

Stainless Steel Grade Selection

The Good, The Bad & Ugly Decisions to be Made

“There is no such thing as a bad grade...only bad grade selection”.

Introduction

Stainless steels have properties which make them attractive choices for a wide range of applications. Many grades have been developed over the years; these form a rich tapestry of alternatives, with grades optimised to offer cost-effective solutions to many of the problem environments in industrial, marine, construction and transport applications. The following table shows some of the more common options.

Alloy Group	Common Grades					
Austenitic	UNS No. Commonly	S30100 301	S30400 304	S30403 304L	S31600 316	S31603 316L
	UNS No. Commonly	S32100 321	S31000 310	S30815 253MA	N08904 904L	S31254 254SMO or “6Mo”
Ferritic	UNS No. Commonly	S40900 409	S41003 3CR12 or 1.4003	S43000 430	S43932 439	S44400 444
Martensitic	UNS No. Commonly	S41000 410	S42000 420	S43100 431	S44004 440C	
Duplex	UNS No. Commonly	S32101 2101	S32304 2304	S32205 2205	S32750 2507	S32520 UR2507Cu
Precipitation Hardening	UNS No. Commonly	S17400 17-4PH or 630	S17700 17-7PH or 631	S15500 15-5PH		

Fundamental Properties for Selection

When considering the choice of a stainless steel for a particular application, the first consideration needs to be on the basis of which of the fundamental "competitive advantage" properties needs to be exploited. These basic properties for selection can be initially looked at from the point of view of the five basic alloy groups – austenitic, duplex, ferritic, martensitic and precipitation hardening.

Required Property	Alloy Groups and Grades Likely to be Selected
Corrosion resistance	Selection depends upon environment. See later discussion.
Heat resistance	Austenitic grades, particularly those high in chromium, often also with high silicon, nitrogen and rare earth elements (e.g. grades 310 and 253MA). Stabilised ferritic's are used in less extreme conditions. High chromium ferritic grades have high oxidation resistance (e.g. 446), but have lower hot strength.
Cryogenic (low temperature) resistance	Austenitic grades have excellent toughness at very low temperatures. No other stainless steels are suitable at very low temperatures.
Magnetic response	Austenitic grades have low magnetic permeability; higher nickel grades (e.g. 316 or 310) are more likely to be non-magnetic if cold worked.
High Strength	Martensitic and precipitation hardening grades. Duplex grades can be useful. Cold worked austenitic grades also have high strength.

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Selection for Corrosion Resistance

The selection of the most cost-effective grade for a particular corrosive environment can be a complex task. References given at the conclusion of this paper give more details. Often the most revealing guide to material selection is the simple consideration of what has been used before (here or in a similar environment), what was the service life and how and when did it corrode? ... was it satisfactory?

For resistance to environments such as strong acids, where uniform general corrosion is the controlling mechanism, there are published tables of recommended grades, and iso-corrosion curves that indicate the rate at which the steel can be expected to corrode. These are usually constructed so that several grades can be compared, and the applicable one selected for the expected environment. Although this approach is useful, some care needs to be taken as there are often minor differences between apparently similar environments that can make a large difference to the corrosion rates in practice. Even traces of chloride for instance can be very harmful.

Local corrosion is very frequently the mechanism by which stainless steels are likely to corrode. The related mechanisms of pitting and crevice corrosion are very largely controlled by the presence of chlorides in the environment, exacerbated by elevated temperature. The resistance of a particular grade of stainless steel to pitting and crevice corrosion is indicated by its Pitting Resistance Equivalent number, or PRE, as shown in the table below. The PRE can be calculated from the composition as:

$$PRE = \%Cr + 3.3 \%Mo + 16 \%N$$

Clearly grades high in the alloying elements chromium and especially molybdenum and nitrogen are more resistant. This is the reason for the use of grade 316 (2%Mo) as the standard for marine fittings, and also explains the selection of duplex grade 2205 (S32205) with 3%Mo and a deliberate addition of 0.15%N for resistance to higher chlorides at higher temperatures. More severe chloride-containing environments can be resisted by the "super austenitic" grades (e.g. N08904 and S31254) with up to 6%Mo and by the "super duplex" grades (e.g. S32750 and S32520) with very high chromium, molybdenum and nitrogen additions. The use of these grades can extend the useful resistance in high chloride environments up to close to boiling point.

