sassda®
southern africa stainless steel
development association

CLASSIFICATION, TYPICAL PROPERTIES AND APPLICATIONS

STAINLESS STEEL

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 (strength, ductility, toughness, hardness)
- physical properties (thermal conductivity, thermal expansion, density)fabrication properties (weldability, formability).

The primary property of stainless steels is corrosion resistance.

Stainless steels also exhibit a wide range of secondary properties which make them exciting and versatile materials.

THE CLASSIFICATION OF STAINLESS STEELS

Metals are crystalline solids - the atoms of the elements that make up the chemical composition arrange themselves in a definite regular pattern or the crystal structure

Different crystal structures are identified by specific names, and these are used to classify the different grades.

Martensite → Martensitic Stainless Steels
Ferrite → Ferritic Stainless Steels
Austenite → Austenitic Stainless Steels
Mixed Ferrite Austenite → Duplex Stainless Steels

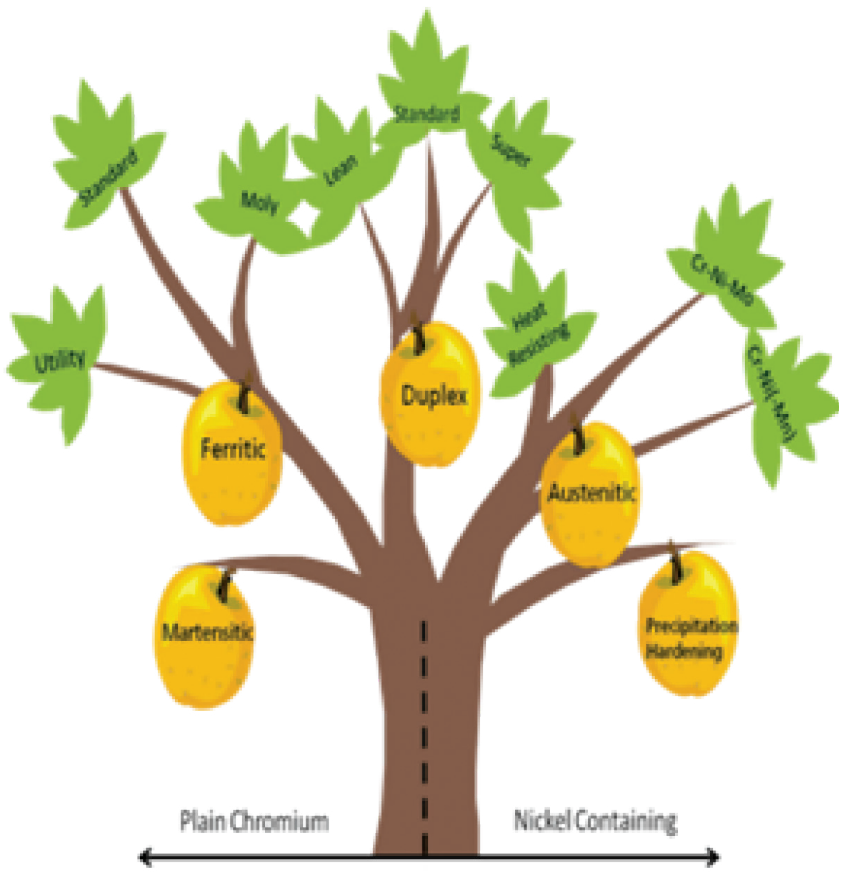

Figure 1 - Schematic representation of the family of Stainless Steels

THE FAMILY OF STAINLESS STEELS

STAINLESS STEEL is not a single material, but a FAMILY, consisting of a variety of stainless steel grades grouped in classifications and sub-classifications as schematically illustrated in Fig 1.

THE CORROSION RESISTANCE OF STAINLESS STEEL

Steel is only considered stainless if it contains more than approximately 11% Chromium (Cr).

The Cr content of stainless steels renders them corrosion resistant due to the formation of a Cr rich oxide film (termed the passive layer) on the surface. (Refer Fig 2.) This passive layer is extremely thin (≈3-5x10-6mm thick)

- uniform & continuous
- stable & tenacious
- smooth
- self repairing

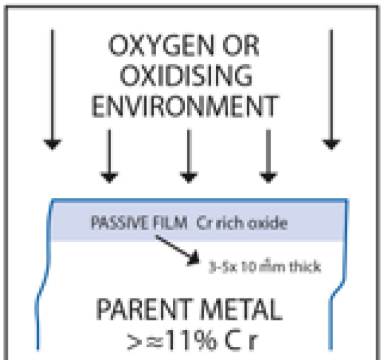

FIGURE 2: Schematic illustration the passive film on the surface of stainless steel by oxygen or an oxidising environment

1 MARTENSITIC STAINLESS STEELS

These were the first stainless steels industrially developed and used 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 ≈12-18%Cr Relatively high to high C contents of ≈0,2-1,2%C.

COMMON GRADES

410	420	431	440A, B & C
[1.4006]	[1.4021]	[1.4057]	[1.4125]

BASIC PROPERTIES

- High strength and hardness which MUST be developed by heat treatment (quenching & tempering)
- Moderate corrosion resistance (i.e. 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).

