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STAINLESS STEELS: A REFRESHER

ENERGYValves MULTIAlloys

In this e-book we review a range of stainless steels that are readily available and highlight their features, benefits and possible limitations if not used appropriately.

INTRODUCTION

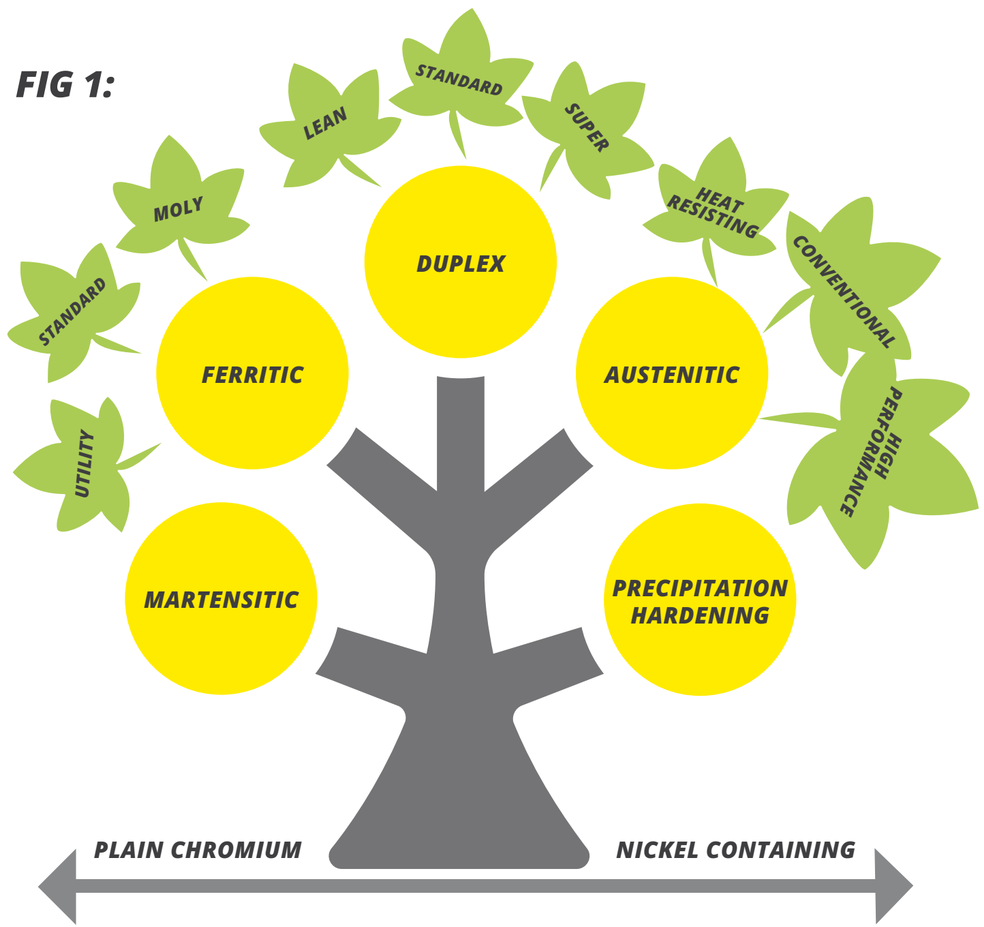
Stainless steels emerged as a sub-group of steels more than 110 years ago and since then their development has been spurred by industrial activities which required metals that were resistant to corrosion in a range of environments but also displayed the other important characteristics of materials of construction viz strength or in broader terms, mechanical properties, ease of fabrication, total cost and availability.

Today, there are more than 250 grades of stainless steel and it has become useful to group these according to their micro-structure and to view these groups as the branches of a family tree. **(Fig 1)**

Stainless steels have been defined by a minimum of 10.5% Cr but the microstructure of a grade and its properties are a result of its composition and a complex interplay of the various elements that are added.

WHAT'S IN A NAME

FIG 1:



The naming of grades of stainless steel may be quite confusing as several different designation systems are used. Some of these are:

AISI: The American Iron and Steel Institute developed a 3-digit system for stainless steels in the 1930's and 1940's. Examples 304, 316L, 310S.

UNS: A Unified Numbering System for metallic materials was developed from the AISI system in the 1970's. Steels have a prefix S and examples are S30400, S31603, S31008.

EN: The European Standards system emerged in the 1980's to standardise designations in Europe. Examples are 1.4301, 1.4404, 1.4845.

