≈20mm
- Corrosion “resisting”
- will stain and discolour, but suffer minimal metal loss even in polluted industrial or marine environments
- good corrosion-abrasion resistance
- Magnetic.

**COMMON USES**
- In “rough and tough” applications
  - materials handling: eg ore cars, railway coal wagons, truck bodies, chutes, launders
  - tanks, silos, hoppers, bins
  - pollution control, dust and fume extraction, chimney stacks, ventilation ducting.
- To replace coated steel in applications in which
  - or, the coating is damaged/destroyed by the operational conditions
  - walkways, stairways and ladders; high level lighting masts; electrification masts, portals and transmission towers; bus and coach frames.

**POTENTIAL USES**
As production of these stainless steels as a range of “long products” becomes more common, it is considered that there is a significant potential for their use
- in structural steel work (ie as angles, channels and beams)
- as reinforcing bar for concrete.

**FORMS COMMONLY AVAILABLE**
- plate, sheet and coil in thicker gauges
- welded tube, fabricated large diameter pipe
- bar and sections (limited size range, but increasing).

**SUPER FERRITIC STAINLESS STEELS**
These stainless steels were developed to address the susceptibility of Conventional Austenitic Stainless Steels to a specific mechanism of corrosion, viz Stress Corrosion Cracking.
In comparison to the Conventional Ferritic Stainless Steels, the higher alloy content (Cr + Mo) improves the corrosion resistance, and limiting both C and N to extra low levels improves the weldability.
They are sometimes referred to as the “Low Interstitial Ferritic Stainless Steels”.

**TYPICAL COMPOSITIONS**
- 18%Cr 2%Mo (stabilised with Ti or Nb+Ta)
- 26%Cr 1%Mo (stabilized with Ta)
- Extra low C & N (both <0.03%).

**COMMON GRADES**
S44400 S44627
[1.4521] { } { }
and also as proprietary grades.

**BASIC PROPERTIES**
- In general, similar to Conventional Ferritic Stainless Steels except that
  - Improved weldability
  - fair to moderate up to thickness of ≈5mm
  - Very good corrosion resistance
  - resistance to Stress Corrosion Cracking (SCC).

**COMMON USES**
- Under conditions where there is a likelihood of SCC
  - heater panels, eg solar heaters
  - heat exchanger and condenser tubing
  - cooling coils in brackish and estuarine water
  - hot water heaters and storage
  - chloride brine solutions used in food processing.

**FORMS COMMONLY AVAILABLE**
- sheet, coil and thinner plate
- welded tube and pipe.

**Austenitic Stainless Steels**
There are five sub-classifications
1. Conventional (CrNi) Austenitic Stainless Steels
2. Heat Resisting Austenitic Stainless Steels
3. CrNiMn Austenitic Stainless Steels
4. CrMnN Austenitic Stainless Steels
5. Austenitic Stainless Alloys

**CONVENTIONAL (CrNi) AUSTENITIC STAINLESS STEELS**
Ni promotes the formation of an austenitic crystal structure, and if sufficient Ni is contained a wholly austenitic crystal structure results.
The stainless steels in this classification have both excellent corrosion resistance and associated secondary properties, and account for the greatest usage of stainless steel (~70%). However, they do have some limitations which necessitates the use of stainless steels from within other classifications.

**BASIC COMPOSITION**
- 18%Cr + 8-12%Ni
- 2-3%Mo in some grades for increased corrosion resistance
- Low carbon (<0.08%C) in the straight grades
- extra low carbon (<0.03%) in the “L” grades
- Ti in the stabilised grades
- the “L” and stabilised grades are used to prevent the possibility of a mechanism of corrosion (viz Intergranular Corrosion), occurring next to the weld in thicker welded fabrications in some corrosive solutions.

**COMMON GRADES**
304 304L 321
[1.4301] [1.4306] [1.4541] { } { } { }
and the grades that contain Mo
316 316L 316Ti
[1.4404] [1.4571] { } { } { }

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**BASIC PROPERTIES**
- Very good to excellent corrosion resistance
- Excellent cleanability and hygienic properties
- and associated excellent product purity
- Excellent formability and weldability
- and associated excellent fabricability
- Moderate strength (in the annealed condition)
- can be strengthened and hardened by cold work, not by heat treatment
- Excellent mechanical properties at cryogenic (ie very low) temperatures
- Good high temperature properties
COMMON USES

- The Conventional Austenitic Stainless Steels are used for a huge variety of applications; in thickness ranging from 0.5mm or less to over 200mm; articles and components weighing but a few grams to over 100 tonnes; and from the mundane teaspoon to super-critical nuclear plant.
- hollow-ware, tableware, cutlery, sinks (both domestic and commercial)
- hospital and medical equipment
- pharmaceutical
- architectural (eg street furniture, facades, shop fronts, signs, balustrades, cladding, roofing)
- builders’ hardware, masonry ties and anchors
- reinforcing bar for concrete
- food and beverage processing (eg abattoirs, dairy, beer, wine, soft drinks), and preparation (eg hotel, restaurant and fast food equipment)
- transport (eg rail cars, tankers, ISO liquefied “tank-tainers”)
- boat and yacht hardware, fittings and rigging
- cryogenic equipment (eg manufacture, storage and transport of liquid gases)
- pollution control and water treatment
- at elevated and high temperatures
- for plant and equipment in petrochemical, chemical, mineral extraction, pulp and paper, nuclear and other industries (eg as tanks, process & pressure vessels, heat exchangers, pipe-work).

