CARPENTER
Specialty Alloys

The Carpenter Selectaloy® Method

Simplifying Stainless Alloy Selection

Simplifying the Selection

CONTENTS

INTRODUCTION i

CRITERIA FOR STAINLESS ALLOY SELECTION 2

CORROSION RESISTANCE 4

MECHANICAL PROPERTIES 9

FABRICATION 18

REVIEW AND APPLICATION OF THE SELECTALOY® METHOD 20

SPECIALIZED ALLOYS TO CONSIDER 22

COST AND AVAILABILITY 25

Introduction

Everyone is familiar with stainless steels but few understand that the versatile family of stainless grades is an alloy system capable of providing a wide variety of corrosion resistance, strength, and workability. Many recognize a finished stainless steel product, but just what are stainless steels? How are they unique compared with other materials?

Typically, stainless steels are alloys of iron to which a minimum of about 12% chromium has been added to impart corrosion resistance. A 12% chromium stainless steel will not corrode or "rust"

# of Stainless Alloys—the Carpenter Selectaloy® Method

when exposed to the weather.
To obtain greater corrosion resistance, more chromium is added to the alloy, so that there are stainless grades with chromium contents of 15%-17%-20% and even 27%.

All stainless alloys are uniform in composition. Chipping, scratching, or other surface damage are not issues, since any freshly exposed surface is as resistant to corrosion as the original surface. This remarkable attribute is the result of an invisible, self-forming and self-healing, passive film (non-reactive chromium oxide) which forms in the presence of oxygen.

Along with iron and chromium, all stainless alloys contain some carbon. Carbon may be present at residual levels or may be deliberately added up to 1.00% or more. Greater carbon content requires higher chromium content, because carbon can extract about 17 times its own weight of chromium to form carbides. This chromium in the form of carbides is of little use for resisting corrosion. The carbon, of course, is added for the same purpose as in ordinary alloys—to make the alloy stronger.

Other alloying elements are added for improved corrosion resistance, fabricability and variations in strength. These elements include nickel, molybdenum, copper, titanium, silicon, aluminum, sulfur and many others which cause pronounced metallurgical changes. The most important of these is nickel. If enough nickel is added, the entire nature of the alloy changes.

The problem facing the manufacturer working with stainless grades becomes the difficult one of choosing the right alloy for a particular job.

While many attempts have been made to portray a simple picture of the stainless alloy family, the Carpenter **Selectaloy®** method represents perhaps the first useful selection system for users of stainless alloys.

ISO 9002 and QS-9000 Registered
Headquarters - Wyomissing, PA

Criteria for Stainless Alloy

CARPENTER'S SELECTALOY® METHOD HAS BEEN DEVELOPED AS A SIMPLIFIED SELECTION TECHNIQUE FOR CHOOSING THE PROPER STAINLESS GRADE FOR THE END-USE APPLICATION THAT YOU HAVE IN MIND.

Before using the Selectaloy method, there are certain variables which must be considered in the choice of any stainless alloy.

The proper selection technique for the evaluation of the many types of stainless alloys is based upon five important criteria.

In order of importance, these requirements are:

1. Corrosion Resistance—
This is the primary reason for specifying stainless alloys. The level of corrosion resistance required and the corrosive environment expected must be known when selecting a stainless alloy. If corrosion were not a problem, a stainless alloy would not be required.

Selection

2. Mechanical Properties—
Special emphasis should be placed upon the alloy's strength. Together with the corrosion resistance factor, this second requirement helps to designate the specific alloy type for the application.

3. Fabrication—
How the material is to be processed. This includes such special considerations as the alloy's ability to be machined, welded, cold headed, etc.

4. Total Cost—
The overall value analysis of the stainless grade, including initial alloy price, installed cost, and the effective life expectancy of the finished product.

5. Product Availability—
Availability of the material from the mill, service center, warehouse, or supplier is a final consideration in choosing the most economical and practical stainless alloy.

Careful consideration of these factors has often been a time-consuming and frustrating experience. This problem arises not from a lack of information, but as a result of the publication of volumes of uncoordinated material.

That's why Carpenter's Selectaloy Method has been developed as a simplified selection technique for choosing the proper stainless grade for your end-use application.

Carpenter's Selectaloy® Method

Corrosion Resistance

When specifying stainless alloys for your particular application, the first factor to consider is corrosion resistance.

The Basic Alloy

Type 304, a basic 18-8 stainless alloy widely used in many industries, is an austenitic stainless alloy possessing a minimum of 18% chromium and 8% nickel, combined with a maximum of 0.08% carbon. It is a non-magnetic grade which cannot be hardened by heat treatment, but must be cold worked to obtain higher tensile strengths.

Corrosion and oxidation resistance is provided by the 18% minimum chromium content. The alloy's metallurgical characteristics are established primarily by the nickel content (8% min.), which also extends resistance to corrosion caused by reducing chemicals. Carbon is held at a level (0.08% max.) that is satisfactory for most service applications.

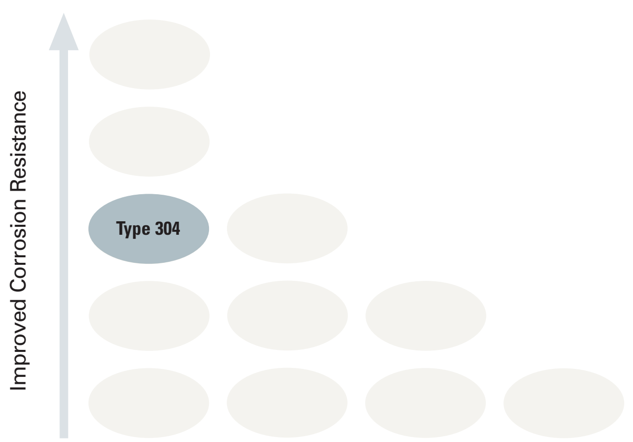
Type 304 resists most oxidizing acids and can withstand all ordinary rusting. It is immune to foodstuffs, sterilizing solutions, most organic chemicals and dyestuffs, and a wide variety of inorganic chemicals. Type 304, or one of its modifications, is the material specified more than 50% of the time for stainless applications.