TRADE NAMES: Where reference to these is easier they are often preferred to the above systems. Examples are 904L, 17-4PH, 253MA.

ALLOYING ELEMENTS

Stainless steels have been defined by a minimum of 10.5% Cr but the microstructure of a grade and its properties are a result of its composition and a complex interplay of the various elements that are added. Briefly the more common of these are:

CHROMIUM
allows for the formation of a passive layer to make the metal corrosion resistant and an oxide scale to protect against attack at elevated temperature.

NICKEL
is the primary element used to create the austenitic structure which increases ductility and formability of the metal. It also enhances the corrosion resistance of the metal in many aqueous and elevated temperature environments.

CARBON
enables the metal to be strengthened / hardened but it also results in the formation of chromium carbides which are harmful to corrosion resistance.

MOLYBDENUM
increases both general and localised corrosion resistance and improves mechanical properties at elevated temperatures.

COPPER
is added to stainless steels as it increases resistance to certain corrosive environments one of which is sulphuric acid. It also provides age hardening effects.

MANGANESE
At a level of up to 2% has no effect on the metal's properties but above this level it may be a deliberate addition to aid in the formation of austenite.

SILICON
enhances the corrosion resistance of the metal under oxidising conditions whether these are under elevated temperature conditions or in an aqueous corrosion application.

ALUMINIUM
is used to improve the protective scale needed for high temperature service and it's also used as a precipitate former.

TITANIUM
is one of several carbide formers that may be used to obviate the formation of chromium carbide and thereby reduce the susceptibility to intergranular corrosion.

Whilst these outline the primary functions of the various elements there are other effects that they may have. These may include their role in the steel making process and the structure and properties of the metal.

01

MARTENSITIC STAINLESS STEELS

The grade designations used are not specifications but they do appear in the specification for a product form eg for stainless steel plate: UNS S31603 will appear in ASTM A240 / ASME SA240. Often a second specification may apply for a product form eg ASTM480 / ASME 480 for plate.

CHARACTERISTICS

- have a carbon content which facilitate the formation of martensite, and low or no nickel.
- display moderate corrosion resistance primarily in line with Cr and Mo contents.
- are heat treatable to achieve a wide range of hardnesses and strengths.
- are magnetic.
- may have low ductility and poor weldability.

APPLICATIONS

The primary applications for martensitic grades are:

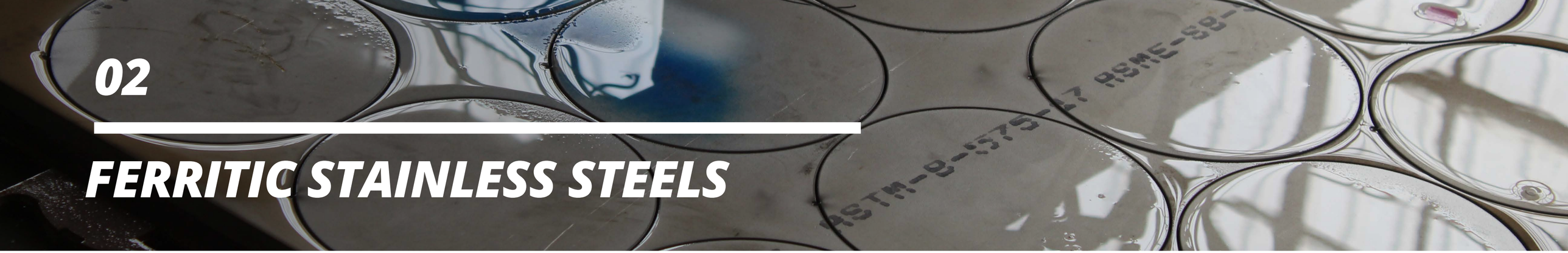
- *Where the high hardnesses achievable make them ideal for applications which require components with an "edge"* ***eg:*** *blades, knives, guillotine and scraper blades.*
- *Shafts for pumps.*
- *Components for valves, nozzles and bushes / sleeve bearings.*

Table 1: Martensitic Stainless Steels

Designations			Nominal Composition (%)				Mech. Properties #		
Common	UNS	EN	C	Cr	Ni	Other	0.2% Proof*	Hardness	Condition
420	(S42000)	1.4021	0,18	13			600		QT800
431	(S43100)	1.4057	0,16	16	2,5	Mo	600		QT800
410	S41000	(1.4006)	0.11	12,5			550		T
440C	S44004	(1.4125)	1,0	17		Mo		58HRC	H
1.4313	(S41500)	1.4313	0,03	13	4	Mo	620		QT780

☐ **Stocked grade** ☐ **Subject to enquiry**

*** Guaranteed Minimum in MPa**
 # Information is for heat treated material



02

FERRITIC STAINLESS STEELS

CHARACTERISTICS

- have low carbon contents with the exception of the heat resisting grades.
- have no or low nickel contents.
- are immune to stress corrosion cracking and have a moderate general corrosion resistance which is enhanced by the addition of Mo, as is pitting resistance.
- are magnetic.
- display a higher proof strength than the general purpose austenitic range and this is combined with good formability.
- have poor weldability but the metallurgy of 3CR12 overcomes this problem.
- are unsuitable for cryogenic service.

