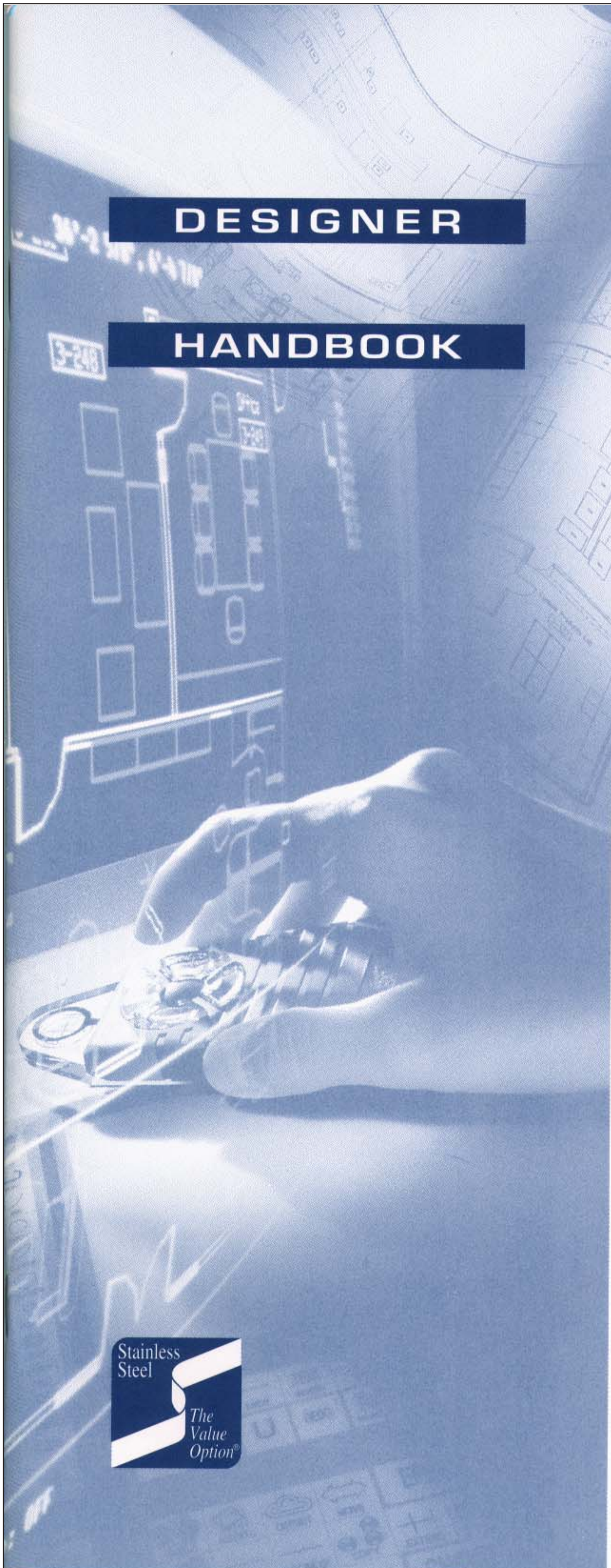

DESIGN GUIDELINES FOR THE SELECTION AND USE OF STAINLESS STEEL

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11-02-18

INTRODUCTION

Stainless steels are iron-base alloys containing 10.5% or more chromium. They have been used for many industrial, architectural, chemical, and consumer applications for over a half century. Currently there are being marketed a number of stainless steels originally recognized by the American Iron and Steel Institute (AISI) as standard alloys. Also commercially available are proprietary stainless steels with special characteristics. (See Appendix A.)

With so many stainless steels from which to choose, designers should have a ready source of information on the characteristics and capabilities of these useful alloys. To fill this need, the Committee of Stainless Steel Producers initially prepared this booklet. The data was reviewed and updated by the Specialty Steel Industry of North America (SSINA). Written especially for design engineers, it presents an overview of a broad range of stainless steels — both standard and proprietary — their compositions, their properties, their fabrication, and their use. More detailed information on the standard grades, with special emphasis on the manufacture, finish designations and dimensional and weight tolerances of the product forms in which they are marketed, is contained in the Iron and Steel Society of the AIME (the American Institute of Mining, Metallurgical and Petroleum Engineers) “Steel Products Manual — Stainless and Heat Resisting Steels.” The AIME undertook the publication, updating and sale of this manual after the AISI discontinued publication in 1986.

Reference is often made to stainless steel in the singular sense as if it were one material. Actually there are well over 100 stainless steel alloys. Three general classifications are used to identify stainless steels. They are: 1. Metallurgical Structure; 2. The AISI numbering system: namely 200, 300, and 400 Series numbers; 3. The Unified Numbering System, which was developed by American Society for Testing Materials (ASTM) and Society of Automotive Engineers (SAE) to apply to all commerical metals and alloys.

There are also a number of grades known by common names that resemble AISI designations and these are recognized by ASTM. These common names, which are neither trademarks nor closely associated with a single producer, are shown and identified in the tables. These common (non-AISI) names also appear in the ASTM specification. Nearly all stainless steels used in North America have UNS designations.

On the following pages there is a description of these classifications. Tables 1-5 list stainless steels according to metallurgical structure: austenitic, ferritic, martensitic, precipitation hardening, and duplex.

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Austenitic stainless steels (Table 1) containing chromium and nickel are identified as 300 Series types. Alloys containing chromium, nickel and manganese are identified as 200 Series types. The stainless steels in the austenitic group have different compositions and properties, but many common characteristics. They can be hardened by cold working, but not by heat treatment. In the annealed condition, all are essentially nonmagnetic, although some may become slightly magnetic by cold working. They have excellent corrosion resistance, unusually good formability, and increase in strength as a result of cold work.

Type 304 (sometimes referred to as 18-8 stainless) is the most widely used alloy of the austenitic group. It has a nominal composition of 18% chromium and 8% nickel.

Table 1
AUSTENITIC STAINLESS STEELS

TYPE	Equivalent UNS	TYPE	Equivalent UNS
201	S20100	310	S31000
202	S20200	310S	S31008
205	S20500	314	S31400
301	S30100	316	S31600
302	S30200	316L	S31603
302B	S30215	316F	S31620
303	S30300	316N	S31651
303Se	S30323	317	S31700
304	S30400	317L	S31703
304L	S30403	317LMN	S31726
302HQ	S30430	321	S32100
304N	S30451	330	NO8330
305	S30500	347	S34700
308	S30800	348	S34800
309	S30900	384	S38400
309S	S30908		

Ferritic stainless steels (Table 2) are straight-chromium 400 Series types that cannot be hardened by heat treatment, and only moderately hardened by cold working. They are magnetic, have good ductility and resistance to corrosion and oxidation. Type 430 is the general-purpose stainless of the ferritic group.

Table 2
FERRITIC STAINLESS STEELS

TYPE	Equivalent UNS	TYPE	Equivalent UNS
405	S40500	430FSe	S43023
409	S40900	434	S43400
429	S42900	436	S43600
430	S43000	442	S44200
430F	S43020	446	S44600

Martensitic stainless steels (Table 3) are straight-chromium 400 Series types that are hardenable by heat treatment. They are magnetic. They resist corrosion in mild environments. They have fairly good ductility, and some can be heat treated to tensile strengths exceeding 200,000 psi (1379 MPa).

Type 410 is the general-purpose alloy of the martensitic group.