Because of its ability to withstand the corrosive action of various acids found in fruits, meats, milk, and vegetables, Type 304 has been used for sinks, tabletops, coffee urns, stoves, refrigerators, milk and cream dispensers and steam tables, as well as numerous other utensils such as cooking appliances, pots, pans, and flatware.

Type 304 has found extensive use in dairy equipment—milking machines, containers, homogenizers, sterilizers, and storage and hauling tanks, including piping, valves, milk trucks and railroad cars. This 18-8 alloy has also found application in the brewing industry where it has been used in pipelines, yeast pans, fermentation vats, storage and railway tank cars, etc. The citrus and fruit juice industry has also used Type 304 for all its handling, crushing, preparation, storage and hauling equipment.

In food processing applications such as in mills, bakeries, and slaughter and packing houses, most stainless equipment exposed to animal and vegetable oils, fats, and acids is manufactured from Type 304.

Type 304 has also been used for the dye tanks, pipelines, buckets, dippers, etc., that come in contact with the formic, acetic, and other organic acids used in the dyeing industry.



Type Analysis of Stainless Type 304:

Carbon	0.08% max.	Silicon	1.00% max.
Manganese	2.00% max.	Chromium	18.00/20.00%
Phosphorus	0.045% max.	Nickel	8.00/10.50%
Sulfur	0.030% max.		

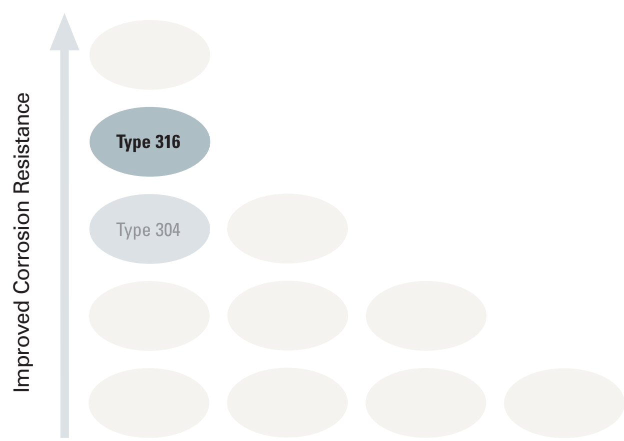
More Severe Environments

There are many industrial processes that require a higher level of resistance to corrosion than Type 304 can offer. For these applications, Type 316 may be the solution.

Type 316 is also an austenitic, non-magnetic, and thermally non-hardenable stainless grade like Type 304. The carbon content is held to 0.08% maximum, while the nickel content is increased slightly. What distinguishes Type 316 from Type 304 is the addition of molybdenum up to a maximum of 3%.

Molybdenum increases the corrosion resistance of this chromium-nickel alloy to withstand attack by many industrial chemicals and solvents, and, in particular, inhibits pitting caused by chlorides. As such, molybdenum is one of the most useful, single alloying additives in the fight against corrosion.

By virtue of the molybdenum addition, Type 316 can withstand corrosive attack by sodium and calcium brines, hypochlorite solutions, phosphoric acid and the sulfite liquors and sulfurous acids used in the paper pulp industry. This alloy has been specified for industrial equipment that handles the corrosion process chemicals used to produce inks, rayons, photographic chemicals, paper, textiles, bleaches, and rubber. Type 316 has also been used for surgical implants within the hostile environment of the body.



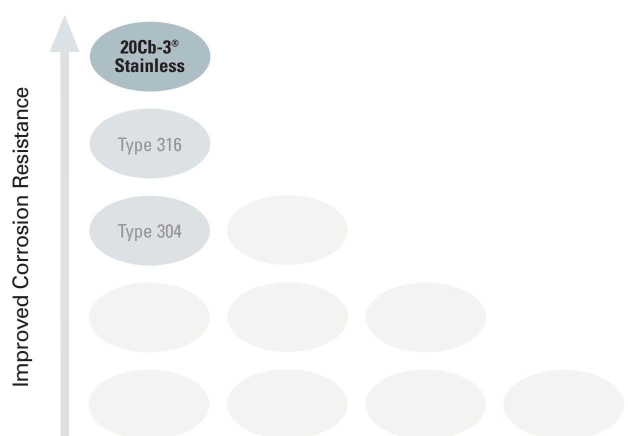
Type Analysis of Stainless Type 316:

Carbon	0.08% max.	Silicon	1.00% max.
Manganese	2.00% max.	Chromium	16.00/18.00%
Phosphorus	0.045% max.	Nickel	10.00/14.00%
Sulfur	0.030% max.	Molybdenum	2.00/3.00%

For those severe corrosion environments where Type 316 is inadequate, 20Cb-3® stainless is the next higher level of corrosion resistance choice available. The chromium content is increased to 20%, while the nickel content is approximately 34%. Such large amounts of chromium and nickel impart high corrosion resistance to the alloy, which is further enhanced by the addition of 2-3% molybdenum. This highly alloyed grade also contains 3-4% copper, which confers special resistance to sulfuric acid. It is stabilized with an addition of columbium (1% max.) against loss of corrosion resistance due to intergranular attack, which may result from welding.

20Cb-3 stainless offers superior resistance to hundreds of common industrial and process corrodents, from acetate solvents, cadmium sulfate, and trichlorethylene to ferrous sulfate, boric acid, and zinc chloride.

This corrosion-resistant alloy provides excellent resistance to 10%-40% sulfuric acid at temperatures ranging up to the boiling point of sulfuric acid and the higher metal temperatures encountered with heat exchanger equipment.