FORMS COMMONLY AVAILABLE

- plate, sheet, coil, strip, bar, pipe & tube, forgings
- castings (as similar cast grades)
- also in product forms (flanges, fittings, fasteners, wire, rope, hollow bar, etc).

LIMITATIONS

Although the Conventional Austenitic Steels are suitable for a wide range of corrosive applications they do have some limitations that necessitate the use of stainless steels from within other classifications, viz:

- They are only suitable for lower concentrations of reducing acids (and reducing acid mixtures) at lower temperatures
- reducing acids break down the passive oxide film which results in General Corrosion
- Halide ions, especially the chloride ion (Cl\textsuperscript{-}), in corrosive solutions have the ability to attack any weak spot that exists in the passive film
- this can result in a highly localised corrosive attack with an associated negligible amount of general metal loss, i.e. Pitting Corrosion and Stress Corrosion Cracking
- In shielded areas or crevices there is a deficiency of oxygen which leads to the break down of the passive film
- another corrosion mechanism can thus occur, viz Crevice Corrosion
- At high temperatures gaseous corrosion takes place, the most common form of which is oxidation (scaling)
- the maximum temperature which can be handled is \(\approx 925^\circ\text{C}\) in oxidising conditions.

HEAT RESISTING AUSTENITIC STAINLESS STEELS

At temperatures in excess of \(925^\circ\text{C}\) a higher content of Cr is necessary to resist oxidation. A corresponding higher Ni content is therefore required to form a fully austenitic crystal structure.

BASIC COMPOSITION

- Higher Cr & Ni
- 24\% Cr 14 or 20\% Ni
- Higher C for better high temperature mechanical properties
- <0,25\%C (<0,08\%C in the “S” grades).

COMMON GRADES

- 309  309S  310  310S
- \{1.4828\}  \{1.4833\}  \{1.4841\}  \{1.4845\}

BASIC PROPERTIES

- Resistant to oxidation (scaling) at high temperatures (950°-1100°C)
- Good high temperature mechanical properties.

COMMON USES

- Furnace equipment, parts and fixtures
- door arches and frames, furnace roofs, muffle liners, radiant tubes, pipe hangers and supports, refractory anchors.

FORMS COMMONLY AVAILABLE

- plate and thicker sheet (and to a lesser extent as bar, pipe and hollow bar)
- castings (as similar cast grades).

CrMnNi AUSTENITIC STAINLESS STEELS

30% higher in the annealed condition
- Originally, these stainless steels were developed as an alternative to 18CrNi austenitic stainless steel at a time when Ni was in short supply. On the whole they have been a “neglected” sub-group of stainless steel (except, notably, in India). However, there is a potential for their greater use more specifically if, in the future, Ni is expected to be either in short supply or highly priced for an extended period.

BASIC COMPOSITION

- 17\%Cr 6-8\%Mn 4.5\%Ni 0,1-0,2\%N
- Higher C content (up to 0,15\%C allowed)
- extra low C, ie <0,03\%C, in the “L” grades
- Manganese (Mn), as does Ni, promotes the formation of an austenitic crystal structure, but is only half as powerful as Ni in this respect
- therefore, for each 1% reduction in the Ni content, an addition of approximately 2%Mn is required to form an equivalent wholly austenitic crystal structure
- alloying with small amounts of nitrogen (N), a powerful austenite former, is now also employed in order to form and stabilise the austenitic crystal structure.

COMMON GRADES

- 201  202  201L
- \{1.4372\}  \{1.4373\}  \{1.4371\}

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BASIC PROPERTIES

- In general, similar to Grades 304[1.4031] and 304L[1.4306].
- the strength is \(\approx\)30\% higher in the annealed condition
- a greater response to cold work (i.e. strengthening and hardening).

POSSIBLE USES

These stainless steels have only been used to a minor extent. However, the potential for their greater use does exist as an alternative (possibly less expensive) material in many of the applications for which Grades 304[1.4031] and 304L[1.4306] are currently used.
FORMS COMMONLY AVAILABLE
Seldom produced and stocked.

CrMnN AUSTENITIC STAINLESS STEELS
In relative terms, the usage of stainless steels within this classification is extremely small. However, it is worthy of mention for the purpose of general information and awareness.

- The principle of replacing Ni with Mn + high levels of N in order to develop the austenitic crystal structure is applied to the extent that these austenitic stainless steels have a very low Ni content.
- Improvements in steel making technology have made this possible.
- The N is completely retained in solid solution within the steel, thus preventing the problem of porosity that used to be associated with stainless steels of such high N content.

TYPICAL GRADES
XM31(S21400) and XM29(S24000)
Nitronic™ Grades 32 and 33.