Table 3
MARTENSITIC STAINLESS STEELS

TYPE	Equivalent UNS	TYPE	Equivalent UNS
403	S40300	420F	S42020
410	S41000	422	S42200
414	S41400	431	S43100
416	S41600	440A	S44002
416Se	S41623	440B	S44003
420	S42000	440C	S44004

Precipitation-hardening stainless steels (Table 4) are chromium-nickel types, some containing other alloying elements, such as copper or aluminum. They can be hardened by solution treating and aging to high strength.

Table 4
PRECIPITATION HARDENING STAINLESS STEELS

UNS	UNS
S13800	S17400
S15500	S17700

Duplex stainless steels (Table 5) have an annealed structure which is typically about equal parts of austenite and ferrite. Although not formally defined, it is generally accepted that the lesser phase will be at least 30% by volume.

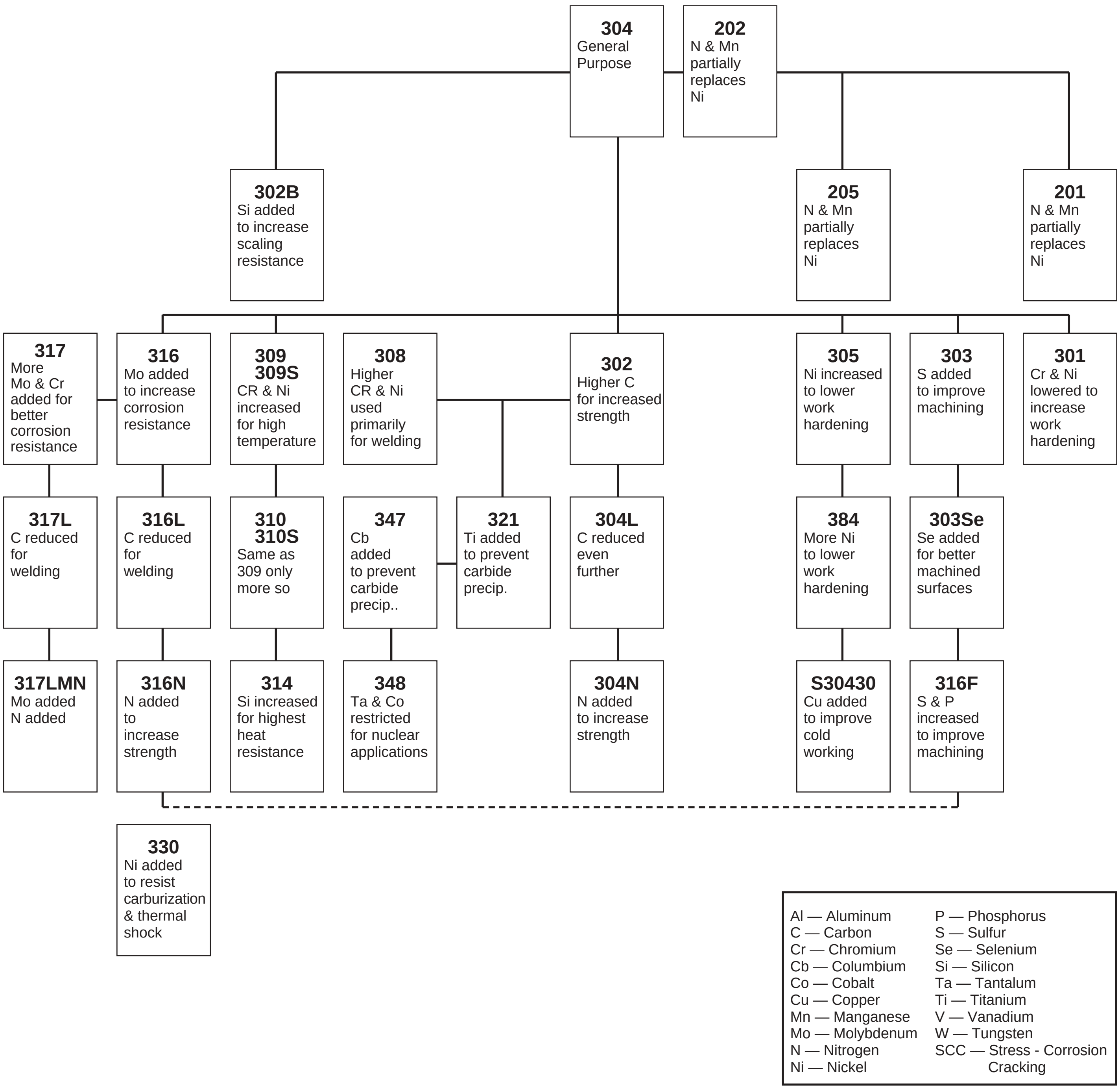
Duplex stainless steels offer several advantages over the common austenitic stainless steels. The duplex grades are highly resistant to chloride stress corrosion cracking, have excellent pitting and crevice corrosion resistance and exhibit about twice the yield strength as conventional grades. Type 329 and 2205 are typical alloys.

With respect to the Unified Numbering System, the UNS designations are shown alongside each AISI type number, in Tables 1-5, except for four stainless steels (see Table 4) for which UNS designations only are listed.