Type Analysis of 20Cb-3® Stainless:

Carbon	0.06% max.	Silicon	1.00% max.
Manganese	2.00% max.	Chromium	19.00/21.00%
Phosphorus	0.035% max.	Nickel	32.50/35.00%
Sulfur	0.035% max.	Molybdenum	2.00/3.00%
Columbium and Tantalum	8 x C min./1.00% max.	Copper	3.00/4.00%

It has been used extensively in many phases of the chemical industry including the manufacture of synthetic rubber, high-octane gasoline, explosives, plastics, heavy chemicals, and pharmaceuticals.

Less Severe Environment

There are also many applications where the corrosion resistance of 20Cb-3 stainless, Type 316, or even Type 304 is not needed. In those instances, Type 430—a less costly grade of stainless steel—provides an adequate level of resistance.

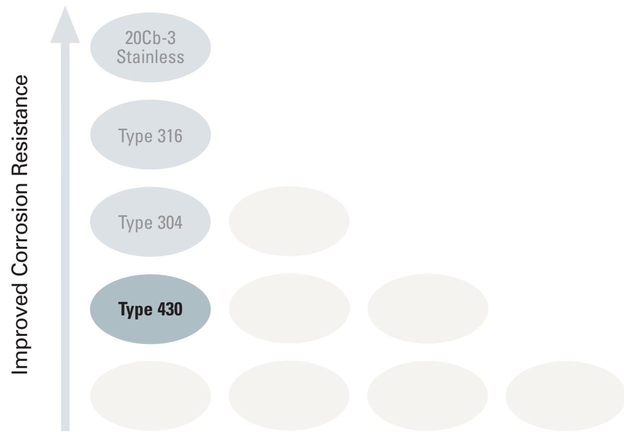
Type 430 is a magnetic, thermally non-hardenable, ferritic stainless alloy that contains a maximum of 0.12% carbon and 16-18% chromium. It contains no nickel. Because of its slightly lower chromium content and absence of nickel, Type 430 is less resistant to corrosion than Type 304.

Even so, Type 430 stainless steel effectively resists foodstuff, fresh water, and non-marine atmospheric corrosion. It also possesses the ability to resist attack from nitric acid. Typical applications for Type 430 have included automotive, appliance and architectural hardware. Type 430 has also been used in handrails, ceiling, elevator lobbies, window sashes, balconies, vault linings, decorative plaques, hub caps, radiator grills, doors, window frames, headlight trim, railroad, bus, and airliner sheathing, trim, and moldings. In hospitals, where ease of cleaning and resistance to sterilizing solutions are important considerations, Type 430 has been used for operating tables, instrument cabinets, trays, etc.

For those applications where only the minimum corrosion resistance is necessary, Type 405 may be specified.

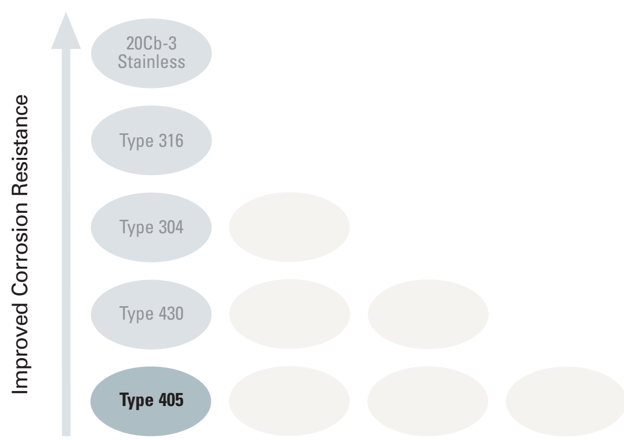
Type 405 is a ferritic, thermally non-hardenable, magnetic chromium alloy. By controlling the carbon content (0.08% max.) and adding aluminum (0.30% max.), processing is simplified because heat treatment is eliminated. It is a low-cost stainless grade that resists simple corrosive attack by unpolluted atmospheres and fresh water.

Type 405 is designed for use in the as-welded condition, often requiring no post-weld annealing treatment. The alloy will resist corrosion from soap, sugar solutions, mine water, steam, carbonic acid, blood, perspiration, ammonia, alcohol, crude oil, gasoline, mercury, and other mild reagents. Its reaction to corrodents is similar to that of Type 410, which is the alloy used in the sample acetic acid corrosion table on the following page.



Type Analysis of Stainless Type 430:

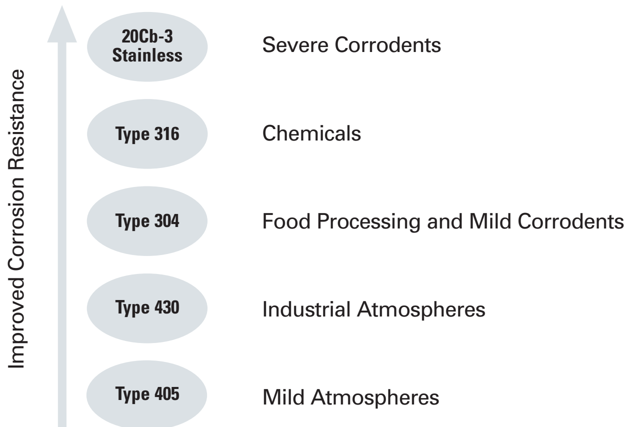
Carbon ....0.12% max.
Manganese.....................1.00% max.
Phosphorus ....0.040% max.
Sulfur ....0.030% max.
Silicon ....1.00% max.
Chromium 16.00/18.00%



Type Analysis of Stainless Type 405:

Carbon ....0.08% max.
Manganese.....................1.00% max.
Phosphorus ....0.040% max.
Sulfur ....0.030% max.
Silicon ....1.00% max.
Chromium.....................11.50/14.50%
Aluminum 0.10/0.30%

Levels of Corrosion Resistance



Although there are many ways to determine the level of corrosion resistance necessary for a specific application, five key factors must be considered:

The nature of the corrodent—what is the material that the stainless steel will be exposed to during the application?

The concentration of the corrodent—what percentage or concentration of the corrodent will be used during the application; 10%, 50%?

The temperature of the corrodent—usually as the temperature is increased, the rate of corrosive attack will also increase.