TYPICAL BASIC COMPOSITION
- 18%Cr 12%Mn 0,3%N
- Low Ni of <1%Ni up to ~2-3%Ni
- Low C (<0,08%).

TYPICAL BASIC PROPERTIES
- Corrosion resistance slightly lower than Grade 304 [1.4301]
- High strength in the annealed condition
- A marked response to cold work
- High tensile strength and hardness can be developed
- Moderate weldability
- Mechanical properties of weld zone do not equal those of the parent material.

TYPICAL & POTENTIAL USES
- High strength structural and constructional components
- Wear and abrasion, particularly wet impact and wet sliding abrasion.

AUSTENITIC STAINLESS ALLOYS
These are the materials sometimes referred to, for example, as High Performance Alloys, Super Alloys and Exotic Materials
- A preferred description is Special Purpose Alloys because they were formulated and developed to resist a specific corrosive condition or set of conditions (both wet/aqueous and high temperature gaseous corrosion) for which other stainless steels were unsuitable.
- They are an extension of the Conventional Austenitic Stainless Steels and are more correctly termed Alloys (as opposed to Steels) because their composition is such that the alloy content exceeds ~50%

- Notably, the Ni content is higher than the Cr content
- The Ni Based Alloys are a further extension of these alloys.

NOMINAL COMPOSITION OF TYPICAL GRADES
Originally these alloys were developed as proprietary grades, many of which have been incorporated in the different national specifications.
- Examples* of the wet/aqueous corrosion resistant grades
  - 20%Cr 25%Ni 4,5%M0 1,5%Cu [1.4539] { }
  - 20%Cr 25%Ni 6,5%M0 1,0%Cu [1.4529] { }
  - 27%Cr 32%Ni 3,5%M0 1,0%Cu [1.4563] { }
  - 20%Cr 36%Ni 2,5%M0 3,5%Cu Nb+Ta [2.4660] { }
  - 21%Cr 42%Ni 3,0%M0 2,0%Cu [2.4858] { }
- Examples* of the heat resistant grades
  - 18%Cr 37%Ni [1.4864] { }
  - 21%Cr 32%Ni [1.4876] { }
* Refer also to Table 1 in the Appendix

BASIC PROPERTIES
In general, similar to the Conventional Austenitic Stainless Steels except that
- For the wet/aqueous corrosion resistant grades
  - A higher corrosion resistance, specifically
  - To reducing acids and reducing acid mixtures at higher concentrations and/or temperatures
  - To both Pitting Corrosion and Stress Corrosion Cracking.
- For the heat resistant grades
  - A higher resistance to oxidation and carburisation
  - Better high temperature mechanical properties.

COMMON USES
- The wet/aqueous corrosion resistant grades
  - In the chemical and petrochemical industries where more aggressive corrosive solutions have to be handled at (usually) higher concentrations and/or temperatures.
- The heat resistant grades
  - High temperature plant and equipment, eg retorts, kilns, muffs, radiant tubes, burners, components, heat treatment boxes, trays and baskets.

FORMS COMMONLY AVAILABLE
- Plate and thicker sheet, pipe & tube
- Castings (as similar cast grades).

Duplex Stainless Steels
These stainless steels contain insufficient Ni to develop a fully austenitic crystal structure and therefore consist of a mixed ferritic-austenitic (ie duplex) crystal structure.
- Until the early 1980’s the crystal structure consisted of approximately 70% ferrite and 30% austenite. The associated weldability was, at best, moderate.
- N, a powerful austenite former, was then included in the composition (sometimes referred to as the “Second Generation Duplex Stainless Steels”)
  - This resulted in a crystal structure of approximately 50% ferrite and 50% austenite, and a greatly improved weldability.

BASIC COMPOSITION
- Higher Cr and lower Ni (ie compared to the Conventional Austenitic Stainless Steels)
- Most contain Mo
- Extra low C (<0,03%C)
- N as an austenite former

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NOMINAL COMPOSITION OF TYPICAL GRADES
Originally these stainless steels were developed as proprietary grades. The preferred, and therefore more often used, grades are now incorporated in different national specifications for example*:
- 23%Cr 4%Ni 0,4%Mo 0,15%N [1.4362] { }
- 22%Cr 5%Ni 3,0%Mo 0,18%N [1.4462] { }
- 25%Cr 7%Ni 3,5%Mo 0,30%N [1.4410] { }
* Refer also to Table 1 in the Appendix

BASIC PROPERTIES
- Excellent corrosion resistance
  - Higher Cr + Mo & Ni improve the resistance to Pitting Corrosion and Crevice Corrosion
PRECIPITATION HARDENABLE STAINLESS STEELS

These stainless steels (often simply termed the PH stainless steels) can be hardened and strengthened by heat treatment.

- They were originally developed for applications in the aerospace and armaments industries that required the corrosion resistance and fabricational properties of the Conventional Austenitic Stainless Steels combined with the strength and hardness properties of the Martensitic Stainless Steels.