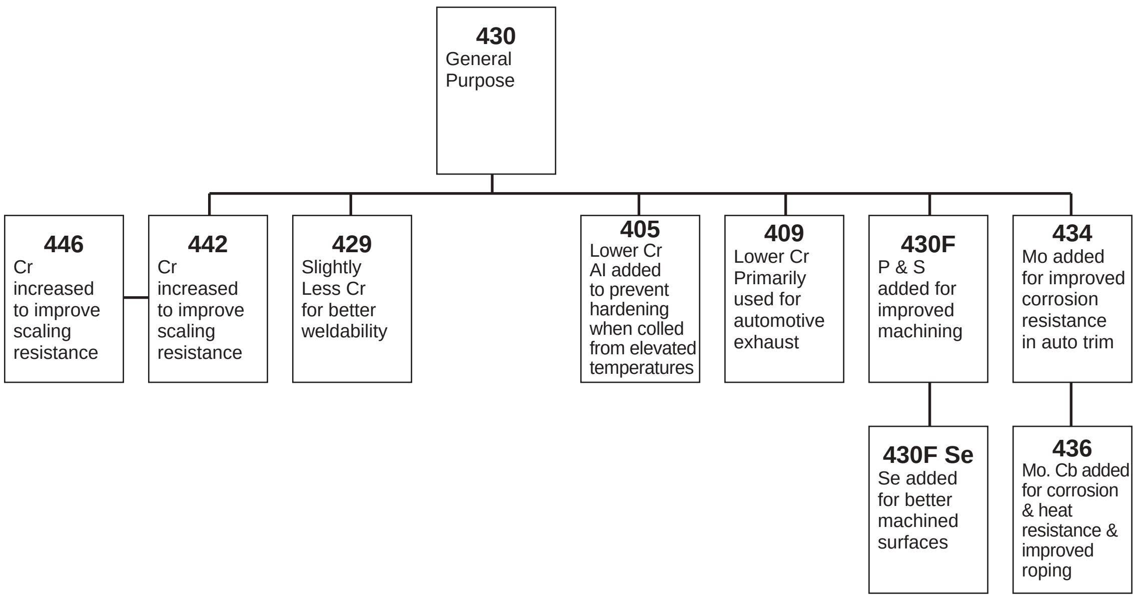
Table 5
DUPLEX STAINLESS STEELS

Type/Name	UNS
329	S32900
2205	S31803
2205 (hi N)	S32205

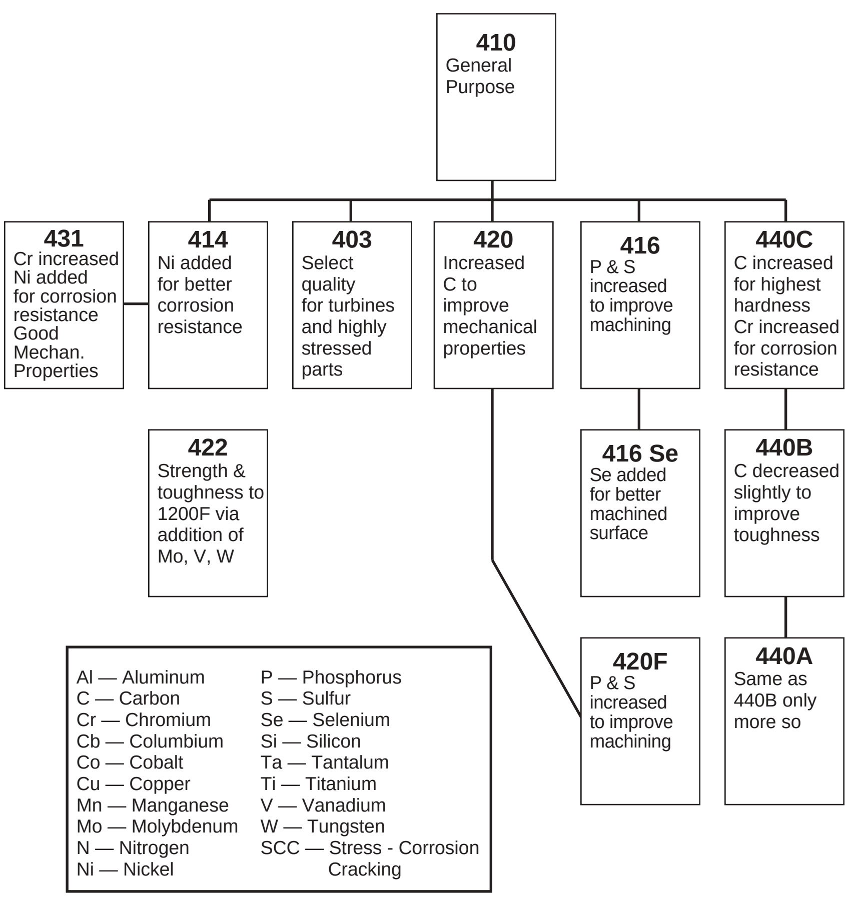
AUSTENITIC


304 General Purpose
202 N & Mn partially replaces Ni
302B Si added to increase scaling resistance
205 N & Mn partially replaces Ni
201 N & Mn partially replaces Ni
317 More Mo & Cr added for better corrosion resistance
316 Mo added to increase corrosion resistance
309 309S CR & Ni increased for high temperature
308 Higher CR & Ni used primarily for welding
302 Higher C for increased strength
305 Ni increased to lower work hardening
303 S added to improve machining
301 Cr & Ni lowered to increase work hardening
317L C reduced for welding
316L C reduced for welding
310 310S Same as 309 only more so
347 Cb added to prevent carbide precip..
321 Ti added to prevent carbide precip.
304L C reduced even further
384 More Ni to lower work hardening
303Se Se added for better machined surfaces
317LMN Mo added N added
316N N added to increase strength
314 Si increased for highest heat resistance
348 Ta & Co restricted for nuclear applications
304N N added to increase strength
S30430 Cu added to improve cold working
316F S & P increased to improve machining
330 Ni added to resist carburization & thermal shock
Al — Aluminum
C — Carbon
Cr — Chromium
Cb — Columbium
Co — Cobalt
Cu — Copper
Mn — Manganese
Mo — Molybdenum
N — Nitrogen
Ni — Nickel
P — Phosphorus
S — Sulfur
Se — Selenium
Si — Silicon
Ta — Tantalum
Ti — Titanium
V — Vanadium
W — Tungsten
SCC — Stress - Corrosion Cracking

FERRITIC



MARTENSITIC



GUIDELINES FOR SELECTION

Stainless steels are engineering materials with good corrosion resistance, strength, and fabrication characteristics. They can readily meet a wide range of design criteria — load, service life, low maintenance, etc. Selecting the proper stainless steel essentially means weighing four elements. In order of importance, they are:

1. **Corrosion or Heat Resistance** — the primary reason for specifying stainless. The specifier needs to know the nature of the environment and the degree of corrosion or heat resistance required.
2. **Mechanical Properties** — with particular emphasis on strength at room, elevated, or low temperature. Generally speaking, the combination of corrosion resistance and strength is the basis for selection.
3. **Fabrication Operations** — and how the product is to be made is a third-level consideration. This includes forging, machining, forming, welding, etc.
4. **Total Cost** — in considering total cost, it is appropriate to consider not only material and production costs, but the life cycle cost including the cost-saving benefits of a maintenance-free product having a long life expectancy.

CORROSION RESISTANCE

Chromium is the alloying element that imparts to stainless steels their corrosion-resistance qualities by combining with oxygen to form a thin, invisible chromium-oxide protective film on the surface. (Figure 1. Figures are shown in Appendix B.) Because the passive film is such an important factor, there are precautions which must be observed in designing stainless steel equipment, in manufacturing the equipment, and in operation and use of the equipment, to avoid destroying or disturbing the film.

In the event that the protective (passive) film is disturbed or even destroyed, it will, in the presence of oxygen in the environment, reform and continue to give maximum protection.

The protective film is stable and protective in normal atmospheric or mild aqueous environments, but can be improved by higher chromium, and by molybdenum, nickel, and other alloying elements. Chromium improves film stability; molybdenum and chromium increase resistance to chloride penetration; and nickel improves film resistance in some acid environments.

Material Selection

Many variables characterize a corrosive environment — i.e. chemicals and their concentration, atmospheric conditions, temperature, time — so it is difficult to select which alloy to use without knowing the exact nature of the environment, However, there are guidelines:

Type 304 serves a wide range of applications. It withstands ordinary rusting in architecture, it is resistant to food processing environments (except possibly for high-temperature conditions involving high acid and chloride contents), it resists organic chemicals, dyestuffs, and a wide variety of inorganic chemicals. Type 304 L (low carbon) resists nitric acid well and sulfuric acids at moderate temperature and concentrations. It is used extensively for storage of liquified gases, equipment for use at cryogenic temperatures (304N), appliances and other consumer products, kitchen equipment, hospital equipment, transportation, and waste-water treatment.

Type 316 contains slightly more nickel than Type 304, and 2-3% molybdenum giving it better resistance to corrosion than Type 304, especially in chloride environments that tend to cause pitting. Type 316 was developed for use in sulfite pulp mills because it resists sulfuric acid compounds. Its use has been broadened, however, to handling many chemicals in the process industries.

Type 317 contains 3-4% molybdenum (higher levels are also available in this series) and more chromium than Type 316 for even better resistance to pitting and crevice corrosion.

Type 430 has lower alloy content than Type 304 and is used for highly polished trim applications in mild atmospheres. It is also used in nitric acid and food processing.

Type 410 has the lowest alloy content of the three general-purpose stainless steels and is selected for highly stressed parts needing the combination of strength and corrosion resistance, such as fasteners. Type 410 resists corrosion in mild atmospheres, steam, and many mild chemical environments.

2205 may have advantages over Type 304 and 316 since it is highly resistant to chloride stress corrosion cracking and is about twice as strong.

