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Compendium on Stainless Steel

Standards and properties

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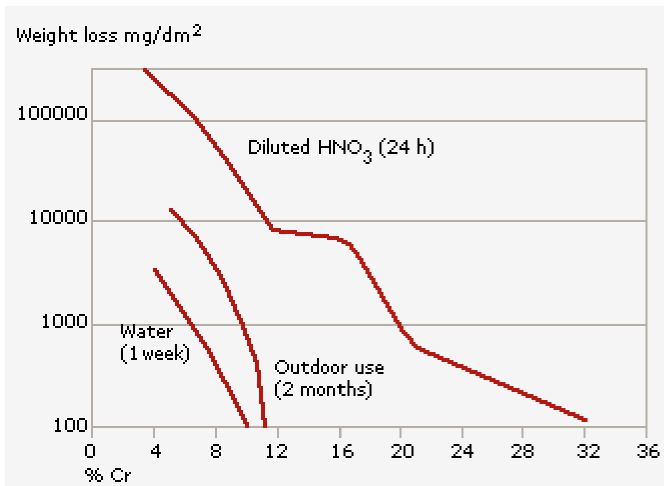
Stainless Steels

Stainless Steels are iron-base alloys containing Chromium. Stainless steels usually contain less than 30% Cr and more than 50% Fe. They attain their stainless characteristics because of the formation of an invisible and adherent chromium-rich oxide surface film. This oxide establishes on the surface and heals itself in the presence of oxygen. Some other alloying elements added to enhance specific characteristics include nickel, molybdenum, copper, titanium, aluminum, silicon, niobium, and nitrogen. Carbon is usually present in amounts ranging from less than 0.03% to over 1.0% in certain martensitic grades. Corrosion resistance and mechanical properties are commonly the principal factors in selecting a grade of stainless steel for a given application.

Effect of Chromium

Stainless steels are chromium containing steel alloys. The minimum chromium content of the standardised stainless steels is 10.5%. Chromium makes the steel 'stainless' this means improved corrosion resistance, as can be seen in the chart.



The better corrosion resistance is due to a chromium oxide film that is formed on the steel surface. This extremely thin layer, under the right conditions, is also self-repairing.

Besides chromium, typical alloying elements are molybdenum, nickel and nitrogen. Nickel is mostly alloyed to improve the formability and ductility of stainless steel. Alloying these elements brings out different crystal structures to enable different properties in machining, forming, welding etc.

Stainless steels are commonly divided into five groups:

- Martensitic stainless steels
- Ferritic stainless steels
- Austenitic stainless steels
- Duplex (ferritic-austenitic) stainless steels
- Precipitation-hardening stainless steels.

Martensitic stainless steels

Martensitic stainless steels are essentially alloys of chromium and carbon that possess a martensitic crystal structure in the hardened condition. They are ferromagnetic, hardenable by heat treatments, and are usually less resistant to corrosion than some other grades of stainless steel. Chromium content usually does not exceed 18%, while carbon content may exceed 1.0 %. The chromium and carbon contents are adjusted to ensure a martensitic structure after hardening. Excess carbides may be present to enhance wear resistance or as in the case of knife blades, to maintain cutting edges.

Ferritic stainless steels

Ferritic stainless steels are chromium containing alloys with Ferritic, body centered cubic (bcc) crystal structures. Chromium content is typically less than 30%. The ferritic stainless steels are ferromagnetic. They may have good ductility and formability, but high-temperature mechanical properties are relatively inferior to the austenitic stainless steels. Toughness is limited at low temperatures and in heavy sections.

Austenitic stainless steels

Austenitic stainless steels have a austenitic, face centered cubic (fcc) crystal structure. Austenite is formed through the generous use of austenitizing elements such as nickel, manganese, and nitrogen. Austenitic stainless steels are effectively nonmagnetic in the annealed condition and can be hardened only by cold working. Some ferromagnetism may be noticed due to cold working or welding. They typically have reasonable cryogenic and high temperature strength properties. Chromium content typically is in the range of 16 to 26%; nickel content is commonly less than 35%.

Duplex stainless steels

Duplex stainless steels are a mixture of bcc ferrite and fcc austenite crystal structures. The percentage each phase is a dependent on the composition and heat treatment. Most Duplex stainless steels are intended to contain around equal amounts of ferrite and austenite phases in the annealed condition. The primary alloying elements are chromium and nickel. Duplex stainless steels generally have similar corrosion resistance to austenitic alloys except they typically have better stress corrosion cracking resistance. Duplex stainless steels also generally have greater tensile and yield strengths, but poorer toughness than austenitic stainless steels.