The PH stainless steels are sub-classified as:
1. Martensitic (also termed Maraging)
2. Semi-austenitic
3. Austenitic (PH stainless steels in this sub-classification are now seldom used).

Do not confuse these sub-classifications of the PH stainless steels with the similarly named classifications of other stainless steels.

BASIC COMPOSITION

- Martensitic grades
  - extra low C (<0,04%C)
  - 15-17%Cr 4,5-6%Ni
  - precipitation hardening elements: Cu or Al, Ti or Nb+Ta
- Semi-austenitic grades
  - low C (<0,07%C)
  - 15-17%Cr 7-8%Ni
  - precipitation hardening elements: Mo, Al or N

TYPICAL GRADES

Originally, these stainless steels were developed as proprietary grades. The preferred, and therefore more often used, grades are now incorporated in different national specifications, for example:

- Martensitic grade
  - [1.4542] 
- Semi-austenitic grades
  - [1.4568] [1.4532]
* Refer also to Table 1 in the Appendix

BASIC PROPERTIES

- High strength and relatively high hardness
- which MUST be developed by a precipitation hardening (ageing) heat treatment that is effected at low intermediate temperatures within the range of ~500°-600°C
- Fair to moderate weldability
- Good corrosion resistance

TYPICAL USES

- High strength welded fabrications
- High strength components, eg shafts, spindles, fasteners.

FORMS COMMONLY AVAILABLE

- plate, thicker sheet, bar and forgings
- castings (as similar cast grades).

Conclusion

There are many different grades of stainless steels in the FAMILY of STAINLESS STEEL.

- All can be logically grouped within five classifications
- Four classifications are by virtue of the inherent crystal structure
- The fifth classification is because of the heat treatment required to develop the properties.
- The grades of stainless steel within any classification have similar properties.

The use of a specific grade of stainless steel is determined by the conditions of the application under which it will operate.

- The vast majority of applications (estimated ~90-95%) are satisfied by relatively few grades from within the Conventional Austenitic, Conventional Ferritic and Utility Ferritic sub-classifications
- Other grades from within these or alternative classifications and sub-classifications fulfill a necessary role when their properties are essential, eg process conditions (temperatures, concentrations, and pressures) are being forced to higher levels to improve efficiencies and attain higher yields
- design and process conditions are inseparably linked to the materials of construction. Minor modifications can often have a major effect and enable the use of the more common grades, which in turn results in the related benefits of better availability, ease of maintenance and overall cost effectiveness.
- Many grades of stainless steel contained in the different standards and specifications are now seldom used. These have been replaced by a far lesser number of more recently developed grades that have both improved and a wider range of properties.

The use of stainless steel has continued to increase at an extraordinary rate compared to most other metals.
- Potential applications, some of which are of an unsophisticated nature, could further accelerate its use.

Stainless steel is not an indestructible material.

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- However, with careful selection, correct fabrication and control of the operating conditions the vast majority of corrosive conditions can be handled.
- When the secondary properties are taken into consideration an even wider variety of other applications can be satisfied.

The use of stainless steel is not always visible. It is more often “behind the scenes”, contributing to mankind’s daily needs and lifestyle in a cost effective and environmentally friendly manner.

It is truly an exciting and versatile material!
Appendix

SPECIFICATIONS & STANDARDS

The many different individual grades of stainless steel are identified by a grade number (or a grade designation).

These are contained in Specifications (or Standards).
- The scope of each Specification is different and can cover a combination of
  - the various product forms, and in some instances the method of manufacture
  - eg, plate, sheet and strip; or bar (hot rolled and/or cold finished); or forgings; or castings; or pipe (welded and/or seamless); or tube (welded and/or seamless); or flanges; or fasteners; etc
  together with
  - the applicable use
    - eg, general purpose; or pressure vessels; or heat exchangers; or high temperature; etc
  and/or
  - the classification (or classifications) of stainless steels included.
- Each Specification specifies the requirements that have to be fulfilled, viz
  - the chemical composition and mechanical properties of each individual grade included in the specification
  - other requirements (often by stipulating a separate Specification that covers “General Requirements”)
    - eg, method of manufacture; heat treatment; dimensional tolerances; special tests; number of tests; inspection; certification; identification; packaging; etc
  - these “other requirements” are more stringent for applications of higher criticality, eg for pressure vessels as compared to general purpose.
- Some Specifications include only a few (5 or 6) grades, whereas others can include many (90 or more) grades
- The same grade of stainless steel will be found in different specifications
  - whereas the chemical composition is identical (or very nearly so), the mechanical properties can differ (dependent on product form)
- The use will be governed by the Specification to which the stainless steel has been produced and certificated
  - eg plate produced to a “General Purpose” Specification cannot be used for the manufacture of pressure vessels.

The requirements of the Specifications are stipulated, reviewed and, if necessary, modified by International or National Standardisation Bodies, examples of which are
- International: - ISO ~ CEN (European Committee for Standardisation)
- National: - USA ~ ASTM; Great Britain ~ BSI; Germany ~ DIN; France ~ AFNOR; Japan ~ JIS

Some countries “adopt” the Specifications contained in the National Standards of other countries.