Table 6 lists the relative corrosion resistance of the AISI standard numbered stainless steels in seven broad categories of corrosive environments. Table 7 details more specific environments in which various grades are used, such as acids, bases, organics, and pharmaceuticals.

The above comments on the suitability of stainless steels in various environments are based on a long history of successful application, but they are intended only as guidelines. Small differences in chemical content and temperature, such as might occur during processing, can affect corrosion rates. The magnitude can be considerable, as suggested by Figures 2 and 3. Figure 2 shows small quantities of hydrofluoric and sulfuric acids having a serious effect on Type 316 stainless steel in an environment of 25% phosphoric acid, and Figure 3 shows effects of temperature on Types 304 and 316 in very concentrated sulfuric acid.

Service tests are most reliable in determining optimum material, and ASTM G 4 is a recommended practice for carrying out such tests. Tests should cover conditions both during operation and shutdown. For instance, sulfuric, sulfurous and polythionic acid condensates formed in some processes during shutdowns may be more corrosive than the process stream itself. Tests should be conducted under the worst operating conditions anticipated.

Several standard reference volumes discuss corrosion and corrosion control, including Uhlig's *Corrosion Handbook;* LaQue and Copsons' *Corrosion Resistance Of Metals and Alloys;* Fontana and Greens' *Corrosion Engineering; A Guide to Corrosion Resistance* by Climax Molybdenum Company; the *Corrosion Data Survey* by the National Association of Corrosion Engineers; and the *ASM Metals Handbook*. Corrosion data, specifications, and recommended practices relating to stainless steels are also issued by ASTM. Stainless steels resist corrosion in a broad range of conditions, but they are not immune to every environment. For example, stainless steels perform poorly in reducing environments, such as 50% sulfuric and hydrochloric acids at elevated temperatures. The corrosive attack experienced is a breakdown of the protective film over the entire metal surface.

Such misapplications of stainless steels are rare and are usually avoided. The types of attack which are more likely to be of concern are pitting, crevice attack, stress corrosion cracking, and intergranular corrosion, which are discussed in Appendix A.

Table 6

Relative Corrosion Resistance of AISI Stainless Steels (1)

TYPE Number	UNS Number	Mild Atmospheric and Fresh Water	Atmospheric		Chemical		
			Industrial	Marine	Miild	Oxidizing	Reducing
201	(S20100)	x	x	x	x	x	
202	(S20200)	x	x	x	x	x	
205	(S20500)	x	x	x	x	x	
301	(S30100)	x	x	x	x	x	
302	(S30200)	x	x	x	x	x	
302B	(S30215)	x	x	x	x	x	
303	(S30300)	x	x		x		
303 Se	(S30323)	x	x	x	x		
304	(S30400)	x	x	x	x	x	
304L	(S30403)	x	x	x	x	x	
	(S30430)	x	x	x	x	x	
304N	(S30451)	x	x	x	x	x	
305	(S30500)	x	x	x	x	x	
308	(S30800)	x	x	x	x	x	
309	(S30900)	x	x	x	x	x	
309S	(S30908)	x	x	x	x	x	
310	(S31000)	x	x	x	x	x	
310S	(S31008)	x	x	x	x	x	
314	(S31400)	x	x	x	x	x	
316	(S31600)	x	x	x	x	x	x
316F	(S31620)	x	x	x	x	x	x
316L	(S31603)	x	x	x	x	x	x
316N	(S31651)	x	x	x	x	x	x
317	(S31700)	x	x	x	x	x	x
317L	(S31703)	x	x	x	x	x	
321	(S32100)	x	x	x	x	x	
329	(S32900)	x	x	x	x	x	x
330	(N08330)	x	x	x	x	x	x
347	(S34700)	x	x	x	x	x	
348	(S34800)	x	x	x	x	x	
384	(S38400)	x	x	x	x	x	
403	(S40300)	x			x		
405	(S40500)	x			x		
409	(S40900)	x			x		
410	(S41000)	x			x		
414	(S41400)	x			x		
416	(S41600)	x					
416 Se	(S41623)	x					
420	(S42000)	x					
420F	(S42020)	x					
422	(S42200)	x					
429	(S42900)	x	x		x	x	
430	(S43000)	x	x		x	x	
430F	(S43020)	x	x		x		
430F Se	(S43023)	x	x		x		
431	(S43100)	x	x	x	x		
434	(S43400)	x	x	x	x	x	
436	(S43600)	x	x	x	x	x	
440A	(S44002)	x			x		
440B	(S44003)	x					
440C	(S44004)	x					
442	(S44200)	x	x		x	x	
446	(S44600)	x	x	x	x	x	
	(S13800)	x	x		x	x	
	(S15500)	x	x	x	x	x	
	(S17400)	x	x	x	x	x	
	(S17700)	x	x	x	x	x	

* The "X" notations indicate that a specific stainless steel type may be considered as resistant to the corrosive environment categories.

This list is suggested as a guideline only and does not suggest or imply a warranty on the part of the Specialty Steel Industry of the United States or any of the member companies. When selecting a stainless steel for any corrosive environment, it is always best to consult with a corrosion engineer and, if possible, conduct tests in the environment involved under actual operating conditions.

Table 7

Where Different Grades Are Used (15)