APPLICATIONS

- *Many applications for the ferritic stainless steels arise from the fact that they offer an optimum combination of corrosion resistance with properties that are adequate for the application AND more stable pricing than the nickel containing grades. The family of alloys is used extensively in consumer related applications and in thicknesses that may be readily welded.*
- *Product availability is primarily sheet with tube and round bar also available in certain grades. The nature of 3CR12 is such that it is weldable in thick sections and thus the plate is readily available as well.*

Table 2: Ferritic Stainless Steels

Designations			Nominal Composition (%)				Mech. Properties #	
Common	UNS	EN	C	Cr	Ni	Other	0.2% Proof*	Hardness (BHN)**
3CR12 Utility	S41003	1.4003	0,03	11,5	0,9	Ti	280	220
430 Standard	S43000	1.4016	0,06	17	0,5		260	183
444 Mo +	S44400	1.4521	0,025	18,5	0,5	Ti,Mo	320	
441 Stabilised	S43940	1.4509	0,03	18		Ti,Nb	250	180
4C54 Heat resisting	S44600	1.4749	0,15	26		N	280	190HV

☐ **Stocked grade** ☐ **Subject to enquiry**

*** Guaranteed Minimum in MPa**
 # ASTM Information is for annealed material
**** max**

03

PRECIPITATION HARDENING STAINLESS STEELS

This branch of the stainless steel tree is the smallest in terms of amount used. Their combination of corrosion resistance and mechanical properties are most useful

CHARACTERISTICS

- may be heat treated to very high strengths combined with a good toughness.
- have good corrosion resistance.
- are weldable.

APPLICATIONS

The properties of these grades are such that their applications are primarily centred around their strength and / or hardness that they display. These grades are used selectively in a wide range of industries including aerospace, chemical and petrochemical and food processing industries. They are used in industrial equipment and mining machines. Specific applications include pins, shafts, springs and retaining rings.

The readily available product is primarily round bar but plate and centrifugal castings can also be supplied.

Table 3: Precipitation Hardening Stainless Steels

Designations			Nominal Composition (%)				Mech. Properties #	
Common	UNS	EN	C	Cr	Ni	Other	0.2% Proof*	Hardness (BHN)**
17-4PH Martensitic	S17400	1.4542	0,07	16,5	4	Cu,Nb		363
17-7PH Semi-Austenitic	S17700		0,09	17	7,25	Al		229
15-5PH Semi-Austenitic	S15500	1.4545/8	0,07	15	4,5	Cu,Nb		363

☐ **Stocked grade** ☐ **Subject to enquiry**

* Not specified for annealed material
# ASTM Information is for solution annealed material
** max

04

AUSTENITIC STAINLESS STEELS

This group of the stainless steels comprise the largest number of grades. It is the most useful of the 5 groups and represents approximately two thirds of stainless steel used

CHARACTERISTICS

- are characterised by a microstructure which is created primarily by nickel but also by manganese and influenced by carbon and nitrogen.
- have low carbon contents for most grades. The strength of the high temperature grades benefits from a slightly raised carbon level.
- display moderate to very good corrosion resistance in line with the alloying element content of the specific grade.
- are non-magnetic when in the annealed condition. If work-hardened they are slightly magnetic.
- have a very high ductility and toughness and they may be easily work hardened.
- have excellent weldability and formability.
- are suitable for cryogenic service and there are grades in the range that are well-suited for service at high temperatures.
- are susceptible to chloride stress corrosion cracking – this is most pronounced with the 304 / 316 range.

The range of austenitic stainless steels is extensive and its best to review them as sub-groups under the 3 headings that follow on pages 10 to 12.