- South Africa is such an example, having traditionally used the ASTM (American Society for Testing and Materials) Specifications and the AISI (American Iron and Steel Institute) grades of stainless steel contained therein, ie the familiar “200 Series”, “300 Series” and “400 Series”
  - “200 Series” include the CrMnNi austenitic stainless steels, eg Grade 201.
  - “300 Series” include the CrNi austenitic stainless steels, eg Grades 304(L), 316(L), 321.
  - “400 Series” include the “plain chromium” stainless steels, both martensitic and ferritic stainless steels, eg Grades 420 and 430 respectively.

Newly developed grades of stainless steel could not be logically accommodated in these AISI “Series”, and therefore the UNS (Unified Numbering System) for grade identification was evolved.
- The UNS grade identification consists of a letter followed by five numerals
  - the letter denotes either a steel or an alloy type, eg
    - S#### is a stainless steel grade
    - N#### is a stainless alloy or a nickel alloy grade
  - for stainless steels the first three numbers are often the same as the previous 200, 300 or 400 “Series Number” (if this existed), and the last two numbers are used for the different grades of the same basic type, eg
    - S30400 = 304; S30403 = 304L; S30409 = 304H; S30415 = no previous grade; S30451 = 304N; S30452 = XM-21; S30453 = 304LN.

THE NEW EUROPEAN EN STANDARD

Historically each country in Europe had their own National Standard and Specifications that applied to stainless steel and other materials.
- As a result, a huge number of individual grade identifications existed that, although similar with respect to composition, were not exactly equivalent.

Therefore, with the objective of promoting trade amongst the members of the European Economic Union and also to improve their commercial efficiencies and competitive status in terms of world trade, the decision was made that CEN should draw up new uniform European EN Standards.
- Exactly the same Standard would then be adopted and used by all the CEN member counties, eg
  - by Great Britain as BS EN ######
  - by Germany as DIN EN ######
  - by France as AFNOR EN ######
  - by Italy as UNI EN ######

- the only difference is the language in which these Standards are written
- the EN Standards are issued in three official languages, English, German and French. Other CEN member counties may (if they wish) translate the EN Standard into their own language, eg Italian, Spanish, etc.
- Initially the standards are issued as a provisional Standard, (pEN ######)

Finally after review and, if necessary, modification as a mandatory European Standard, EN ######
- the previously existing National Standard becomes obsolete and is no longer applicable.

EN Standards exist for stainless steel for general and pressure vessel purposes, viz
- EN 10088-1 Stainless Steels Part 1: List of stainless steel
- EN 10088-2 Stainless Steels Part 2: Technical delivery conditions for sheet/plate and strip for general purposes
- EN 10088-3 Stainless Steels Part 3: Technical delivery conditions for semi finished products, bars, rods and sections for general purposes
- EN 10028-7 Flat products made of steels for pressure purposes Part 7: Stainless steels
- Other Standards that pertain to stainless steel have been issued (either as provisional or final Standards)
The complete task should, expectedly, be finalised by 2003/2004.

The advantages associated with the new EN Standards include:
- The multitude of grades that existed within the different National Standards have been condensed as relatively few grades in one Standard
- further rationalisation has been effected by the exclusion of grades that are no longer (or very seldom) used.
- One standard grade exists for stainless steels or stainless alloys that were previously proprietary grades
- this has eliminated the situation where often several very similar proprietary grades existed, together with similar grades in some Specifications.
- Higher minimum tensile and proof strength values are specified for some grades
  - eg, in some instances the minimum 0.2% proof strengths are ≈40% higher
- these higher assigned values are simply a recognition of that which had naturally occurred as a result of improved steel making and processing technology
- depending on the design criteria employed the use of thinner material could be possible, thereby increasing both the competitiveness and cost effectiveness of stainless steel as a material of construction.
- More technical information is included in the standards
  - as optional certifiable properties
    - 1% proof strength for austenitic stainless steels
    - impact energy
    - minimum 0.2% proof strength (and 1% proof strength for austenitic stainless steels) at elevated temperatures
    - minimum tensile strength values at elevated temperature (austenitic stainless steel only)
    - as ‘informative’ information
      - density and modulus of elasticity of austenitic creep-resisting steels
      - coefficient of thermal expansion, thermal conductivity, specific thermal capacity, specific electrical resistivity
      - guideline temperatures for hot forming and heat treatment
      - post weld treatment
      - preliminary data for the tensile strength of duplex stainless steels at elevated temperatures (≤ 250°C)
      - creep strain and rupture properties of austenitic creep-resisting steels
      - mechanical properties at low temperatures of austenitic stainless steels.

There are some aspects that may lead to confusion.
- The new EN Standards are NOT
  - in any way related to the old EN grades of stainless steel (eg En56 and En57). Although these became obsolete in the early 1970’s they are still sometimes referred to
  - the same as the previous EURONORM Standards (that were also designated as “EN”) which now fall away and are replaced by the new EN Standards.
- The grade numbers and the grade designations in the new EN Standards appear to be the same as the old DIN Werkstoff numbers and Kunzname
  - Whereas the chemical composition may be identical (or very similar) there are differences, particularly with respect to the stipulated mechanical properties as mentioned above
  - CARE SHOULD THEREFORE BE TAKEN NOT TO CONFUSE THE TWO.