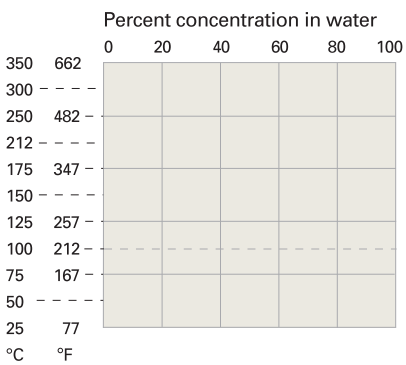
The presence of contaminants—contaminants in the corrodent have an important effect upon corrosion and may either increase or decrease the rate of corrosive attack.

The acceptable corrosion rate—how long must the product function in the corrosive environment?

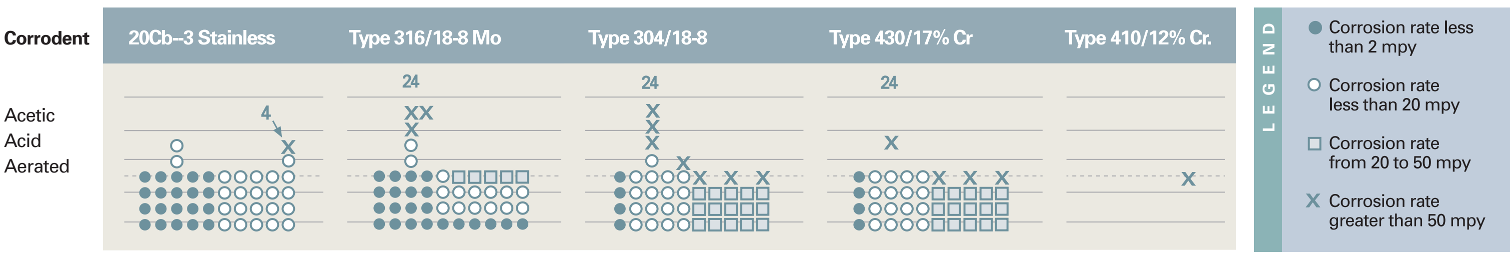
To assist in selecting the proper alloy type for your application, a more complete summation of corrosion data can be found in **Carpenter's Stainless Steels Manual.** Over 250 charts and tables illustrate the corrosion resistance of five representative Selectaloy grades to the more common corrosive chemicals.

The sample table below lists chemical concentration (%) and temperature (to 660°F/350°C) keyed to a coded corrosion scale indicating the corrosion rates in terms of depth of attack per year.

Knowing only the corrodent, concentration, temperature and the desired level of corrosion resistance required, the corresponding stainless steel for a particular application can be chosen.



Acetic Acid Corrosion Table



Mechanical Properties

Once corrosion resistance levels have been ascertained, a careful study of mechanical properties is necessary to determine the proper grade for an application.

As can be seen in the diagram, yield and tensile strengths for the five basic Selectaloy alloys are similar in the most popular (annealed) condition.

If resistance to corrosion at the Type 405 level is adequate but higher strength is required, Type 410 offers similar corrosion resistance with greater strength.

Five Basic Selectaloy Alloys Popular (Annealed) Condition

	YIELD STRENGTH		TENSILE STRENGTH	
	ksi	MPa	ksi	MPa
20Cb-3 Stainless	45	310	95	655
Type 316	35	241	85	586
Type 304	35	241	85	586
Type 430	45	310	75	517
Type 405	40	276	70	482

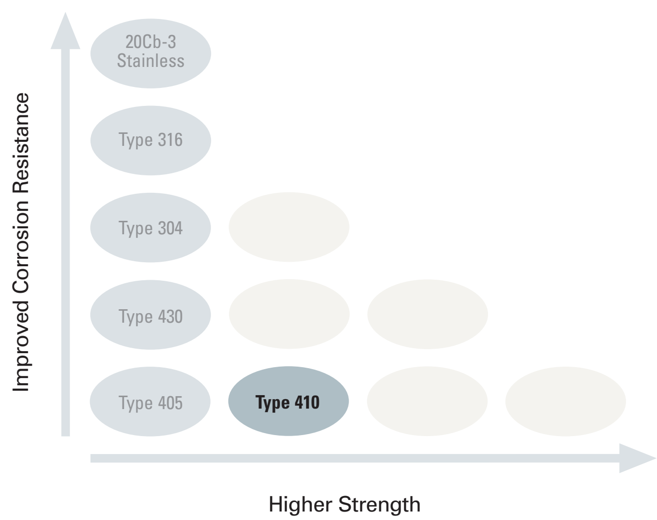
Type 410 is a martensitic alloy similar to Type 405 but with a higher carbon content and no aluminum. It is this increase in carbon and absence of aluminum that improves the mechanical properties of Type 410 by making it a hardenable alloy similar to regular carbon and alloy steels.

Type 410 has found extensive use in such highly stressed parts as steam-turbine buckets and blades, gas-turbine compressor blades, and nuclear-reactor control-rod mechanisms.

The comparison chart below illustrates the strength differentials between Types 405 and 410 resulting from the differing percentages of carbon in their analysis.

However, in many cases the strength levels offered by Type 410 may not be sufficient. For greater strength and hardness at the same level of corrosion resistance, Type 420 should be considered.

Type 420 stainless is also a martensitic alloy that is strengthened by simple carbon addition.