Precipitation hardening stainless steels

Precipitation hardening stainless steels are chromium-nickel alloys. Precipitation-hardening stainless steels may be either austenitic or martensitic in the annealed condition. In most cases, precipitation hardening stainless steels attain high strength by precipitation hardening of the martensitic structure.

Selecting a Stainless Steel

There are a large number of stainless steels produced. Corrosion resistance, physical properties, and mechanical properties are generally among the properties considered when selecting stainless steel for an application. A more detailed list of selection criteria is listed below:

- Corrosion resistance
- Resistance to oxidation and sulfidation
- Toughness
- Cryogenic strength
- Resistance to abrasion and erosion
- Resistance to galling and seizing
- Surface finish
- Magnetic properties
- Retention of cutting edge
- Ambient strength
- Ductility
- Elevated temperature strength
- Suitability for intended cleaning procedures
- Stability of properties in service
- Thermal conductivity
- Electrical resistivity
- Suitability for intended fabrication techniques

Corrosion resistance is commonly the most significant characteristic of a stainless steel, but can also be the most difficult to assess for a specific application. General corrosion resistance is comparatively easy to determine, but real environments are usually more complex. An evaluation of other pertinent variables such as fluid velocity, stagnation, turbulence, galvanic couples, welds, crevices, deposits, impurities, variation in temperature, and variation from planned operating chemistry among others issues need to be factored in to selecting the proper stainless steel for a specific environment.

AMC can provide engineering services to determine how to optimize the selection of stainless steel for your application. Our engineering analysis can reduce overall costs, minimize service problems, and optimize fabrication of your structure.

Stainless steel and Magnetism

Background
Magnetic permeability is the ability of a material to carry magnetism, indicated by the degree to which it is attracted to a magnet. All stainless steels, with the exception of the austenitic group, are strongly attracted to a magnet.

Austenitic Grades
All austenitic grades have very low magnetic permeabilities and hence show almost no response to a magnet when in the annealed condition; the situation is, however, far less clear when these steels have been cold worked by wire drawing, rolling or even centreless grinding, shot blasting or heavy polishing. After substantial cold working Grade 304 may exhibit quite strong response to a magnet, whereas Grades 310 and 316 will in most instances still be almost totally non-responsive.

The change in magnetic response is due to atomic lattice straining and formation of martensite. In general, the higher the nickel to chromium ratio the more stable is the austenitic structure and the less magnetic response that will be induced by cold work. Magnetic response can therefore be used as a method for sorting grades of stainless steel, but considerable caution needs to be exercised.

Stress Relieving
Any austenitic (300 series) stainless steel which has developed magnetic response due to cold work can be returned to a non-magnetic condition by stress relieving. In general this can be readily achieved by briefly heating to approximately 700 - 800°C (this can be conveniently carried out by careful use of an oxy-acetylene torch). Note, however, unless the steel is a stabilised grade it could become sensitised to carbide precipitation. Full solution treatment at 1000 - 1150°C will remove all magnetic response without danger of reduced corrosion resistance due to carbides.
If magnetic permeability is a factor of design or is incorporated into a specification, this should be clearly indicated when purchasing the stainless steel from a supplier.

Cold Working
Many cold drawn and/or polished bars have a noticeable amount of magnetism as a result of the previous cold work. This is particularly the case with grades 304 and 303, and much less so for the higher nickel grades such as 310 and 316. Even within the chemical limitations of a single standard analysis range there can be a pronounced variation in the rate of inducement of magnetic response from cold work.

Magnetically Soft Stainless Steels

In some applications there is a requirement for a steel to be "magnetically soft". This is often required for solenoid shafts, where it is necessary for the plunger to respond efficiently to the magnetic field from the surrounding coil when the current is switched on, but when the current is switched off the magnetic field induced in the steel must quickly collapse, allowing the plunger to return to its original position. Steels which behave in this way are said to be magnetically soft. For corrosion resisting applications there are ferritic stainless steels which are magnetically soft, usually variants of a grade "18/2" (18% chromium and 2% molybdenum) but with very tightly controlled additions of silicon and often with sulphur added to make them free machining. Special mill processing guarantees the magnetic properties of the steels.