The different grades of stainless steel within the EN Standards are identified by both a grade number and a grade designation (either may be used)
- The grade number consists of five numbers, eg 1.4401 and 1.4404
  - 1= denotes that this is a grade of steel
  - 44 = these two numbers denote stainless steel of the same basic type (in this example a CrNiMo austenitic stain-less steel)
  - 01 and 04 = these two numbers simply denote the different individual grades of the same basic type.
- The grade designation consists of a combination of letters and numbers, eg X5CrNiMo17-12-2 and X2CrNiMo17-12-2 (the same grades as above)
  - X = denotes a highly alloyed wrought steel
  - (GX = denotes a highly alloyed cast steel)
  - 5 and 2 = indicate the nominal percentage points of carbon contained ie 0.05%C (the straight grade) and 0.02%C (the “L” grade)
  - Cr, Ni, and Mo are the alloying elements contained
  - 17-12-2 = indicates the nominal percentage content of these alloying elements, ie = 17%Cr, =12%Ni and =2%Mo.
- The advantage of the grade designation is that it indicates the chemical composition
  - It is, however, more cumbersome and therefore the grade number is normally used.

**COMPARISON & SUBSTITUTION**

On the basis of chemical composition, most of the grades contained in the Specifications of one National Standard will have a very similar comparable grade in the Specifications of another National Standard. Refer to Table 1.
- However, if the other requirements of the Specification are taken into account, such seemingly similar grades can be very different.
- The question of substitution often arises
  - with respect to corrosion resistance there will be, in practical terms and in most instances, a negligible (or no) difference between the two very similar comparable grades
  - therefore, with due care and consideration, substitution can normally be made.
- However, in the case where the design has been based on the mechanical properties stipulated in a specific Specification the steel so specified cannot simply be substituted by a grade of similar composition in another Specification.
  - In some instances it may be possible
    - but very careful consideration must be given to all pertinent factors, and all parties involved must fully agree to the substitution.
  - eg the substitution of Grade 316L for the “old” Werkstoff Grade 1.4404 was often feasible. But this is LESS so for the new EN Grade 1.4404 because of the much greater difference in the mechanical properties, eg

**TABLE 1:**

Nominal composition of some of the more common grades of stainless steel

<table>
<thead>
<tr>
<th>Similar grades</th>
<th>NOMINAL COMPOSITION</th>
<th>NOT</th>
<th>FROM THE ASTM &amp; EN STANDARDS</th>
<th>GROUPED TOGETHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nominal compositions are given in this table. These must not be used for specification purposes. For the exact composition reference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Page 1.8

| 316L | · RM 485 MPa (min) and R P0,2 170 MPa (min) |
| · “old” Werkstoff 1.4404 |
| · RM 500 MPa (min) and R P0,2 200 MPa (min) |
| · EN Grade 1.4404 up to 6mm thick (and, by agreement, up to 12mm thick if continuously hot rolled) |
| · RM 530 MPa (min) and R P0,2 240 MPa (min). |
must be made to the appropriate Specification
2. The % content is a maximum unless a compositional range is given
3. Al = aluminium ~ C = carbon ~ Cr = chromium ~ Cu = copper ~ Mn = manganese ~ Mo = molybdenum ~ N = nitrogen ~ Nb = niobium
   (as Cb = columbium in American Specifications) ~ Ni = nickel ~ P = phosphorus ~ S = sulphur ~ Se = selenium ~ Si = silicon ~ Ti =
   titanium ~ V = vanadium
4. Only the primary alloying elements (C, Cr, Ni, Mo & N) are individually listed in the Table
5. All stainless steels contain Si, Mn, P & S. These are controlled to maximum contents of typically 0.75% or 2.0%Mn ~ 0.015%S and
   0.045%P. If these elements are intentionally added as alloying elements the higher % content is listed under "% Other"
6. The % content of any other alloying elements that are contained in some of the stainless steels is listed under "% Other"
7. Typical Proprietary Grades (which are commonly referred to in South Africa) are given for the purpose of example only. The inclusion
   of any such Proprietary Grade must not be interpreted as an endorsement or recommendation; and vice versa, the exclusion of any such
   Proprietary Grade must not be interpreted as a non-recommendation