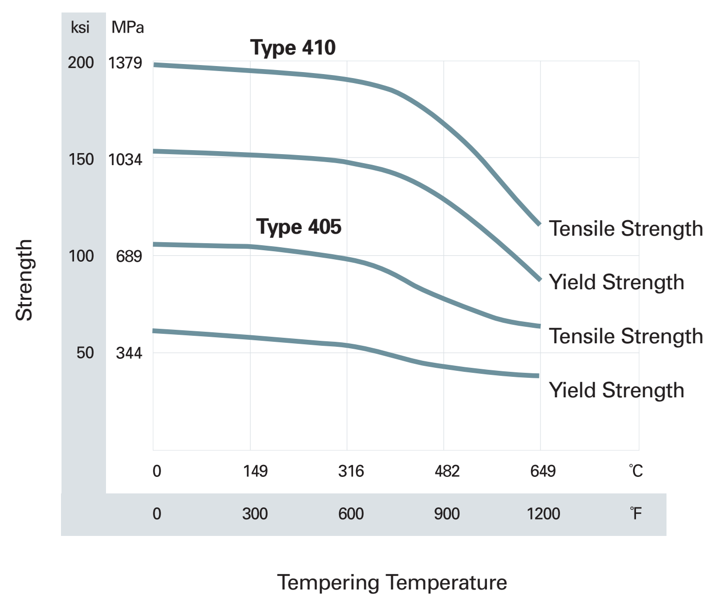


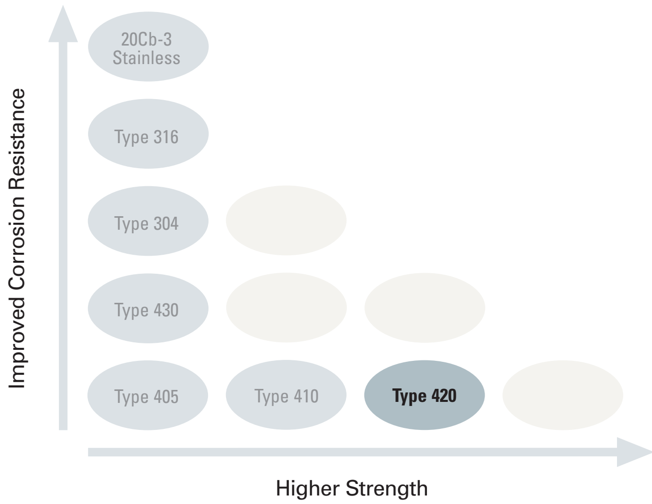
Type Analysis of Stainless Type 410:

Carbon ....0.15% max.	Sulfur ....0.030% max.
Manganese....................1.00% max.	Silicon ....1.00% max.
Phosphorus.................0.040% max.	Chromium 11.50/13.00%

Type 410 Mechanical Properties (Typical Room Temperature):
(Bar, hardened 1850°F/1010°C, 30 Minutes, Oil Quench,
plus tempered 4 hours at 500°F/260°C)

Yield Strength, 0.2% offset	ksi 158	..........................MPa 1089
Ultimate Tensile Strength	ksi 193	..........................MPa 1331
Elongation in 2", %...		17
Reduction of Area, %..		62
Rockwell C Hardness..		43
Brinell Hardness..		401



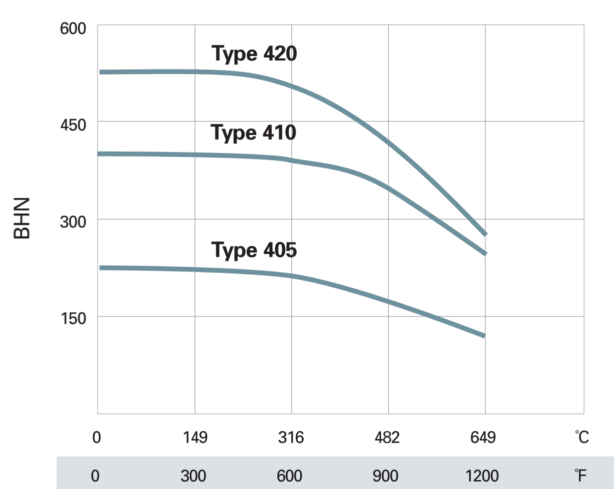


Type Analysis of Stainless Type 420:

Carbon	0.15% min.	Sulfur	0.030% max.
Manganese	1.00% max.	Silicon	1.00% max.
Phosphorus	0.040% max.	Chromium	12.00/14.00%

Type 420 Mechanical Properties (Typical Room Temperature):
(1 inch/25.4mm Round Bar—Hardened 1900°F/1038°C, Oil Quench, Tempered at 400°F/204°C)

Yield Strength, 0.2% offset	ksi 215	MPa 1482
Ultimate Tensile Strength	ksi 250	MPa 1724
Elongation in 2", %		8
Reduction of Area, %		25
Brinell Hardness		512

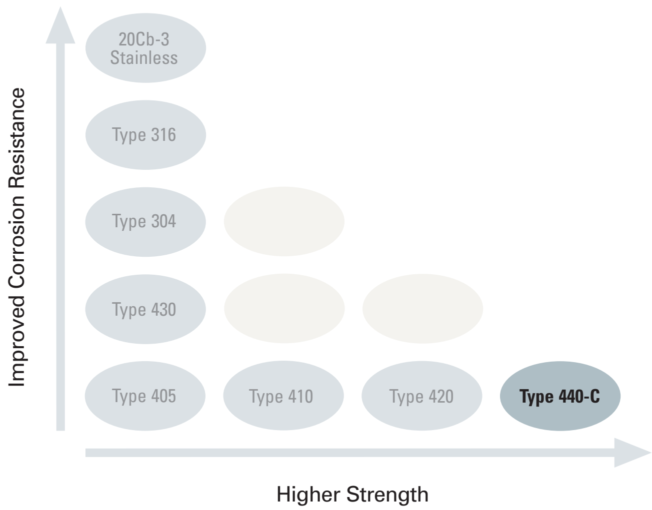


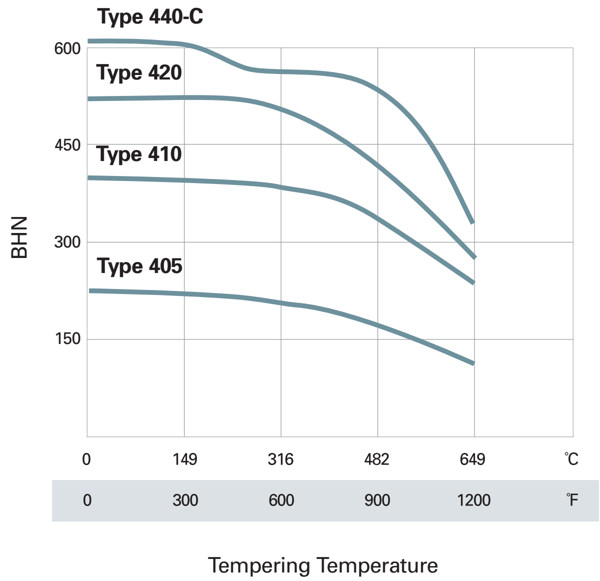
Tempering Temperature

Carbon content is increased to a 0.15% minimum (0.30% nominal) compared to the 0.15% maximum limit for Type 410. Along with the carbon, chromium content is also slightly increased to offset the tendency of the higher carbon content to lower the alloy's resistance to corrosion.