U.S.A	GERMANY	GERMANY	FRANCE	ITALY	U.K.	U.E.
AISI	**DIN 17006**	**W.N. 17007**	**AFNOR**	**UNI**	**BSI**	**EURONORM**
201						
301	X 12 CrNi 17 7	1.4310	Z 12 CN 17-07	X 12 CrNi 1707	301S21	X 12 CrNi 17 7
302	X 5 CrNi 18 7	1.4319	Z 10 CN 18-09	X 10 CrNi 1809	302S25	X 10 CrNi 18 9
303	X 10 CrNiS 18 9	1.4305	Z 10 CNF 18-09	X 10 CrNiS 1809	303S21	X 10 CrNiS 18 9
303 Se			Z 10 CNF 18-09	X 10 CrNiS 1809	303S41	
304	X 5 CrNi 18 10 X 5 CrNi 18 12	1.4301 1.4303	Z 6 CN 18-09	X 5 CrNi 1810	304S15 304S16	X 6 CrNi 18 10
304 N				X 5 CrNiN 1810		
304 H				X 8 CrNi 1910		
304 L	X 2 CrNi 18 11	1.4306	Z 2 CN 18-10	X 2 CrNi 1911	304S11	X 3 CrNi 18 10
	X 2 CrNiN 18 10	1.4311	Z 2 CN 18-10-Az	X 2 CrNiN 1811		
305			Z 8 CN 18-12	X 8 CrNi 1812	305S19	X 8 CrNi 18 12
			Z 6 CNU 18-10			X 6 CrNiCu 18 10 4 Kd
309	X 15 CrNiS 20 12	1.4828	Z 15 CN 24-13	X 16 CrNi 2314	309S24	X 15 CrNi 23 13
309 S				X 6 CrNi 2314		X 6 CrNi 22 13
310	X 12 CrNi 25 21	1.4845		X 22 CrNi 2520	310S24	
310 S	X 12 CrNi 25 20	1.4842	Z 12 CN 25-20	X 5 CrNi 2520		X 6 CrNi 25 20
314	X 15 CrNiSi 25 20	1.4841	Z 12 CNS 25-20	X 16 CrNiSi 2520		X 15 CrNiSi 25 20
316	X 5 CrNiMo 17 12 2	1.4401	Z 6 CND 17-11	X 5 CrNiMo 1712	316S31	X 6 CrNiMo 17 12 2
316	X 5 CrNiMo 17 13 3	1.4436	Z 6 CND 17-12	X 5 CrNiMo 1713	316S33	X 6 CrNiMo 17 13 3
316 F	X 12 CrNiMoS 18 11	1.4427				
316 N						
316 H				X 8 CrNiMo 1712		
316 H				X 8 CrNiMo 1713		
316 L	X 2 CrNiMo 17 13 2	1.4404	Z 2 CND 17-12	X 2 CrNiMo 1712	316S11	X 3 CrNiMo 17 12 2
	X 2 CrNiMoN 17 12 2	1.4406	Z 2 CND 17-12-Az	X 2 CrNiMoN 1712		
316 L	X 2 CrNiMo 18 14 3	1.4435	Z 2 CND 17-13	X 2 CrNiMo 1713	316S13	X 3 CrNiMo 17 13 3
	X 2 CrNiMoN 17 13 3	1.4429	Z 2 CND 17-13-Az	X 2 CrNiMoN 1713		
	X 6 CrNiMoTi 17 12 2	1.4571	Z6 CNDT 17-12	X 6 CrNiMoTi 1712	320S31	X 6 CrNiMoTi 17 12 2
	X 10 CrNiMoTi 18 12	1.4573		X 6 CrNiMoTi 1713	320S33	X 6 CrNiMoTI 17 13 3