Environment	Grades
Acids	
Hydrochloric acid	Stainless generally is not recommended except when solutions are very dilute and at room temperature.
"Mixed acids"	There is usually no appreciable attack on Type 304 or 316 as long as sufficient nitric acid is present.
Nitric acid	Type 304L or 430 is used.
Phosphoric acid	Type 304 is satisfactory for storing cold phosphoric acid up to 85% and for handling concentrations up to 5% in some unit processes of manufacture. Type 316 is more resistant and is generally used for storing and manufacture if the fluorine content is not too high. Type 317 is somewhat more resistant then Type 316. At concentrations up to 85%, the metal temperature should not exceed 212 F (100 C) with Type 316 and slightly higher with Type 317. Oxidizing ions inhibit attack and other inhibitors such as arsenic may be added.
Sulfuric acid	Type 304 can be used at room temperature for concentrations over 80%. Type 316 can be used in contact with sulfuric acid up to 10% at temperatures up to 120 F (50 C), if the solutions are aerated; the attack is greater in airfree solutions. Type 317 may be used at temperatures as high as 150 F (65 C) with up to 5% concentration. The presence of other materials may markedly change the corrosion rate. As little as 500 to 2000 ppm of cupric ions make it possible to use Type 304 in hot solutions of moderate concentration. Other additives may have the opposite effect.
Sulfurous acid	Type 304 may be subject to pitting, particularly if some sulfuric acid is present. Type 316 is usable at moderate concentrations and temperatures.
Bases	
Ammonium hydroxide, sodium hydroxide, caustic solutions	Steels in the 300 series generally have good corrosion resistance at virtually all concentrations and temperatures in weak bases, such as ammonium hydroxide. In stronger bases, such as sodium hydroxide, there may be some attack, cracking or etching in more concentrated solutions and at higher temperatures. Commercial purity caustic solutions may contain chlorides, which will accentuate any attack and may cause pitting of Type 316 as well Type 304.
Organics	
Acetic acid	Acetic acid is seldom pure in chemical plants but generally includes numerous and varied minor constituents. Type 304 is used for a wide variety of equipment including stills, base heaters, holding tanks, heat exchangers, pipelines, valves and pumps for concentrations up to 99% at temperatures up to about 120 F (50 C). Type 304 is also satisfactory for contact with 100% acetic acid vapors, and — if small amounts of turbidity or color pickup can be tolerated — for room temperature storage of glacial acetic acid. Types 316 and 317 have the broadest range of usefulness, especially if formic acid is also present or if solutions are unaerated. Type 316 is used for fractionating equipment, for 30 to 99% concentrations where Type 304 cannot be used, for storage vessels, pumps and process equipment handling glacial acetic acid, which would be discolored by Type 304. Type 316 is likewise applicable for parts having temperatures above 120 F (50 C), for dilute vapors and high pressures. Type 317 has somewhat greater corrosion resistance than Type 316 under severely corrosive conditions. None of the stainless steels has adequate corrosion resistance to glacial acetic acid at the boiling temperature or at superheated vapor temperatures.
Aldehydes	Type 304 is generally satisfactory.
Amines	Type 316 is usually preferred to Type 304.
Cellulose acetate	Type 304 is satisfactory for low temperatures, but Type 316 or Type 317 is needed for high temperatures.
Citric, formic and tartaric acids	Type 304 is generally acceptable at moderate temperatures, but Type 316 is resistant to all concentrations at temperatures up to boiling.
Esters	From the corrosion standpoint, esters are comparable with organic acids.
Fatty acids	Up at about 300 F (150 C), Type 304 is resistant to fats and fatty acids, but Type 316 is needed at 300 to 500 F (150 to 260 C) and Type 317 at higher temperatures.
Paint vehicles	Type 316 may be needed if exact color and lack of contamination are important.
Phthalic anhydride	Type 316 is usually used for reactors, fractionating columns, traps, baffles, caps and piping.
Soaps	Type 304 is used for parts such as spray towers, but Type 316 may be preferred for spray nozzles and flake-drying belts to miniimize offcolor products.
Synthetic detergents	Type 316 is used for preheat, piping, pumps and reactors in catalytic hydrogenation of fatty acids to give salts of sulfonated high molecular alcohols.
Tall oil (pump and paper industry)	Type 304 has only limited usage in tall-oil distillation service. High-rosin-acid streams can be handled by Type 316L with a minimum molybdenum content of 2.75%. Type 316 can also be used in the more corrosive high-fatty acid streams at temperatures up to 475F (245 C), but Type 317 will probably be required at higher temperatures.
Tar	Tar distillation equipment is almost all Type 316 because coal tar has a high chloride content; Type 304 does not have adequate resistance to pitting.
Urea	Type 316L is generally required.
Pharmaceuticals	Type 316 is usually selected for all parts in contact with the product because of its inherent corrosion resistance and greater assurance of product purity.

Table 8
AUSTENITIC STAINLESS STEELS

	Chemical Analysis % (Max. unless noted otherwise)									Nominal Mechanical Properties (Annealed Sheet unless noted otherwise)						
										Tensile Strength		Yield Strength (0.2% offset)		Elongation in 2" (50.80mm)	Hardness (Rockwell)	Product Form
Type	C	Mn	P	S	Si	Cr	Ni	Mo	Other	ksi	MPa	ksi	MPa	%		
201	0.15	5.50/7.50	0.060	0.030	1.00	16.00/18.00	3.50/5.50		0.25N	95	655	45	310	40	B90	
202	0.15	7.50/10.00	0.060	0.030	1.00	17.00/19.00	4.00/6.00		0.25N	90	612	45	310	40	B90	
205	0.12/0.25	14.00/15.50	0.030	0.030	0.50	16.50/18.00	1.00/1.75		0.32/0.40N	120.5	831	69	476	58	B98	(Plate)
301	0.15	2.00	0.045	0.030	1.00	16.00/18.00	6.00/8.00			110	758	40	276	60	B85	
302	0.15	2.00	0.045	0.030	1.00	17.00/19.00	8.00/10.00			90	612	40	276	50	B85	
302B	0.15	2.00	0.045	0.030	2.00/3.00	17.00/19.00	8.00/10.00			95	655	40	276	55	B85	
303	0.15	2.00	0.20	0.15 (min)	1.00	17.00/19.00	8.00/10.00	0.60*		90	621	35	241	50		(Bar)
303Se	0.15	2.00	0.20	0.060	1.00	17.00/19.00	8.00/10.00		0.15Se (min)	90	621	35	241	50		(Bar)
304	0.08	2.00	0.045	0.030	1.00	18.00/20.00	8.00/10.50			84	579	42	290	55	B80	
304L	0.030	2.00	0.045	0.030	1.00	18.00/20.00	8.00/12.00			81	558	39	269	55	B79	
S30430	0.08	2.00	0.045	0.030	1.00	17.00/19.00	8.00/10.00		3.00/4.00Cu	73	503	31	214	70	B70	(Wire)
304N	0.08	2.00	0.045	0.030	1.00	18.00/20.00	8.00/10.50		0.10/0.16N	90	621	48	331	50	B85	
305	0.12	2.00	0.045	0.030	1.00	17.00/19.00	10.50/13.00			85	586	38	262	50	B80	
308	0.08	2.00	0.045	0.030	1.00	19.00/21.00	10.00/12.00			115	793	80	552	40		(Wire)
309	0.20	2.00	0.045	0.030	1.00	22.00/24.00	12.00/15.00			90	621	45	310	45	B85	
309S	0.08	2.00	0.045	0.030	1.00	22.00/24.00	12.00/15.00			90	621	45	310	45	B85	
310	0.25	2.00	0.045	0.030	1.50	24.00/26.00	19.00/22.00			95	655	45	310	45	B85	
310S	0.08	2.00	0.045	0.030	1.50	24.00/26.00	19.00/22.00			95	655	45	310	45	B85	
314	0.25	2.00	0.045	0.030	1.50/3.00	23.00/26.00	19.00/22.00			100	689	50	345	40	B85	
316	0.08	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00		84	579	42	290	50	B79	
316F	0.08	2.00	0.20	0.10 (min)	1.00	16.00/18.00	10.00/14.00	1.75/2.50		85	586	38	262	60	B85	
316L	0.030	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00		81	558	42	290	50	B79	
316N	0.08	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00	0.10/0.16N	90	621	48	331	48	B85	
317	0.08	2.00	0.045	0.030	1.00	18.00/20.00	11.00/15.00	3.00/4.00		90	621	40	276	45	B85	
317L	0.030	2.00	0.045	0.030	1.00	18.00/20.00	11.00/15.00	3.00/4.00		86	593	38	262	55	B85	
317LMN	0.030	2.00	0.045	0.030	0.75	17.00/20.00	13.50/17.50	4.00/5.00	0.10/0.20N	96	662	54	373	49	B88	
321	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/12.00		5xC Ti (min.)	90	621	35	241	45	B80	
330	0.08	2.00	0.040	0.030	0.75/1.50	17.00/20.00	34.00/37.00		0.10Ta 0.20Cb	80	552	38	262	40	B80	
347	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/13.00		10xC Cb (min)	95	655	40	276	45	B85	
348	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/13.00		Cb + Ta 10xC (min) Ta 0.10 max Co 0.20 max	95	655	40	276	45	B85	
384	0.08	2.00	0.045	0.030	1.00	15.00/17.00	17.00/19.00			75	517	35	241	55	B70	(Wire)

* May be added at manufacturer's option.

MECHANICAL AND PHYSICAL PROPERTIES (Room Temperature)

Austenitic Stainless Steels

The austenitic stainless steels cannot be hardened by heat treatment but can be strengthened by cold work, and thus they exhibit a wide range of mechanical properties. At room temperature, austenitic stainless steels exhibit yield strengths between 30 and 200 ksi (207-1379 MPa), depending on composition and amount of cold work. They also exhibit good ductility and toughness even at high strengths, and this good ductility and toughness is retained at cryogenic temperatures. The chemical compositions and nominal mechanical properties of annealed austenitic stainless steels are given in Table 8.