Grade	Group	PRE
3CR12	Ferritic	11
430	Ferritic	17
303	Austenitic	18*
304/L	Austenitic	18
316/L	Austenitic	24
444	Ferritic	24
2205	Duplex	34
904L	Austenitic	34
S31254	Austenitic	43
S32750	Duplex	43
S32520	Duplex	43
*See comments in the text on grade 303.		

"Tea staining" is a particular form of localised corrosion seen in stainless steel items exposed to aggressive atmospheric environments; the classic case is handrails and fittings with marine exposure. Grades with higher PRE values do resist tea staining better, but the quality of the finish, method of fabrication and installation and extent of ongoing maintenance are all highly relevant. Selection of a lower PRE (and hence generally lower cost) grade in some cases can be compensated for by increased effort in finishing and increased maintenance.

A particular problem for the common austenitic grades (e.g. 304 and 316) is stress corrosion cracking (SCC). Like pitting corrosion this occurs in chloride environments, but it is possible for SCC to take place with only traces of chlorides, so long as the temperature is over about 60°C,

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and so long as a tensile stress is present in the steel, which is very common. The ferritic grades are virtually immune from this form of attack, and the duplex grades are highly resistant. If SCC is likely to be a problem, it would be prudent to specify a grade from these branches of the stainless family tree.

Selection for Mechanical and Physical Properties

High strength martensitic (e.g. 431) and precipitation hardening (e.g. 630 / 17-4PH) grades are often the material of choice for shafts and valve spindles – here the high strength is as fundamental to the selection process as is the corrosion resistance. These grades have strengths up to more than twice that of grades 304 and 316.

Very commonly a grade is selected for required corrosion resistance (or resistance to high or low temperature or because of required magnetic response), and then the structure or component is designed around the mechanical and physical properties of the grade selected. These secondary aspects should be considered as early as possible in the selection process. The selection of a high strength duplex grade such as 2205 may not only solve the corrosion problem but could also contribute to the cost effectiveness of the product because of its high strength. The selection of a ferritic grade such as 3CR12 may result in adequate corrosion resistance for a non-decorative application, and its low coefficient of thermal expansion could be desirable because of less distortion from temperature changes. The thermal expansion rates of the ferritic grades are similar to that of mild steel, and only 2/3 that of austenitic grades such as 304.

Selection for Fabrication

Again, it is usually the case that grades are selected for corrosion resistance and then consideration is given to how the product can be fabricated. Fabrication should be considered as early as possible in the grade selection process, as it greatly influences the economics of the product. The table at right lists some common grades and compares their relative fabrication characteristics. These comparisons are on arbitrary 1 to 10 scales, with 10 indicating excellent fabrication by the particular method.

Grade	Form-ability	Machin-ability	Weld-ability
303	1	8*	1
304	8	5*	8
316	8	5*	8
444	6	5	5
416	1	10	1
430	4	6	2
2205	5	4	6
3CR12	5	6	7

*Improved Machineability versions of these grades offer higher machinability's in some products.

It is important to realise that there may be a trade-off between desirable properties. An example is grade 303. This has excellent machinability, but the high sulphur content which increases the cutting speed so dramatically also substantially reduces the grade's weldability, formability and corrosion resistance. With this grade the calculated PRE is wrong, as it does not factor in the negative effect of the sulphur. This grade must not be used in any marine or other chloride environment.

Selection for Cost

Cost can be viewed as the obvious \$/kg or \$/metre purchase price; this is an easy way of comparing materials and grades, but it can give a distorted short-term view. A more realistic approach in many cases is the "Total Cost of Ownership" (TCO) or "Life Cycle Cost" (LCC) view. This evaluates the cost to the asset owner over the required life time of the item, generally

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evaluated by accounting techniques such as discounted cash flow. The point is that if a purchased item is required to be used for saying 20 years, but needs to be maintained or replaced within that time there are extra costs to be paid – these costs should be factored into the purchase cost of the material choice. A selection that reduces these ongoing costs may then have a lower Total Cost of Ownership despite a higher initial purchase price.

Examples of the value of this approach are not difficult to find. The choice of stainless steel grade 301 for suburban rail cars ensures that the basic vehicle will survive without structural rust for the required life, measured in decades. The stainless panels will be cleanable, will require no painting and the structural members will not need costly regular inspections to validate integrity. These long-term savings may out-weigh any higher initial purchase price compared to some other construction options.