<table>
<thead>
<tr>
<th>Grade Number</th>
<th>UNS Number</th>
<th>Grade Designation</th>
<th>%C</th>
<th>%Cr</th>
<th>%Ni</th>
<th>%Mo</th>
<th>%N</th>
<th>%Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>201</td>
<td>S20100</td>
<td>0.15</td>
<td>16.0-18.0</td>
<td>3.5-5.5</td>
<td>0.25</td>
<td>5.5-7.5 Mn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>201L</td>
<td>X2CrMnNi17-7-5</td>
<td>0.03</td>
<td>16.0-18.0</td>
<td>3.5-5.5</td>
<td>0.25</td>
<td>5.5-7.5 Mn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>202</td>
<td>S20200</td>
<td>0.15</td>
<td>17.0-19.0</td>
<td>4.0-6.0</td>
<td>0.25</td>
<td>7.5-10.0 Mn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>301</td>
<td>S30100</td>
<td>0.15</td>
<td>16.0-18.0</td>
<td>6.0-8.0</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>304</td>
<td>S30400</td>
<td>0.08</td>
<td>18.0-20.0</td>
<td>8.0-10.5</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>304H</td>
<td>S30409</td>
<td>0.04-0.10</td>
<td>18.0-20.0</td>
<td>8.0-10.5</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>309S</td>
<td>S30908</td>
<td>0.08</td>
<td>22.0-24.0</td>
<td>12.0-15.0</td>
<td>0.11</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>310</td>
<td>S31000</td>
<td>0.02</td>
<td>24.0-26.0</td>
<td>19.0-22.0</td>
<td>1.5 Si</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>310LN</td>
<td>S31053</td>
<td>0.03</td>
<td>18.0-20.0</td>
<td>8.0-12.0</td>
<td>0.10-0.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>316</td>
<td>S31600</td>
<td>0.08</td>
<td>16.0-18.0</td>
<td>10.0-14.0</td>
<td>2.0-3.0</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>316L</td>
<td>S31603</td>
<td>0.03</td>
<td>16.0-18.0</td>
<td>10.0-14.0</td>
<td>2.0-3.0</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>316LN</td>
<td>S31653</td>
<td>0.03</td>
<td>16.0-18.0</td>
<td>10.0-14.0</td>
<td>2.0-3.0</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>316Ti</td>
<td>S31635</td>
<td>0.08</td>
<td>16.0-18.0</td>
<td>10.0-14.0</td>
<td>2.0-3.0</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>317L</td>
<td>S31703</td>
<td>0.03</td>
<td>18.0-20.0</td>
<td>11.0-15.0</td>
<td>3.0-4.0</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>317LN</td>
<td>S31753</td>
<td>0.03</td>
<td>18.0-20.0</td>
<td>11.0-15.0</td>
<td>3.0-4.0</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>317LN</td>
<td>X2CrNiMoN17-13-3</td>
<td>0.03</td>
<td>16.5-18.5</td>
<td>10.5-14.0</td>
<td>2.5-3.0</td>
<td>0.12-0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>318</td>
<td>S31803</td>
<td>0.03</td>
<td>16.0-18.0</td>
<td>10.0-14.0</td>
<td>2.0-3.0</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>321</td>
<td>S32100</td>
<td>0.08</td>
<td>17.0-19.0</td>
<td>9.0-12.0</td>
<td>0.10</td>
<td>5x(%C+%N)-0.7 Ti</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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### Stainless Steels

#### Ferritic Stainless Steels

<table>
<thead>
<tr>
<th>Grade Number</th>
<th>UNS Number</th>
<th>Grade Designation</th>
<th>%C</th>
<th>%Cr</th>
<th>%Ni</th>
<th>%Mo</th>
<th>%N</th>
<th>%Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>3CR12™</td>
<td>1.4003</td>
<td>X2CRNi 12</td>
<td>0.03</td>
<td>11.0-12.0</td>
<td>1.5</td>
<td>0.03</td>
<td>0.6 Ti</td>
<td></td>
</tr>
<tr>
<td>S40910</td>
<td>1.4152</td>
<td>X2CrTi 12</td>
<td>0.03</td>
<td>10.5-11.7</td>
<td>0.5</td>
<td>0.03</td>
<td>(6x[%C+%N])-0.5 T-0.17 Cb</td>
<td></td>
</tr>
<tr>
<td>S430</td>
<td>1.4016</td>
<td>X6Cr 18</td>
<td>0.08</td>
<td>16.0-18.0</td>
<td>0.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X2CrTiNb 18</td>
<td>1.4509</td>
<td>X2CrTiNb 18</td>
<td>0.03</td>
<td>17.5-18.5</td>
<td>0.045</td>
<td>0.10-0.60 Ti-(0.3+(3x%N))</td>
<td>1.0 Nb</td>
<td></td>
</tr>
<tr>
<td>S43000</td>
<td>1.4521</td>
<td>X2CrMoTi 18-2</td>
<td>0.025</td>
<td>17.5-19.5</td>
<td>1.0</td>
<td>1.8-2.5</td>
<td>0.035</td>
<td>(0.20+4x[%C+%N])-1.1 T-0.15 Al</td>
</tr>
<tr>
<td>S446000</td>
<td>1.4762</td>
<td>X10CrAlSi 25</td>
<td>0.12</td>
<td>23.0-26.0</td>
<td>0.75</td>
<td>0.25</td>
<td>1.2-1.7 Al &amp; 0.7-1.4 Si</td>
<td></td>
</tr>
<tr>
<td>S44627</td>
<td>1.4876</td>
<td>X10NiCrAlTi 32-21</td>
<td>0.12</td>
<td>19.0-23.0</td>
<td>30.0-34.0</td>
<td>0.15-0.60 Ti-0.15-0.60 Al</td>
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<td></td>
</tr>
</tbody>
</table>