In the hardened and tempered condition, the alloy's yield strengths are substantially greater than Type 410. Its greater hardness is sometimes an even more important consideration when choosing an alloy for a specific use, particularly when wear resistance is necessary.

Type 420 has been used principally for such applications as surgical and dental instruments, cutlery, scissors, gauges, valves, gears, shafts, ball bearings, and magnets.





Type Analysis of Stainless Type 440-C:

Carbon 0.95/1.20%	Silicon ....1.00% max.
Manganese....................1.00% max.	Chromium....................16.00/18.00%
Phosphorus ....0.040% max.	Molybdenum ....0.75% max.
Sulfur ....0.030% max.	

Type 440-C Mechanical Properties (Typical Room Temperature):
(Hardened 1900°F/1038°C, Oil Quench, Tempered at 600°F/316°C)

Yield Strength, 0.2% offset	ksi 275	.... MPa 1896
Ultimate Tensile Strength	ksi 285	.... MPa 1965

Elongation in 2", %..2
Reduction of Area, %...10
Brinell Hardness 580

To obtain the ultimate in hardness within the first corrosion-resistance level, Type 440-C is suggested.

Type 440-C is a thermally hardenable, martensitic stainless alloy combining corrosion-resistant properties with the maximum hardness available of any stainless alloy.

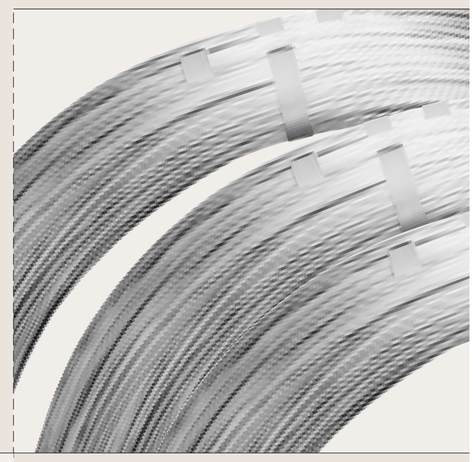
Both carbon and chromium contents are increased substantially to impart hardness. While strongest of all stainless alloys, its high carbon content (0.95-1.20%) is the principal reason why Type 440-C is placed at the lowest level of corrosion resistance.

Type 440-C should be considered for products such as quality bushings, cutlery, valves, and ball bearings which require the highest hardness values obtainable.

As we have seen, the various Selectaloy grades are categorized vertically according to increased resistance to corrosion. Similarly, the alloys may also be classified horizontally—according to increased strength characteristics. At the lowest level of corrosion resistance, Type 405 is representative of that category of steels having less than 50 ksi (345 MPa) yield strength. All those Selectaloy alloys above Type 405 share the same 50 ksi (345 MPa) limitation in the most popular (annealed) condition. Type 410 is representative of those stainless steels possessing yield strengths up to 175 ksi (1207 MPa); Type 420—up to 250 ksi (1724 MPa). Type 440-C obtains a yield strength in excess of 250 ksi (1724 MPa).

In many applications, both increased strength and greater resistance to corrosion are required. To obtain these properties, representative alloys of the second corrosion level must be considered. Type 430, the alloy with the lowest strength level in this category, has already been discussed.

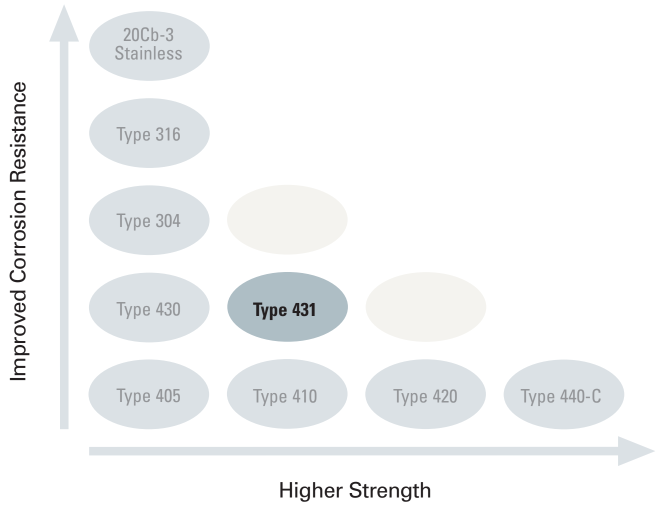
To find increased strength at the level of corrosion of Type 430, Type 431 should be examined.