Another consideration that impacts on both purchase price and delivery time is the choice between standard and special products. Standard products that are available from stockists' shelves will usually be a lower cost than products that differ from standard in some way, and so need to be specially manufactured, possibly in another country. Designing based on standard stock items usually pays dividends. An exception to this is if the required quantity is large and the requirement has been planned well into the future – here a special product can be lower cost and also reduce fabrication costs. An example would be a special low work hardening rate “forging quality” bar that enabled an item to be cold forged to shape rather than machined from a larger starting size.

Conclusion

Before selecting a grade of stainless steel, it is essential to consider the required properties such as corrosion resistance, but it is also important to consider the secondary properties such as the physical and mechanical properties and the ease of fabrication of any candidate grades. The correct choice will be rewarded not just by long, trouble-free life, but also by cost-effective fabrication and installation.

References

- “Corrosion Data”, ASM International.
- Sedriks, A.J., "Corrosion of Stainless Steels".
- “ASM Specialty Handbook – Stainless Steels”, ASM International.
- “Corrosion Handbook”, Outokumpu Stainless AB.
- “Tea Staining Technical Bulletin”, ASSDA.
- Tech Note No. 6, “Life Cycle Costing”, Atlas Steels.

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Grade Properties for Selection an Overview of Specific Grades

3CR12 / 3CR12Ti

Good For:

- ☺ - Economical stainless steel grade due to low alloy content.
- ☺ - Low thermal expansion coefficient results in reduced distortion in welding and in high temperature applications.
- ☺ - Good scaling resistance to over 600°C, and useful strength at these elevated temperatures – can be a good choice for furnace bodies.
- ☺ - Good resistance to mildly corrosive environments – especially those with some abrasion or wear.
- ☺ - Immune to Chloride stress corrosion cracking.
- ☺ - Readily fabricated by bending, plasma cutting and conventional electric welding processes.

Not Good For:

- ☹ - Low resistance to corrosive media – PRE about 11. Unsuitable for marine exposure.
- ☹ - Cannot be strengthened by heat treatment or cold work.
- ☹ - Not able to be given a bright decorative finish.

303

Good For:

- ☺ - Excellent machinability – readily used for high productivity machining.
- ☺ - Useful scaling resistance to about 870°C.
- ☺ - Resists corrosion from mild atmospheres and clean water.

Not Good For:

- ☹ - Poor resistance to general corrosion, due to the Sulphur addition.
- ☹ - Very poor resistance to Chloride pitting and crevice corrosion – not suitable for any marine applications at any temperature.
- ☹ - Poor resistance to stress corrosion cracking – susceptible above 60°C in even low Chloride environments.
- ☹ - Low ductility – cannot be bent around a tight radius, or heavily drawn.
- ☹ - Poor weldability – not recommended for structural welds.

304

Good For:

- ☺ - Good resistance to a wide range of corrosive environments.
- ☺ - Excellent formability – readily deep drawn, bent and forged hot or cold.

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- ☺ - Available in Improved Machinability bars.
- ☺ - Available in Deep Drawing Quality (DDQ) for very severe drawing.
- ☺ - Excellent weldability.
- ☺ - Useful scaling resistance to 870°C.
- ☺ - Can be cold worked to high strength for use as springs and clips.
- ☺ - Available in the widest range of products, across all product classes and finishes.

Not Good For:

- ☹ - Poor resistance to sea water – safe exposure temperature only about 10°C.
- ☹ - Only moderate resistance to pitting and crevice corrosion – PRE = 18.
- ☹ - 205MPa minimum proof stress limits structural use in the annealed condition.
- ☹ - Poor resistance to stress corrosion cracking – susceptible above 60°C in even low Chloride environments. (316 is no better – use 439, 444 or 2205 instead).

304L

Good For:

- ☺ - Same good general corrosion resistance as Grade 304.
- ☺ - Low Carbon (generally 0.03% max) gives resistance to sensitization for use in temperature range 450-850°C and in heavy section welding (over about 5-10mm thick).
- ☺ - Low carbon content also reduces work hardening rate slightly – improves ductility for cold forging, drawing etc.

Not Good For:

- ☹ - Lower hot strength than 304 – design codes limit use to about 500°C maximum. This limit also applies to nominal Grade 304 with less than 0.03% Carbon.
- ☹ - Same local corrosion resistance as 304, so only moderate resistance to pitting and crevice corrosion in Chloride environments.
- ☹ - Same poor resistance to stress corrosion cracking as 304. Use 439, 444 or 2205 instead.