The difference in effect of cold work of Types 301 and 304 is indicated by the stress strain diagrams in Figure 11.

Carbon and nitrogen contents affect yield strength, as shown by the differences among Types 304, 304L, and 304N. The effect of manganese and nitrogen on strength can be seen by comparing Types 301 and 302 against Types 201 and 202.

Figures 12, 13, 14, and 15 illustrate other effects of small composition changes. For example, at a given amount of cold work, Types 202 and 301 exhibit higher yield and tensile strengths than Types 305 and 310.

Austenitic stainless steels which can be cold worked to high tensile and yield strengths, while retaining good ductility and toughness, meet a wide range of design criteria. For example, sheet and strip of austenitic steels — usually Types 301 and 201 — are produced in the following tempers:

Temper	Tensile Strength Minimum		Yield Strength Minimum	
	ksi	MPa	ksi	MPa
1/4-Hard	125	862	75	517
1/2-Hard	150	1034	110	758
3/4-Hard	175	1207	135	931
Full-Hard	185	1276	140	965

In structural applications, the toughness and fatigue strength of these steels are important. At room temperature in the annealed condition, the austenitic steels exhibit Charpy V-notch energy absorption values in excess of 100 ft.-lb. The effect of cold rolling Type 301 on toughness is illustrated in Figure 16. This shows Type 301 to have good toughness even after cold rolling to high tensile strengths.

Fatigue or endurance limits (in bending) of austenitic stainless steels in the annealed condition shown in Table 9 are about one-half the tensile strength.

New Design Specification

Until recently, design engineers wanting to use austenitic stainless steels structurally had to improvise due to the lack of an appropriate design specification. The familiar American Institute for Steel Construction and AISI design specifications for carbon steel design do not apply to the design of stainless steel members because of differences in strength properties, modulus of elasticity, and the shape of the stress strain curve. Figure 17 shows that there is no well-defined yield point for stainless steel.

Table 9
TYPICAL ENDURANCE LIMITS OF ANNEALED CHROMIUM-NICKEL STAINLESS STEEL SHEET (2)

AISI Type	Endurance limit, ksi	MPa
301	35	241
302	34	234
303	35	241
304	35	241
316	39	269
321	38	262
347	39	269

Now the American Society of Civil Engineers (ASCE), in conjunction with the SSINA, has prepared a standard (ANSI/ASCE-8-90) “Specification for the Design of Cold-Formed Stainless Steel Structural Members.” This standard covers four types of austenitic stainless steel, specifically Types 201, 301, 304 and 316, and three types of ferritic stainless steels (See Ferritic section below). This standard requires the use of structural quality stainless steel as defined in general by the provisions of the American Society for Testing and Materials (ASTM) specifications.

Some of the physical properties of austenitic stainless steels are similar to those of the martensitic and ferritic stainless steels. The modulus of elasticity, for example, is 28 x 10^6 psi (193 GPa) and density is 0.29 lb. per cu. in. (8060 Kg/m^3). The physical properties of annealed Type 304 are shown in Table 10.

Ferritic Stainless Steels

Ferritic stainless steels contain approximately 12% chromium (and up). The chemical composition of the standard grades are shown in Table 11 along with nominal mechanical properties. Also several proprietary grades (see Appendix A) have achieved relatively wide commercial acceptance.

Three ferritic stainless steels, namely Types 409, 430 and 439 are included in the ASCE “Specification for the Design of Cold-Formed Stainless Steel Structural Members.” Designers should be aware of two notations in this specification:

(1) The maximum thickness for Type 409 ferritic stainless used in the standard is limited to 0.15 inches.

(2) The maximum thickness for Type 430 and 439 ferritic stainless steels is limited to 0.125 inches.

This is in recognition of concerns for the ductile to brittle transition temperature of the ferritic stainless steels in structural application. It should be noted that these alloys have been used in plate thickness for other applications.

Generally, toughness in the annealed condition decreases as the chromium content increases. Molybdenum tends to increase ductility, whereas carbon tends to decrease ductility. Ferritic stainless steels can be used for structural applications (as noted above), as well as such traditional applications as kitchen sinks, and automotive, appliance, and luggage trim, which require good resistance to corrosion and bright, highly polished finishes.

When compared to low-carbon steels, such as SAE 1010, the standard numbered AISI ferritic stainless steels, (such as Type 430) exhibit somewhat higher yield and tensile strengths, and low elongations. Thus, they are not as formable as the low-carbon steels. The proprietary ferritic stainless steels, on the other hand, with lower carbon levels have improved ductility and formability comparable with that of low-carbon steels. Because of the higher strength levels, the ferritic stainless steels require slightly more power to form.

Micro cleanliness is important to good formability of the ferritic types because inclusions can act as initiation sites for cracks during forming.

Type 405 stainless is used where the annealed mechanical properties and corrosion resistance of Type 410 are satisfactory but when better weldability is desired. Type 430 is used for formed products, such as sinks and decorative trim. Physical properties of Type 430 are shown in Table 10. Types 434 and 436 are used when better corrosion resistance is required and for relatively severe stretching.

For fasteners and other machined parts, Types 430F and 430F Se are often used, the latter being specified when forming is required in addition to machining.

Types 442 and 446 are heat resisting grades.

Type 409, which has the lowest chromium content of the stainless steels, is widely used for automotive exhaust systems.

Table 10 PHYSICAL PROPERTIES OF GENERAL-PURPOSE STAINLESS STEELS (ANNEALED) (1)

	Type 304	Type 430	Type 410	S13800
Modulus of Elasticity in Tension psi x 10^6 (GPa)	28.0 (193)	29.0 (200)	29.0 (200)	29.4 (203)
Modulus of Elasticity in Torsion psi x 10^6 (GPa)	12.5 (86.2)	— —	— —	— —
Density, lbs/in^3 (kg/m^3)	0.29 (8060)	0.28 (7780)	0.28 (7780)	0.28 (7780)
Specific Heat, Btu/lb/F (J/kg•K) 32-212F (0-100C)	0.12 (503)	0.11 (460)	0.11 (460)	0.11 (460)
Thermal Conductivity, Btu/hr/ft/F (W/m•K)				
212F (100C)	9.4 (0.113)	15.1 (0.182)	14.4 (0.174)	8.1 (0.097)
932F (500C)	12.4 (0.149)	15.2 (0.183)	16.6 (0.201)	12.7 (0.152)
Mean Coefficient of Thermal Expansion x10^{-6}/F (x10^{-6}/C)				
32-212F (0-100C)	9.6 (17.3)	5.8 (10.4)	5.5 (9.9)	5.9 (10.6)
32-600F (0-315C)	9.9 (17.9)	6.1 (11.0)	6.3 (11.4)	6.2 (11.2)
32-1000F (0-538C)	10.2 (18.4)	6.3 (11.4)	6.4 (11.6)	6.6 (11.9)
32-1200F (0-648C)	10.4 (18.8)	6.6 (11.9)	6.5 (11.7)	— —
32-1800F (0.982C)	— —	6.9 (12.4) [32-1500F]	— —	— —
Melting Point Range F	2550 to 2650	2600 to 2750	2700 to 2790	2560 to 2625
(C)	(1398 to 1454)	(1427 to 1510)	(1483 to 1532)	(1404 to 1440)

Table 11 FERRITIC STAINLESS STEELS (1)