CONVENTIONAL AUSTENITIC STAINLESS STEELS

CHARACTERISTICS

Conventional Austenitic Stainless Steels are the core of the austenitic branch with 304 and 316 as the basis. The molybdenum in the latter ensures improved pitting and crevice corrosion resistance. There are 2 approaches to preserve the optimum corrosion resistance of grades that may need to be welded:

- Keeping the carbon content low. The so-called "L" grades as in 304L and 316L.
- The addition of titanium to which combines with the carbon in preference to the chromium. These are referred to as stabilised grades e.g. 321 and 316Ti

The downside of the lower carbon solution is that it affects strength as illustrated in table 4 but more so at temperatures above ambient.

APPLICATIONS

The applications for this range of stainless steels are diverse and widespread and with grade selection taking into account mechanical properties and corrosion resistance they include:

- *Domestic and consumer items*
- *Food and beverage equipment*
- *Chemical and pharmaceutical plant*
- *Water reticulation and treatment*
- *Pulp, paper and minerals processing industries.*
- *Elevated temperatures (to +/-500°C)*
- *Architectural items*
- *Urban furniture*
- *Cryogenic applications*

Table 4: Conventional Austenitic Stainless Steels

Designations			Nominal Composition (%)					Mech. Properties #	
Common	UNS	EN	C	Cr	Ni	Mo	Other	0.2% Proof*	Hardness (BHN)**
304	S30400	1.4301	0,07	18,5	9,25			205	201
304L	S30403	1.4307	0,03	18,5	9,5			170	201
321	S32100	1.4541	0,08	18	10,5		Ti	205	217
316	S31600	1.4401	0,07	17,5	11,5	2,5		205	217
316L	S31603	1.4404	0,03	17,5	11,5	2,5		170	217
316Ti	S31635	1.4571	0,08	17,5	12	2,5	Ti	205	217

☐ **Stocked grade** ☐ **Subject to enquiry**

* Guaranteed Minimum in MPa
# ASTM Information is for solution annealed material
** max

HIGH PERFORMANCE AUSTENITIC STAINLESS STEELS

Whilst this refresher is about stainless steels, this subgroup has grades which are technically nickel alloys. ALLOY 35 is such a grade. Although there are other grades listed with the UNS prefix N, they are stainless steels

CHARACTERISTICS

High Performance Austenitic Stainless Steels are frequently also referred to as Super austenitic Stainless Steel. They are characterised by superior corrosion resistance in a wide range of aggressive environments. This feature results from the selective use of specific alloying elements in amounts that are significantly higher than the core grades of 304 and 316. Table 5 reflects this as well as the higher strengths of this sub-group.

The corrosion benefits that accrues from the various elements are in line with the explanation on **pg 5** with the exception of nitrogen (N). Nitrogen significantly enhances the pitting resistance of the alloy but it also contributes to a higher strength of austenitic grades in general.

APPLICATIONS

The applications for High Performance Austenitic Stainless Steels overlap largely with the conventional range but in conditions which are more demanding in respect of corrosion resistance and strength. Typically the alloys will be used in environments which may have high corrosivity because of temperature, pressure, acidity and the presence of significant amounts of contaminants such as chlorides.

- *Chemical and petro-chemical plant*
- *Desalination and water treatment*
- *Pulp, paper and minerals processing industries.*
- *Elevated temperatures (to +/-500°C)*
- *Offshore oil and gas industries*
- *FGD and air pollution control*

Table 5: High Performance Austenitic Stainless Steels

Designations			Nominal Composition (%)					Mech. Properties	
Common	UNS	EN	C	Cr	Ni	Mo	Other	0.2% Proof*	Hardness (BHN)#
254SMO	S31254	1.4547	0,02	20,0	18.0	6.25	N; Cu	310	223
904L	N08904	1.4539	0,02	21,0	25.0	4.5	Cu	220	
926	N08926	1.4529	0,02	20,0	25,0	6,5	N; Cu	295	
Alloy 20	N08020	2.4660	0,07	20.0	35.0	2.5	Cu; Nb	240	217
Alloy 35	N08935		0,03	27	35	6.5	N; Cu	380**	

☐ **Stocked grade** ☐ **Subject to enquiry**

* Guaranteed Minimum in MPa
** Typical value
# max

HEAT RESISTING AUSTENITIC STAINLESS STEELS STEELS

The selection of these grades for each application is often a compromise between demands on mechanical strength, structure stability and corrosion resistance[6]

CHARACTERISTICS

Heat Resisting Austenitic Stainless Steels are intended for use at temperatures above 500°C. The upper temperature limit will vary for each grade but none are likely to exceed 1200°C as this approaches their melting points.