310

Good For:

- ☺ - High Nickel content gives resistance to Carbon pick-up at high temperatures – better than 253MA.
- ☺ - Good scaling resistance – to about 1050-1100°C.
- ☺ - High creep resistance, although not as high as 253MA.
- ☺ - Readily fabricated by bending, plasma cutting and welding.
- ☺ - High Nickel gives good resistance to nitriding atmospheres – better than 253MA.

Not Good For:

- ☹ - Sigma phase embrittlement after exposure at approximately 800°C reduces toughness.

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- ☹ - Exposure to high Sulphur atmospheres.
- ☹ - Exposure in temperature range 450-850°C results in sensitization, hence reducing subsequent wet corrosion resistance.

316

Good For:

- 😊 - Good resistance to a wide range of chemicals – generally significantly better than 304.
- 😊 - Useful resistance to Chlorides, especially if cold – safe sea water temperature 22°C.
- 😊 - Higher resistance to pitting and crevice corrosion than 304 – PRE = 24.
- 😊 - Excellent formability – readily deep drawn, bent and forged hot or cold.
- 😊 - Available in Improved Machinability bars.
- 😊 - Excellent weldability
- 😊 - Useful high temperature strength to 870°C – higher hot strength than 304.

Not Good For:

- ☹ - Poor resistance to stress corrosion cracking – susceptible above 60°C in even low Chloride environments. No better than 304 – use 2205 or 444 instead.
- ☹ - Not suitable for exposure to hot concentrated nitric acid – 304 is better.
- ☹ - Reduced scaling resistance in some environments above about 500°C, due to Molybdenum.
- ☹ - 205MPa minimum proof stress limits structural use in the annealed condition.

316L

Good For:

- 😊 - Same good general corrosion resistance as Grade 316.
- 😊 - Low Carbon (generally 0.03% max) gives resistance to sensitization for use in temperature range 450-850°C and in heavy section welding (over about 5–10mm thick).
- 😊 - Low Carbon content also reduces work hardening rate slightly – improves ductility for cold forging, drawing etc.

Not Good For:

- ☹ - Lower hot strength than 316 – design codes limit use to about 500°C maximum. This limit also applies to nominal Grade 316 with less than 0.03% Carbon.
- ☹ - Same local corrosion resistance as 316, so poor resistance to stress corrosion cracking in Chloride environments – limit about 60°C. Use 2205 or 444 instead.

321

Good For:

- 😊 - Specifically formulated to resist intergranular corrosion from sensitization at 450-850°C,

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following exposure in welding or in service.

- ☺ - Good resistance to a wide range of corrosive environments, similar to Grade 304.
- ☺ - Excellent formability – readily deep drawn, bent and forged hot or cold.
- ☺ - Excellent weldability.
- ☺ - Useful scaling resistance to 870°C.

Not Good For:

- ☹ - Does not polish well – always left with streaks from Titanium inclusions.
- ☹ - Only moderate resistance to pitting and crevice corrosion (same as 304) – PRE = 18.
- ☹ - Poor resistance to seawater – Safe exposure temperature about 5°C.
- ☹ - Poor resistance to stress corrosion cracking – susceptible above 60°C.

416

Good For:

- ☺ - Excellent machinability – best of the common stainless steels – readily used for high productivity machining.
- ☺ - Useful scaling resistance to about 700°C.
- ☺ - Can be hardened and tempered to give high hardness or strength, so useful for shaft applications.

Not Good For:

- ☹ - Poor resistance to general corrosion, due to the Sulphur addition.
- ☹ - Very poor resistance to Chloride pitting and crevice corrosion – not suitable for any marine applications at any temperature.
- ☹ - Low ductility – cannot be bent around a tight radius, or heavily drawn.
- ☹ - Poor weldability – not regarded as weldable.

430

Good For:

- ☺ - Low cost (no Nickel).
- ☺ - Useful corrosion resistance to mild atmospheres and clean waters.
- ☺ - Useful scaling resistance to 800°C.
- ☺ - Formable by deep drawing, bending and cold heading etc, although not as readily as 304 and 316.
- ☺ - Virtually immune from Chloride stress corrosion cracking.

Not Good For:

- ☹ - Poor resistance to pitting and crevice corrosion. Significantly inferior to 304. Not recommended for exterior exposure.
- ☹ - Not readily welded – welds tend to be coarse grained and brittle.

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- ☹ - Cannot be greatly strengthened by cold working.
- ☹ - Cannot be strengthened by heat treatment.