Chemical Analysis % (Max. unless noted otherwise)

Type	C	Mn	P	S	Si	Cr	Ni	Mo	Other
405	0.08	1.00	0.040	0.030	1.00	11.50/14.50	0.60		0.10/0.30 Al
409	0.08	1.00	0.045	0.045	1.00	10.50/11.75	0.50		6xC/0.75 Ti
429	0.12	1.00	0.040	0.030	1.00	14.00/16.00	0.75		
430	0.12	1.00	0.040	0.030	1.00	16.00/18.00	0.75		
430F	0.12	1.25	0.060	0.15 (min)	1.00	16.00/18.00		0.60*	
430F Se	0.12	1.25	0.060	0.060	1.00	16.00/18.00			0.15 Se (min.)
434	0.12	1.00	0.040	0.030	1.00	16.00/18.00		0.75/1.25	
436	0.12	1.00	0.040	0.030	1.00	16.00/18.00		0.75/1.25	5xC/0.70 Cb+Ta
442	0.20	1.00	0.040	0.030	1.00	18.00/23.00	0.60		
446	0.20	1.50	0.040	0.030	1.00	23.00/27.00	0.75		0.25N

*May be added at manufacturer's option.

Nominal Mechanical Properties (Annealed sheet unless noted otherwise)

Type	Tensile Strength		Yield Strength (0.2% offset)		Elongation in 2" (50.80 mm) %	Hardness (Rockwell)	Product Form
	ksi	MPa	ksi	MPa			
405	65	448	40	276	25	B75	
409	65	448	35	241	25	B75	
429	70	483	40	276	30	B80	(Plate)
430	75	517	50	345	25	B85	
430F	95	655	85	586	10	B92	
430F Se	95	655	85	586	10	B92	(Wire)
434	77	531	53	365	23	B83	
436	77	531	53	365	23	B83	
442	80	552	45	310	20	B90	(Bar)
446	80	552	50	345	20	B83	

Martensitic Stainless Steels

The martensitic grades are so named because when heated above their critical temperature (1600F or 870C) and cooled rapidly, a metallurgical structure known as martensite is obtained. In the hardened condition the steel has very high strength and hardness, but to obtain optimum corrosion resistance, ductility, and impact strength, the steel is given a stress-relieving or tempering treatment (usually in the range 300-700F (149-371C)).

Tables 12, 13 and 14 give the chemical compositions and mechanical properties of martensitic grades in the annealed and hardened conditions.

The martensitic stainless steels fall into two main groups that are associated with two ranges of mechanical properties: low-carbon compositions with a maximum hardness of about Rockwell C45 and the higher-carbon compositions, which can be hardened up to Rockwell C60. (The maximum hardness of both groups in the annealed condition is about Rockwell C24.) The dividing line between the two groups is a carbon content of approximately 0.15%.

In the low-carbon class are Types 410, 416 (a free-machining grade) and 403 (a "turbine-quality" grade). The properties, performance, heat treatment, and fabrication of these three stainless steels are similar except for the better machinability of Type 416.

On the high-carbon side are Types 440A, B, and C.

Types 420, 414, and 431, however, do not fit into either category. Type 420 has a minimum carbon content of 0.15% and is usually produced to a carbon specification of 0.3-0.4%. While it will not harden to such high values as the 440 types, it can be tempered without substantial loss in corrosion resistance. Hence, a combination of hardness and adequate ductility (suitable for cutlery or plastic molds) is attained.

Types 414 and 431 contain 1.25 — 2.50% nickel, which is enough to increase hardenability, but not enough to make them austenitic at ambient temperature. The addition of nickel serves two purposes: (1) it improves corrosion resistance because it permits a higher chromium content, and (2) it enhances toughness.

Martensitic stainless steels are subject to temper embrittlement and should not be heat treated or used in the range of 800 to 1050F (427-566C) if toughness is important. The effect of tempering in this range is shown by the graph in Figure 18. Tempering is usually performed above this temperature range.

Impact tests on martensitic grades show that toughness tends to decrease with increasing hardness. High-strength (high-carbon) Type 440A exhibits lower toughness than Type 410. Nickel increases toughness, and Type 414 has a higher level of toughness than Type 410 at the same strength level.

Martensitic grades exhibit a ductile-brittle transition temperature at which notch ductility drops very suddenly. The transition temperature is near room temperature, and at low temperature about -300F (-184C) they become very brittle, as shown by the data in Figure 19. This effect depends on composition, heat treatment, and other variables.

Clearly, if notch ductility is critical at room temperature or below, and the steel is to be used in the hardened condition, careful evaluation is required. If the material is to be used much below room temperature, the chances are that quenched-and-tempered Type 410 will not be satisfactory. While its notch ductility is better in the annealed condition down to -100F (-73C), another type of stainless steel is probably more appropriate.

The fatigue properties of the martensitic stainless steels depend on heat treatment and design. A notch in a structure or the effect of a corrosive environment can do more to reduce fatigue limit than alloy content or heat treatment.

Figure 20 gives fatigue data for Type 403 turbine quality stainless at three test temperatures. The samples were smooth and polished, and the atmosphere was air.

Another important property is abrasion or wear resistance. Generally, the harder the material, the more resistance to abrasion it exhibits. In applications where corrosion occurs, however, such as in coal handling operations, this general rule may not hold, because the oxide film is continuously removed, resulting in a high apparent abrasion/corrosion rate.

Other mechanical properties of martensitic stainless steels, such as compressive yield shear strength, are generally similar to those of carbon and alloy steels at the same strength level.

Room-temperature physical properties of Type 410 are shown in Table 10. The property of most interest is modulus of elasticity. The moduli of the martensitic stainless steels (29×10^6 psi) (200 GPa) are slightly less than the modulus of carbon steel (30×10^6 psi) (207 GPa) but are markedly higher than the moduli of other engineering materials, such as aluminum (10×10^6 psi) (67 GPa).

The densities of the martensitic stainless steels (about 0.28 Ib. per cu. in.) (7780 Kg/m^3) are slightly lower than those of the carbon and alloy steels. As a result, they have excellent vibration damping capacity.

The martensitic stainless steels are generally selected for moderate resistance to corrosion, relatively high strength, and good fatigue properties after suitable heat treatment. Type 410 is used for fasteners, machinery parts and press plates. If greater hardenability or higher toughness is required, Type 414 may be used, and for better machinability, Types 416 or 416 Se are used. Springs, flatware, knife blades, and hand tools are often made from Type 420, while Type 431 is frequently used for aircraft parts requiring high yield strength and resistance to shock. Cutlery consumes most of Types 440A and B, whereas Type 440C is frequently used for valve parts requiring good wear resistance.

High-carbon martensitic stainless steels are generally not recommended for welded applications, although Type 410 can be welded with relative ease. Hardening heat treatments should follow forming operations because of the poor forming qualities of the hardened steels.