#### Martensitic Stainless Steels

<table>
<thead>
<tr>
<th>Grade Number</th>
<th>UNS Number</th>
<th>Grade Designation</th>
<th>%C</th>
<th>%Cr</th>
<th>%Ni</th>
<th>%Mo</th>
<th>%N</th>
<th>%Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>410</td>
<td>1.4006</td>
<td>X12Cr 13</td>
<td>0.08-0.15</td>
<td>11.5-13.5</td>
<td>0.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>416</td>
<td>1.4005</td>
<td>X12CrS 13</td>
<td>0.08-0.15</td>
<td>12.0-14.0</td>
<td>0.60</td>
<td>&gt;0.15 S (Free Machining)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>420</td>
<td>1.4101</td>
<td>X20Cr 13</td>
<td>0.16-0.25</td>
<td>12.0-14.0</td>
<td>0.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>431</td>
<td>1.4057</td>
<td>X17CrNi 16-2</td>
<td>0.12-0.22</td>
<td>15.0-17.0</td>
<td>1.25-2.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>440A</td>
<td>1.4403</td>
<td>X4CrNiCuNb 18-10</td>
<td>0.03</td>
<td>21.5-24.5</td>
<td>3.0-5.5</td>
<td>0.1-0.6</td>
<td>0.05-0.20</td>
<td>0.05-0.06 Cu</td>
</tr>
<tr>
<td>S32304</td>
<td>1.4362</td>
<td>X2CrNiN 23-4</td>
<td>0.03</td>
<td>22.0-24.0</td>
<td>3.5-5.5</td>
<td>0.1-0.6</td>
<td>0.05-0.20</td>
<td>0.1-0.6 Cu</td>
</tr>
<tr>
<td>3204</td>
<td>1.4312</td>
<td>X2CrNi 23-4</td>
<td>0.03</td>
<td>22.0-24.0</td>
<td>3.5-5.5</td>
<td>0.1-0.6</td>
<td>0.05-0.20</td>
<td>0.1-0.6 Cu</td>
</tr>
<tr>
<td>3204</td>
<td>1.4312</td>
<td>X2CrNi 23-4</td>
<td>0.03</td>
<td>22.0-24.0</td>
<td>3.5-5.5</td>
<td>0.1-0.6</td>
<td>0.05-0.20</td>
<td>0.1-0.6 Cu</td>
</tr>
</tbody>
</table>

#### Duplex Stainless Steels

<table>
<thead>
<tr>
<th>Grade Number</th>
<th>UNS Number</th>
<th>Grade Designation</th>
<th>%C</th>
<th>%Cr</th>
<th>%Ni</th>
<th>%Mo</th>
<th>%N</th>
<th>%Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>2507</td>
<td>1.4507</td>
<td>X2CrNiMoCuN 25-6-3</td>
<td>0.03</td>
<td>24.0-26.0</td>
<td>4.5-6.5</td>
<td>2.9-3.9</td>
<td>0.10-0.25</td>
<td>1.5-2.5 Cu</td>
</tr>
<tr>
<td>S32550</td>
<td>1.4507</td>
<td>X2CrNiMoCuN 25-6-3</td>
<td>0.03</td>
<td>24.0-26.0</td>
<td>4.5-6.5</td>
<td>2.7-4.0</td>
<td>0.15-0.30</td>
<td>1.0-2.5 Cu</td>
</tr>
</tbody>
</table>

#### Precipitation Hardenable (PH) Stainless Steels

<table>
<thead>
<tr>
<th>Grade Number</th>
<th>UNS Number</th>
<th>Grade Designation</th>
<th>%C</th>
<th>%Cr</th>
<th>%Ni</th>
<th>%Mo</th>
<th>%N</th>
<th>%Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>630</td>
<td>1.4542</td>
<td>X5CrNiCuN 16-4</td>
<td>0.07</td>
<td>15.0-17.5</td>
<td>3.0-5.0</td>
<td>0.6</td>
<td>3.0-5.0 Cu-(5x%c)-0.45 Nb</td>
<td></td>
</tr>
<tr>
<td>Typical similar proprietary grade: 17-4PH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>------------------------------------------</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>631 S17700 0.09 16.0-18.0 6.5-7.75</td>
<td>0.7-1.5 Al</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1.4568 X7CrNiAl 17-7 0.09 16.0-18.0 6.5-7.8</td>
<td>0.7-1.5 Al</td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Typical similar proprietary grade: 17-7PH</th>
</tr>
</thead>
<tbody>
<tr>
<td>632 S15700 0.09 14.0-16.0 6.5-7.75 2.0-3.0</td>
</tr>
<tr>
<td>1.4532 X8CrNiMoAl 15-7-2 0.10 14.0-16.0 6.5-7.8 2.0-3.0</td>
</tr>
</tbody>
</table>

Typical similar proprietary grade: PH 15-7Mo