2 FERRITIC STAINLESS STEELS

There are three sub-classifications

1. Conventional Ferritic Stainless Steels
2. Utility Ferritic Stainless Steels
3. Moly Ferritic Stainless Steels.

1) 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 in thin gauges.

BASIC COMPOSITION

Plain chromium stainless steels

- Cr in the range of ≈12-18%Cr
- Relatively low C contents of <≈0,08%C.

COMMON GRADES

430	409	439/441
[1.4016]	[1.4512]	[1.4509]

Some grades may contain titanium and/or niobium.

BASIC PROPERTIES

Moderate to good corrosion resistance (i.e. in relative 'stainless steel' terms)

- Increased Cr contents improve the corrosion resistance
- Good strength and low hardness
- Always used in the annealed (i.e. fully softened) condition
- Magnetic
- Poor to moderate weldability which generally limits their application as welded components to thin gauge material.

COMMON USES

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

FORMS COMMONLY AVAILABLE

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

2) UTILITY FERRITIC STAINLESS STEELS

The initial 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 other plain chromium stainless steels.
They contain the minimum amount of Cr to render them "stainless" – generally 11-12%.
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] {410S}

BASIC PROPERTIES

- Good weldability in thicknesses of up to 30mm
- 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: e.g. 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 either, the coating is damaged by the operational conditions or where maintenance is difficult or costly walkways, stairways and ladders; high level lighting masts; electrification masts, portals and transmission towers; bus and coach frames.

FORMS COMMONLY AVAILABLE

- plate, sheet and coil in thicker gauges
- welded tube, fabricated large diameter pipe.

3) MOLY FERRITIC STAINLESS STEELS

These stainless steels were developed to address the susceptibility of conventional austenitic stainless steels to Stress Corrosion Cracking (SCC).
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.

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

444 446 [1.4521] ~~
and also as proprietary grades.

BASIC PROPERTIES

In general, similar to conventional ferritic stainless steels except:

- Improved weldability fair to moderate up to thickness of 3mm
- Very good corrosion resistance resistance to Stress Corrosion Cracking (SCC).

COMMON USES

Under conditions where there is a likelihood of SCC

- heater panels, e.g. solar heating
- heat exchanger and condenser tubing cooling coils in brackish and estuarine water
- hot water heaters and storage
- balustrades in coastal buildings
- chloride brine solutions used in food processing.

FORMS COMMONLY AVAILABLE

- sheet, coil and thinner plate
- welded tube and pipe.

3 AUSTENITIC STAINLESS STEELS

There are four sub-classifications

1. Conventional (CrNi) Austenitic Stainless Steels
2. Heat Resisting Austenitic Stainless Steels
3. CrNiMn Austenitic Stainless Steels
4. Austenitic Stainless Alloys

1) CONVENTIONAL (CrNi) AUSTENITIC STAINLESS STEELS

Nickel (Ni) promotes the formation of an austenitic crystal structure and, if sufficient Ni is present, a fully austenitic crystal structure at room temperature 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 necessitate 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%C) in the "L" grades
- Ti in the stabilised grades the "L" and stabilised grades are used to prevent the possibility of intergranular corrosion occurring after welding of thicker gauges in some corrosive solutions.

COMMON GRADES

304	304L	321
[1.4301]	[1.4306]	[1.4541]

and the grades that contain Mo

316	316L	316Ti
[1.4401]	[1.4404]	[1.4571]

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 by cold work but not by heat treatment
- Excellent mechanical properties at cryogenic (i.e. very low) temperatures
- Good high temperature properties
- Non-magnetic.

COMMON USES

The Conventional Austenitic Stainless Steels are used for a large 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 (street furniture, façades, shop fronts, signs, balustrades, cladding, roofing)
- builders' hardware, masonry ties and anchors
- reinforcing bar for concrete
- food and beverage equipment (abattoirs, dairy, beer, wine, soft drink processing), and food preparation (hotel, restaurant and fast food kitchens)
- transport (rail cars, tankers, ISO "tank containers")
- boat and yacht hardware, fittings and rigging
- cryogenic equipment (manufacture, storage and transport of liquid gases)
- pollution control and water treatment
- furnace components
- plant and equipment in petrochemical, chemical, mineral extraction, pulp and paper, nuclear and other industries (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 stainless 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:

They are only suitable for lower concentrations of reducing acids and reducing acid mixtures at lower temperatures

Halide ions, especially the chloride ion (Cl-), in corrosive solutions have the ability to attack weak spot that exists in the passive film which can result in highly localised corrosive attack known as Pitting Corrosion, Crevice Corrosion or Stress Corrosion Cracking
At high temperatures gaseous corrosion takes place, the most common form of which is oxidation or scaling the maximum temperature which can be handled is ≈925°C in oxidising conditions.

2) HEAT RESISTING AUSTENITIC STAINLESS STEELS

At temperatures in excess of 925°C a higher content of Cr is necessary to resist oxidation. A corresponding higher Ni content is necessary to maintain a fully austenitic crystal structure.