Table 12 MARTENSITIC STAINLESS STEELS (1)
Chemical Analysis % (Max. unless noted otherwise)

Type	C	Mn	P	S	Si	Cr	Ni	Mo	Other
403	0.15	1.00	0.040	0.030	0.50	11.50/13.00			
410	0.15	1.00	0.040	0.030	1.00	11.50/13.50			
414	0.15	1.00	0.040	0.030	1.00	11.50/13.50	1.25/2.50		
416	0.15	1.25	0.060	0.15 (Min)	1.00	12.00/14.00		0.60*	
416 Se	0.15	1.25	0.060	0.060	1.00	12.00/14.00			0.15 Se (Min.)
420	0.15(Min.)	1.00	0.040	0.030	1.00	12.00/14.00			
420 F	0.15(Min.)	1.25	0.060	0.15 (Min.)	1.00	12.00/14.00		0.60*	
422	0.20/0.25	1.00	0.025	0.025	0.75	11.00/13.00	0.50/1.00	0.75/1.25	0.15/0.30 V 0.75/1.25 W
431	0.20	1.00	0.040	0.030	1.00	15.00/17.00	1.25/2.50		
440A	0.60/0.75	1.00	0.040	0.030	1.00	16.00/18.00		0.75	
440B	0.75/0.95	1.00	0.040	0.030	1.00	16.00/18.00		0.75	
440C	0.95/1.20	1.00	0.040	0.030	1.00	16.00/18.00		0.75	

*May be added at manufacturer's option

Table 13 Nominal Mechanical Properties
(Annealed sheet unless noted otherwise)

Type	Tensile Strength		Yield Strength (0.2% offset)		Elongation in 2" (50.80 mm) %	Hardness (Rockwell)	Product Form
	ksi	MPa	ksi	MPa			
403	70	483	45	310	25	B80	
410	70	483	45	310	25	B80	
414	120	827	105	724	15	B98	
416	75	517	40	276	30	B82	(Bar)
416Se	75	517	40	276	30	B82	(Bar)
420	95	655	50	345	25	B92	(Bar)
420F	95	655	55	379	22	220 (Brinell)	(Bar)
422*	145	1000	125	862	18	320 (Brinell)	(Bar)
431	125	862	95	655	20	C24	(Bar)
440A	105	724	60	414	20	B95	(Bar)
440B	107	738	62	427	18	B96	(Bar)
440C	110	758	65	448	14	B97	(Bar)

*Hardened and Tempered

Precipitation Hardening Stainless Steels

The principle of precipitation hardening is that a supercooled solid solution (solution annealed material) changes its metallurgical structure on aging. The principal advantage is that products can be fabricated in the annealed condition and then strengthened by a relatively low-temperature 900-1150F (482-620C) treatment, minimizing the problems associated with high-temperature treatments. Strength levels of up to 260 ksi (1793 MPa) (tensile) can be achieved — exceeding even those of the martensitic stainless steels — while corrosion resistance is usually superior — nearly equal to that of Type 304 stainless. Ductility is similar to corresponding martensitic grades at the same strength level. Table 15 shows the chemical composition and the nominal mechanical properties of four AISI standard precipitation hardening stainless steels in solution treated and age hardened conditions.

Precipitation hardening stainless steels have high strength, relatively good ductility, and good corrosion resistance at moderate temperatures. They are utilized for aerospace structural components, fuel tanks, landing gear covers, pump parts, shafting, bolts, saws, knives, and flexible bellows-type expansion joints.

Physical properties of UNS S13800 are shown in Table 10.

Table 14
NOMINAL MECHANICAL PROPERTIES
As Quenched Hardness and Properties After Hardening and Tempering 1 in. (25.4 mm) Diameter Bars

Type	UNS	Hardening Temp. F. (C)	As Quenched Hardness HB	As Quenched Hardness HR	Tempering Temp. F. (C)	Tensile Strength, ksi (MPa)	Yield Str. 0.2 % Offset ksi (MPa)	Elon. in. 2 in. (50.80 mm) %	Red. of Area %	Izod Impact V-Notch Ft. Lbs. (J)	Tempered Hardness HB	Tempered Hardness HR
403 and 410	S40300 S41000	1800 (981)	410	C43	400 (204)	190 (1310)	145 (1000)	15	55	35 (47)	390	C41
					600 (315)	180 (1241)	140 (965)	15	55	35 (47)	375	C39
					800* (426)	195 (1344)	150 (1034)	17	55		390	C41
					1000* (538)	145 (1000)	115 (793)	20	65		300	C31
					1200 (648)	110 (758)	85 (586)	23	65	75 (102)	225	B97
					1400 (760)	90 (621)	60 (414)	30	70	100 (136)	180	B89
416 and 416 Se	S41600 S41623	1800 (981)	410	C43	400 (204)	190 (1310)	145 (1000)	12	45	20 (27)	390	C41
					600 (315)	180 (1241)	140 (965)	13	45	20 (27)	375	C39
					800* (426)	195 (1344)	150 (1034)	13	50		390	C41
					1000* (538)	145 (1000)	115 (793)	15	50		300	C31
					1200 (648)	110 (758)	85 (586)	18	55	30 (41)	225	B97
					1400 (760)	90 (621)	60 (414)	25	60	60 (81)	180	B89
414	S41400	1800 (981)	425	C44	400 (204)	100 (1379)	150 (1034)	15	55	45 (61)	410	C43
					600 (315)	190 (1310)	145 (1000)	15	55	45 (61)	400	C41
					800 (426)	200 (1379)	150 (1034)	16	58		415	C43
					1000* (538)	145 (1000)	120 (827)	20	60		290	C30
					1200 (760)	120 (827)	105 (724)	20	65	50 (68)	250	C22
431	S43100	1900 (1036)	440	C45	400 (204)	205 (1413)	155 (1069)	15	55	30 (41)	415	C43
					600 (315)	195 (1344)	150 (1034)	15	55	45 (61)	400	C41
					800* (426)	205 (1413)	155 (1069)	15	60		415	C43
					1000* (538)	150 (1034)	130 (896)	18	60		325	C34
					1200 (760)	125 (862)	95 (655)	20	60	50 (68)	260	C24
420	S42000	1900 (1036)	540	C54	600 (315)	230 (1586)	195 (1344)	8	25	10 (14)	500	C50
440A	S44002	1900 (1036)	570	C56	600 (315)	260 (1793)	240 (1655)	5	20	4 (5)	510	C51
440B	S44003	1900 (1036)	590	C58	600 (315)	280 (1931)	270 (1862)	3	15	3 (4)	555	C55
440C	S44004	1900 (1036)	610	C60	600 (315)	285 (1965)	275 (1896)	2	10	2 (3)	580	C57

*Tempering within the range of 750 to 1050 F (399 to 565 C) is not recommended because such treatment will result in low and erratic impact properties and loss of corrosion resistance. Note. Variations in chemical composition within the individual type ranges may affect the mechanical properties.

Table 15
PRECIPITATION HARDENING STAINLESS STEELS (1)
Chemical Analysis % (Max. unless noted otherwise)

Type	C	Mn	P	S	Si	Cr	Ni	Mo	Other
S13800	0.05	0.10	0.010	0.008	0.10	12.25/13.25	7.50/8.50	2.00/2.50	0.90/1.35 Al 0.010 N
S15500	0.07	1.00	0.040	0.030	1.00	14.00/15.50	3.50/5.50		2.50/4.50 Cu 0.15/0.45 Cb + Ta
S17400	0.07	1.00	0.040	0.030	1.00	15.50/17.50	3.00/5.00		3.00/5.00 Cu 0.15/0.45 Cb + Ta
S17700	0.09	1.00	0.040	0.040	0.040	16.00/18.00	6.50/7.75		0.75/1.50 Al

Nominal Mechanical Properties
(Solution Treated Bar)

Type	Tensile Strength		Yield Strength (0.2% offset)		Elongation in 2" (50.80 mm) %	Hardness (Rockwell)
	ksi	MPa	ksi	MPa		
S13800	160	1103	120	827	17	C33
S15500	160	1103	145	1000	15	C35
S17400	160	1103	145	1000	15	C35
S17700	130	896	40	276	10	B90