	X 6 CrNiMoNb 17 12 2	1.4580	Z 6 CNDNb 17-12	X 6 CrNiMoNb 1712		X 6 CrNiMoNb 17 12 2
	X 10 CrNiMoNb 18 12	1.4583		X 6 CrNiMoNb 1713		X 6 CrNiMoNb 17 13 3
317				X 5 CrNiMo 1815	317S16	
317 L	X 2 CrNiMo 18 16 4	1.4438	Z 2 CND 19-15	X 2 CrNiMo 1815	317S12	X 3 CrNiMo 18 16 4
317 L	X 2 CrNiMo 18 16 4	1.4438	Z 2 CND 19-15	X 2 CrNiMo 1816	317S12	X 3 CrNiMo 18 16 4
330	X 12 NiCrSi 36 16	1.4864	Z 12NCS 35-16			
321	X 6 CrNiTi 18 10 X 12 CrNiTi 18 9	1.4541 1.4878	Z 6 CNT 18-10	X 6 CrNiTi 1811	321S31	X 6 CrNiTi 18 10
321 H				X 8 CrNiTi 1811	321S20	
329	X 8 CrNiMo 27 5	1.4460				
347	X 6 CrNiNb 18 10	1.4550	Z 6 CNNb 18-10	X 6 CrNiNb 1811	347S31	X 6 CrNiNb 18 10
347 H				X 8 CrNiNb 1811		
904L		1.4939	Z 12 CNDV 12-02			
	X 20 CrNiSi 25 4	1.4821				
UNS31803	X 2 CrNiMoN 22 5	1.4462				
UNS32760	X 3 CrNiMoN 25 7	1.4501	Z 3 CND 25-06Az			
403	X 6 Cr 13 X 10 Cr 13 X 15 Cr 13	1.4000 1.4006 1.4024	Z 12 C 13	X 12 Cr 13	403S17	X 10 Cr 13 X 12 Cr 13
405	X 6 CrAl 13	1.4002	Z 6 CA 13	X 6 CrAl 13	405S17	X 6 CrAl 13
	X 10 CrAl 7	1.4713	Z 8 CA 7			X 10 CrAl 7
	X 10 CrAl 13	1.4724		X 10 CrAl 12		
	X 10 CrAl 18	1.4742				X 10 CrSiAl 18
409	X 6 CrTi 12	1.4512	Z 6 CT 12	X 6 CrTi 12	409S19	X 5 CrTi 12
				X 2 CrTi 12		
410	X 6 Cr 13 X 10 Cr 13 X 15 Cr 13	1.4000 1.4006 1.4024	Z 10 C 13 Z 12 C 13	X 12 Cr 13	410S21	X 12 Cr 13
410 S	X 6 Cr 13	1.4000	Z 6 C 13	X 6 Cr 13	403S17	X 6 Cr 13
414						

These are austenitic grades

These are ferritic grades

These are ferritic-austenitic grades (otherwise known as Duplex and Superduplex)

Chemical Composition of alloy:

Standard of country			Chemical Composition							
USA	German									
AISI	W-Nr	DIN KURZNAME	C Max	SI Max	Mn Max	P max	S Max	Ni	Cr	Mo
301	14310	X12CrNi 177	0.15	1.00	2.00	0.045	0.030	6.00-8.00	16.00-18.00	-
304	14301	XDCr Ni 189	0.08	1.00	2.00	0.045	0.030	8.00-10.50	18.00-20.00	-
304L	14306	X3Cr Ni 89	0.03	1.00	2.00	0.045	0.030	9.00-13.00	18.00-20.00	-
305	14303	X5Cr Ni 1911	0.12	1.00	2.00	0.045	0.030	10.50-13.00	17.00-19.00	-
310S	14841	X 15 Cr Ni Si 2520	0.08	1.50	2.00	0.045	0.030	19.00-22.00	24.00-26.00	-
316	14401	X15 Cr Ni Mo 1810	0.08	1.00	2.00	0.045	0.030	10.00-14.00	16.00-18.00	2.00-3.00
316L	14435	X15 Cr Ni Mo 1812	0.03	1.00	2.00	0.045	0.030	12.00-15.00	16.00-18.00	2.00-3.00
430	14016	X8Cr 17	0.12	0.75	1.00	0.040	0.030	0.60	16.00-18.00	-
434	14113	-	0.12	1.00	1.00	0.040	0.030	0.60	16.00-18.00	0.75-1.25
410	14006	X10 Cr 13	0.15	1.00	1.00	0.040	0.030	0.60	11.50-13.50	-
420	14021	X 20 Cr 13	0.16-0.25	1.00	1.00	0.040	0.030	0.60	12.00-14.00	-
420	14034	X 40 Cr 13	0.26 - 0.40	1.00	1.00	0.040	0.030	0.60	12.00-14.00	-

Mechanical Properties:

Standard of country	Mechanical Properties							
USA	Tensile test (min)				Hardness (Max)			
	Y/S		T/S		Elongation	HB	HRB	Hv
	kg/mm2	N/mm2	kgf/mm2	N/mm2				
301	21	206	53	520	40	187	90	200
304	21	206	53	520	40	187	90	200
304L	18	177	49	481	40	187	90	200
305	18	177	49	481	40	187	90	200
310S	21	206	53	520	40	187	90	200
316	21	206	53	520	40	187	90	200
316L	18	177	49	481	40	187	90	200
430	21	206	46	451	22	183	88	200
434	21	206	46	451	22	183	88	200
410	21	206	45	441	20	200	93	210
420	23	226	53	520	18	223	97	234
420	23	226	55	539	18	235	99	247