BASIC COMPOSITION

- Higher Cr & Ni
- 24% Cr14 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
- Non-magnetic.

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).

3) CrMnNi AUSTENITIC STAINLESS STEELS

Originally, these stainless steels were developed as an alternative to 18Cr8Ni austenitic stainless steel at a time when Ni was in short supply.
However now they are mainly used to reduce cost by minimizing the Ni content.

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, i.e. <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]

Plus several proprietary grades

BASIC PROPERTIES

In general, similar to
Grades 304 [1.4031] and 304L [1.4307].
the strength is ≈30% higher in the annealed condition a greater response to cold work

POTENTIAL USES:
As a replacement for conventional austenitic grades in less critical applications to reduce cost

FORMS COMMONLY AVAILABLE

Sheet and coil.

4) AUSTENITIC STAINLESS ALLOYS

These are sometimes referred to as high performance alloys or super Alloys

- A preferred description is special purpose alloys because many of them were formulated to resist specific corrosive conditions or set of conditions 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 may exceed 50%
- Often the Ni content may be 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 aqueous corrosion resistant grades

20%Cr	25%Ni	4,5%Mo	1,5%Cu	[1.4539]
20%Cr	25%Ni	6,5%Mo	1,0%Cu	[1.4529]
27%Cr	32%Ni	3,5%Mo	1,0%Cu	[1.4563]
20%Cr	36%Ni	2,5%Mo	3,5% Cu+Nb+Ta	[2.4660]
21%Cr	42%Ni	3.0%Mo	2,0%Cu	[2.4858]

Examples of the heat resistant grades

18%Cr 37%Ni	[1.4864]
21%Cr 32%Ni	[1.4876]

BASIC PROPERTIES

In general, similar to the conventional austenitic stainless steels except that for the corrosion resistant grades 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 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 such as retorts, kilns, muffles, radiant tubes, burner components, heat treatment boxes, trays and baskets.

FORMS COMMONLY AVAILABLE

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

4 DUPLEX STAINLESS STEELS

These stainless steels contain insufficient Ni to develop a fully austenitic crystal structure and therefore consist of a mixed ferritic-austenitic (i.e. duplex) crystal structure.

These grades were originally developed to address the susceptibility of the austenitic stainless steels to stress corrosion cracking in thicker gauge welded structures.

As these grades have developed, a range of sub-groups have formed, namely:

- Lean Duplex grades – contain no Mo
- Conventional duplex grades – the original grades
- Super duplex grades – contain very high levels of both Mo and N for increased corrosion resistance, and increased Ni to maintain the ferrite/austenite balance.

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 and stabilizer

NOMINAL COMPOSITION OF TYPICAL GRADES

Originally these stainless steels were developed as proprietary grades but many have now been incorporated into standard specifications:

Lean	21% Cr 2%	Ni 0,6%	Mo 0,15% N5%	Mn	[1.4482	{2001}
Lean	21% Cr 1.5%	Ni 0,3%	Mo 0,22% N 5%	Mn	[1.4162	{2101}
Lean	23% Cr 4%	Ni 0,4%	Mo 0,15% N		[1.4362]	{2304}
	22% Cr 5%	Ni 3,0%	Mo 0,18% N		[1.4462]	{2205}
Super	25% Cr 7%	Ni 3,5%	Mo 0,30% N		[1.4410]	{2507}

BASIC PROPERTIES

Excellent corrosion resistance

- higher Cr + Mo & N improve the resistance to Pitting Corrosion and Crevice Corrosion
- a high resistance to Stress Corrosion Cracking due to the duplex ferritic-austenitic crystal structure
- Proof stress is about double that of the conventional austenitic stainless steels
- Good formability, limited by the high strength
- Very good weldability.

COMMON USES

As welded process plant and equipment,

- heat exchanger tubing & panels
- in the chemical and petrochemical industries for resistance to corrosive solutions that are likely to cause Pitting Corrosion and/or Stress Corrosion Cracking
- in marine and off-shore oil applications
- to handle chloride brine solutions.

FORMS COMMONLY AVAILABLE

plate, sheet, pipe & tube.

5 PRECIPITATION HARDENING STAINLESS STEELS

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

They were originally developed for applications in the aerospace and armaments industries that required the corrosion resistance and fabrication 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

- Martensitic (also termed Maraging)
- Semi-austenitic
- Austenitic (PH stainless steels in this sub-classification are now seldom used).

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 more commonly used grades are now incorporated into standard specifications:

- Martensitic grade [1.4542]
- Semi-austenitic grades [1.4568] [1.4532]

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, e.g. shafts, spindles, fasteners.

FORMS COMMONLY AVAILABLE

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

CONCLUSION

There are many different grades in the

Family of Stainless Steels.

All can be logically grouped within five classifications.

The grades of stainless steel within any classification have similar properties.

The use of a specific grade of stainless steel should be 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 fulfil a necessary role where process conditions (temperatures, concentrations, and pressures) are beyond the capabilities of the standard grades

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 fewer 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 may be of an unsophisticated nature, could further accelerate its use.

Stainless steels are not indestructible materials.

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.

TRULY AN EXCITING AND VERSATILE MATERIAL!