Yield Strengths

Less than 50 ksi/ 345 MPa	Up to 175 ksi/ 1207 MPa	Up to 250 ksi/ 1724 MPa	Over 250 ksi/ 1724 MPa
Type 405	Type 410	Type 420	Type 440-C

Higher Strength



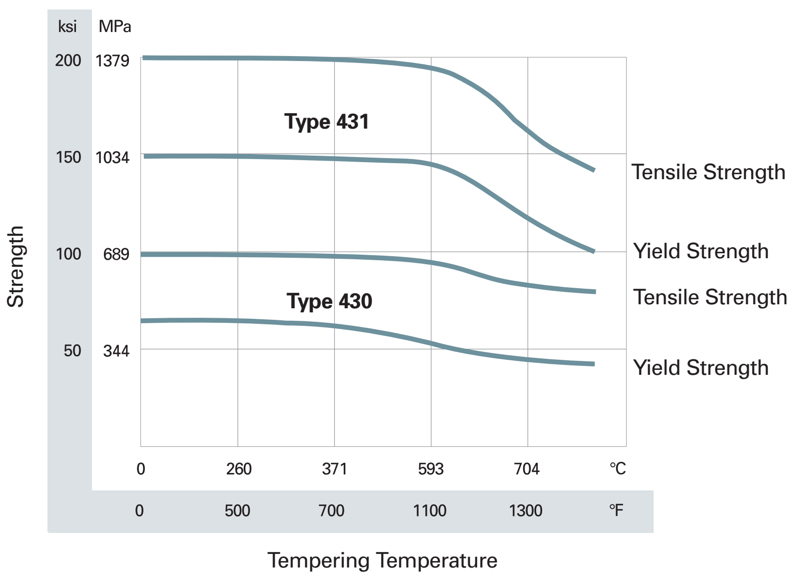
Type Analysis of Stainless Type 431:

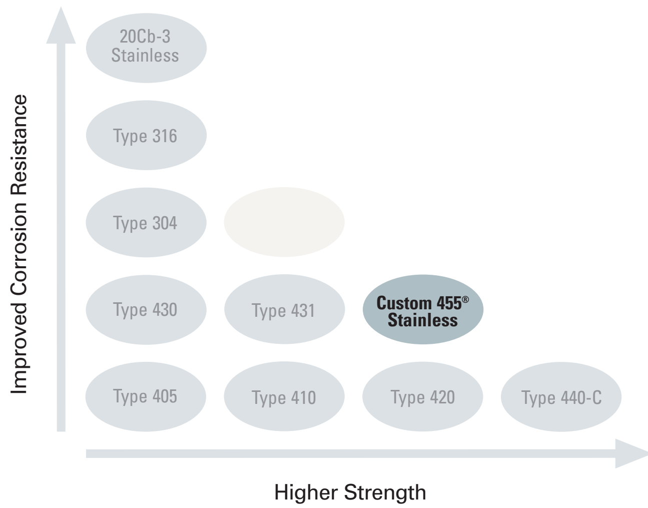
Carbon ....0.20% max.	Silicon..............................1.00% max.
Manganese.....................1.00% max.	Chromium.....................15.00/17.00%
Phosphorus ....0.040% max.	Nickel.................................1.25/2.50%
Sulfur ....0.030% max.	

Type 431 is a magnetic, martensitic, stainless steel which is thermally hardenable. The carbon content is held between 0.12 and 0.17% compared to Type 430's maximum 0.12% carbon. With 1.50 to 2.50% nickel added, good toughness is maintained at high strength levels.

Its corrosion resistance and toughness make it a candidate for aircraft fasteners and fittings, and for structural members exposed to marine atmospheres. This optimum combination of corrosion resistance, hardness, and toughness is suggested for temperature applications between -100°F (-73°C) and 1200°F (649°C).

For highest strength at the second level of corrosion resistance, Custom 455® stainless should be considered.





Type Analysis of Custom 455 Stainless:

Carbon	0.05% max.	Nickel	7.50/9.50%
Manganese	0.50% max.	Titanium	0.80/1.40%
Phosphorus	0.040% max.	Columbium and Tantalum	0.10/0.50%
Sulfur	0.030% max.	Copper	1.50/2.50%
Silicon	0.50% max.	Molybdenum	0.50% max.
Chromium	11.00/12.50%		

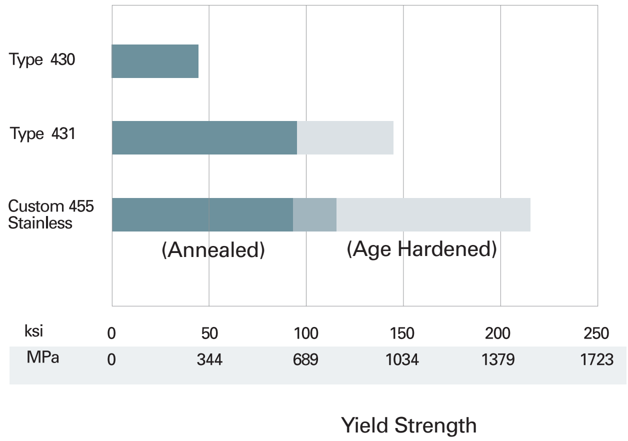
Custom 455 Stainless Mechanical Properties (Room Temperature):

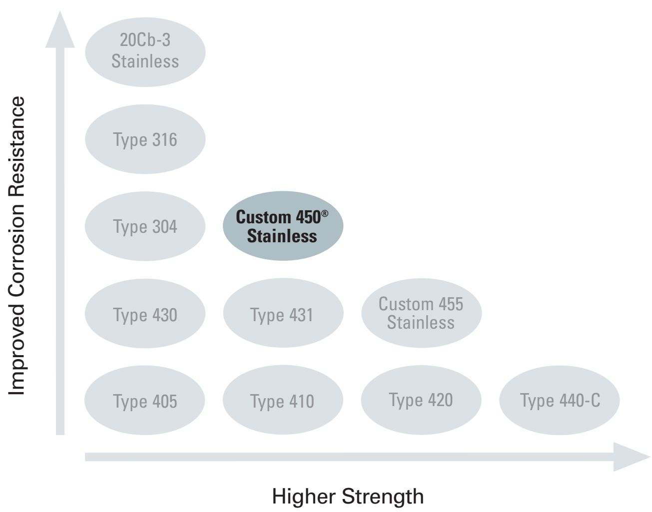
		Annealed Condition	Age Hardened Condition (H950)
Yield Strength, 0.2%	ksi	115	220
	MPa	793	1517
Ultimate Tensile Strength	ksi	145	230
	MPa	1000	1586
Notch Tensile Strength, $k_t = 10$	ksi	230	300
	MPa	1586	2068
Elongation in 4D, %		14	12
Reduction of Area, %		60	50
Rockwell C Hardness		31	48
Charpy V-Notch Impact Strength			
	ft-lbs	70	14
	J	95	19

Custom 455 stainless may be classified as martensitic—age hardening or maraging. Unlike the preceding alloys, Custom 455 stainless is not strengthened by a simple carbon addition. Further additions of carbon would adversely affect its corrosion resistance and mechanical properties. Instead, Custom 455 stainless is strengthened by precipitation of a second phase, thereby achieving a special degree of corrosion resistance and strength.