431

Good For:

- ☺ - High Chromium content gives 431 best corrosion resistances of any of the martensitic grades; similar to Grade 304 in many environments.
- ☺ - High strength after hardening and tempering enables use in shaft and bolting applications.
- ☺ - High ductility and toughness allow use in many engineering applications.
- ☺ - Useful scaling resistance to about 900°C (but exposure above the tempering temperature will result in softening, so not generally used at elevated temperatures).

Not Good For:

- ☹ - Poor weldability – but weldable so long as precautions are taken.
- ☹ - High strength even in the annealed condition precludes many forming operations.
- ☹ - Poor resistance to sea water (similar to 304).

444

Good For:

- ☺ - Low cost and stable cost (no Nickel).
- ☺ - Good corrosion resistance – approximately the same as 316 in most environments, including hot water.
- ☺ - Resistant to exterior exposure for building applications.
- ☺ - Good formability – can be bent, drawn, spun, folded, roll-formed etc.
- ☺ - Weldable by all usual electric processes.

Not Good For:

- ☹ - Not weldable in sections over about 3mm, so not available in these heavier gauges.
- ☹ - Not readily stretch formed, so very deep drawn products may not be possible.
- ☹ - Suffers from loss of toughness at sub-zero temperatures, particularly in welds.

630 (17-4PH)

Good For:

- ☺ - Good general corrosion resistance – similar to Grade 304.
- ☺ - High strength after precipitation hardening heat treatment enables use in shafts and valve spindles.
- ☺ - Precipitation hardening treatment does not distort long components – therefore useful for long shafts with stringent straightness requirements.

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☺ - Good weldability – readily weldable so long as precautions are taken.

Not Good For:

- ☹ - High strength even in the annealed condition precludes many forming operations.
- ☹ - Poor resistance to sea water.
- ☹ - High strength is lost if heated above precipitation hardening temperature (495-620°C depending upon condition).

253MA (S30815)

Good For:

- ☺ - Excellent scaling resistance to about 1150°C – highest of any stainless steel.
- ☺ - High creep resistance – allows some load to be carried at high temperatures.
- ☺ - Lower Nickel content than 310 gives improved resistance to Sulphur-rich atmospheres at high temperature.
- ☺ - Good resistance to cyclic heating and cooling – stable protective scale.
- ☺ - Resistant to formation of brittle sigma phase.
- ☺ - Good resistance to wet corrosion, including pitting and crevice corrosion in Chlorides. PRE = 24, but this presumes no sensitization has occurred.

Not Good For:

- ☹ - Should not be used in high Sulphur environments – Nickel-free grades better.
- ☹ - High Carbon content (0.1%) means sensitization can be a problem following welding or high temperature exposure – do not use in wet corrosive environments if sensitised.
- ☹ - Poor surface finish so not suitable for decorative applications.
- ☹ - Not generally suitable for nitriding atmospheres – particularly if free of oxygen.

2205 (S31803 / S32205)

Good For:

- ☺ - High strength – Proof stress 450MPa minimum, Tensile strength 620MPa minimum
- ☺ - High general corrosion – useful for some strong acids at moderate temperatures
- ☺ - High pitting and crevice corrosion – PRE = 34, CPT = 35°C, Safe seawater exposure to 35°C.
- ☺ - High resistance to Chloride stress corrosion cracking – safe up to at least 160°C.
- ☺ - Readily welded by the usual processes.

Not Good For:

- ☹ - Low toughness after exposure at high temperatures – do not use above 300°C.
- ☹ - Low toughness while at sub-zero temperatures – do not use below -50°C.
- ☹ - High strength means high forces needed for bending etc; cold forging virtually impossible.

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2507 (S32750)

Good For:

- ☺ - Excellent general corrosion resistance – resists corrosion by many strong acids.
- ☺ - Excellent resistance to pitting and crevice corrosion – PRE = 40 minimum.
- ☺ - Seawater safe temperature approximately 90°C.
- ☺ - Very high resistance to Chloride stress corrosion cracking – safe up to at least 200°C.
- ☺ - High resistance to Sulphide stress corrosion.
- ☺ - High strength – Proof stress 550MPa and Tensile strength 750MPa minimum.
- ☺ - Weldable by standard processes.

Not Good For:

- ☹ - Low toughness after exposure at high temperatures – do not use above 270°C.
- ☹ - Low toughness while at sub-zero temperatures – do not use below -50°C.
- ☹ - High strength means high forces needed for bending etc; cold forging virtually impossible.