The 3 parameters influencing the selection of a grade in this range are listed above and are reviewed more fully in ***SELECTING ALLOYS FOR HIGH TEMPERATURE APPLICATIONS »*** In summary:

- There are a number of distinctive forms of high temperature corrosion and these are a function of the environment that the metal is exposed to.
- The phenomenon of creep becomes more pronounced at temperatures above 500°C and may be the limiting strength parameter for this range of metals
- Metals may undergo microstructural changes when exposed to elevated temperatures and this may in turn affect their strength and corrosion resistance. The alloys listed are intended for use under these conditions.

APPLICATIONS

The applications for the alloys listed are diverse and include:

- *Petro-chemical plant*
- *Temperature measurement instrumentation*
- *Furnace and kiln components*
- *heat exchangers and boilers*
- *Furnace furniture*

Table 6: Heat Resisting Austenitic Stainless Steels

Designations			Nominal Composition (%)					Mech. Properties 0.2% Proof*	
Common	UNS	EN	C	Cr	Ni	Si	Other	100°C	450°C
310	S31000		0,15	25,0	20,0	1,0		(205#)	
310S	S31008	1.4845	0,05	25.5	19.1	0.5		210	86
1,4841	S31400	1.4841	0.06	24.3	19.2	1.6		230	86
309S	S30908	1.4833	0,06	22.3	12.3	0.03		210	86
253MA	S30815	1.4835	0,09	21.0	11	1.6	N, Ce	310	155

☐ **Stocked grade** ☐ **Subject to enquiry**

*** Guaranteed Minimum in MPa**
 # at ambient temperature

05

DUPLEX STAINLESS STEELS

The "Hyper Duplexes" are yet another subgroup in this range of stainless steel. Their combination of strength and corrosion resistance is such that they extend the useful range for these alloys

CHARACTERISTICS

- duplex stainless steels have a balanced microstructure comprising ferrite and austenite.
- display moderate to very good resistance to general corrosion and pitting / crevice corrosion.
- they are very resistant to stress corrosion cracking.
- have high strengths.
- are magnetic in line with the ferrite level in their structure.
- may undergo damaging structural changes if exposed to temperatures above 300°C for a significant time.
- can be readily fabricated provided their mechanical properties are taken into account.

The characteristics are reviewed in more detail in ***DUPLEX BUT NOT COMPLEX »***

APPLICATIONS

- *The attributes of duplex stainless steels are such that their applications are wide ranging. They are useful materials of construction for tanks and pressure vessels, heat exchangers and water heaters, piping systems, fasteners, impellers, shafts and mixers and public use structures such as bridges and bus shelters.*
- *Alloys in the range are used for water treatment and desalination, pulp and paper production, minerals processing and recovery, chemical and petrochemical production and in the marine and offshore industries.*

Table 7: Duplex Stainless Steels

Designations			Nominal Composition (%)					Mech. Properties	
Common	UNS	EN	C	Cr	Ni	Mo	Other	0.2% Proof*	Hardness (HRC)#
LDX2101 Lean	S32101	1.4162	0,04	21,5	1.6	0.4	Mn,N,Cu	450	-
Alloy 2304 Lean	S32304	1.4362	0,03	23,0	4,5	0,35	N	450	31
Alloy 2205 Standard	S32205	1.4462	0,03	22,0	5,5	3.25	N	450	31
Alloy 2507 Super	S32750	1.4410	0,03	25,0	7,0	4,0	N,Cu	550	32
S32760 Super	S32760	1.4501	0,03	25,0	7,0	3,5	N,Cu,W	550	
Alloy 255 Super	S32550	1.4507	0,04	25,5	5.5	3.4	N,Cu	550	32

☐ **Stocked grade** ☐ **Subject to enquiry**

* Guaranteed Minimum in MPa
\# max

"The optimum materials are those which provide the lowest cost to life ratio when corrected for tax rates and accounting procedures and which incorporate certain aspects of safety, health, and environmental considerations, and reliability. The desired end result includes profitable operations with a minimum of unscheduled shutdowns and regularly scheduled refurbishing or replacement." *(6)*

CONCLUSION

In addition to the general properties of the 5 branches and the various grades highlighted, **2 practical considerations** are:

- The product forms produced / stocked do vary – e.g. some grades may be limited to bar and possibly plate whilst others have established applications for a number of product forms.

- In South Africa the ex-stock availability of the grades listed does depend on their usage. Those grades or product forms or dimensions used less frequently may have to be imported to meet specific needs.

The range of stainless steels types is vast and the more common of those used in South Africa have been highlighted. Their properties and the benefits each offers vary but by careful selection finding the optimum referred to above is possible for most applications.

We welcome the opportunity to be of assistance.

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