Custom 455 stainless is a precipitation-hardening alloy which offers good corrosion resistance to atmospheric and salt water environments, as well as exceptionally high yield strengths with good ductility and notch toughness. This unique alloy can be considered where a combination of high strength, good corrosion resistance, simple heat treatment, and ease of fabrication is required.

Custom 455 stainless has been used in various applications such as high-performance springs made from wire and strip, nuclear reactor parts, bomb racks, high-performance fasteners, and pumps and high-pressure vessel components that are in contact with corrosive elements.





Type Analysis of Stainless Custom 450 Stainless:

Carbon ....0.05% max.	Chromium.....................14.00/16.00%
Manganese.....................1.00% max.	Nickel.................................5.00/7.00%
Silicon ....1.00% max.	Molybdenum....................0.50/1.00%
Phosphorus..................0.030% max.	Copper...............................1.25/1.75%
Sulfur.............................0.030% max.	Columbium........................8 x C min.

For those applications where an even greater level of corrosion resistance coupled with increased strength is necessary, the third level of corrosion resistance should be considered. The familiar Type 304 alloy is representative of the third level of resistance to corrosion at the lowest strength level.

When searching for best mechanical strength at this third level of corrosion resistance, Custom 450® stainless is suggested.

Custom 450 stainless is a relatively low-cost, martensitic stainless grade designed to be supplied and used in the annealed condition. This alloy exhibits an unusual combination of formability and high strength with a resistance to corrosion that is unique for 100 ksi (690 MPa) minimum yield strength material.

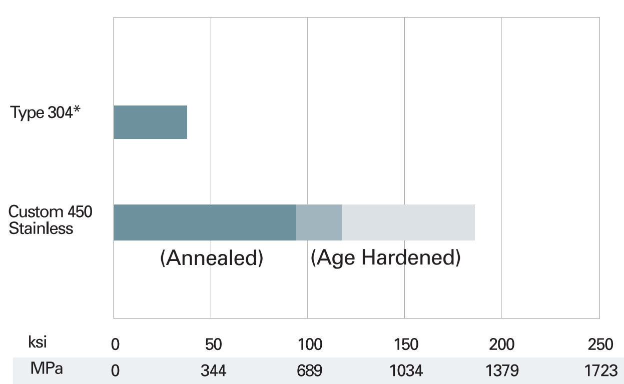
Like Custom 455 stainless, Custom 450 stainless may be strengthened by an age-hardening mechanism to achieve high strength. The yield strength of Custom 450 stainless can be increased 50% through a simple, one-step, low-temperature aging process—without significantly decreasing the alloy's corrosion resistance. In the solution-annealed condition, it can be machined, welded, and cold formed in the same manner as other stainless steels.

Custom 450 Stainless Mechanical Properties (Typical Room Temperature)

1 inch (25.4mm) round bar:

		Annealed Condition	Aged Hardened Conditioned (H900)
Yield Strength, 0.2%	ksi	118	188
	MPa	814	1296
Ultimate Tensile Strength	ksi	142	196
	MPa	979	1351
Elongation in 4D, %		13	14
Reduction of Area, %		50	56
Rockwell C Hardness		28.0	42.5
Charpy V-Notch Impact Strength			
	ft-lbs	98	40
	J	133	54

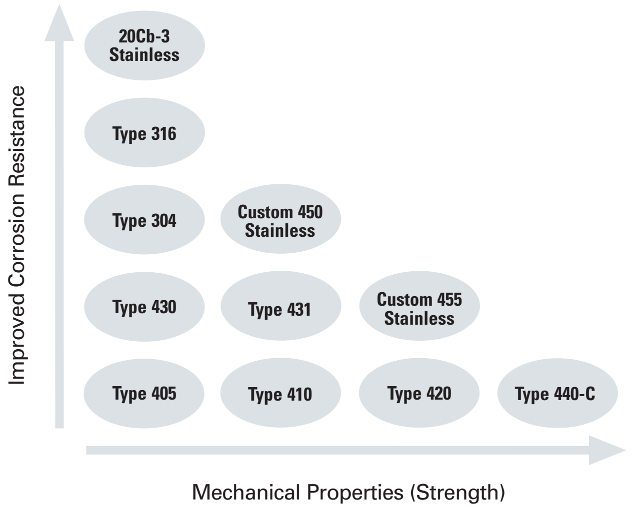
Custom 450 stainless exhibits excellent resistance to rusting and pitting in 5-20% salt spray at 95°F (35°C) and normal atmospheric and marine corrosion. Because this alloy combines the corrosion resistance of Type 304 with the strength of Type 410, it has been widely used for such applications as pump shafts and fluid ends, valve shafts, and bodies, tubing, fasteners, and countless other possible applications utilizing the excellent combination of corrosion resistance and high strength.



Yield Strength

* Note: Type 304 can be cold worked to higher strength levels, but only in small sections.

Fabrication



After making your selection according to resistance to corrosion and mechanical properties, fabrication—the third most important selection variable—should be considered. Each of the 11 basic grades shown on the diagram is representative of a group or family of closely allied alloys having equivalent corrosion resistance and strength levels.

These many variations and modifications of the 11 basic stainless alloys offer improved fabrication properties. In turn, each modification is given a different name or Type number dependent upon its chemical analysis. The entire stainless alloy family continues to grow because of variations to improve important fabrication qualities within the basic 11 alloy groups.

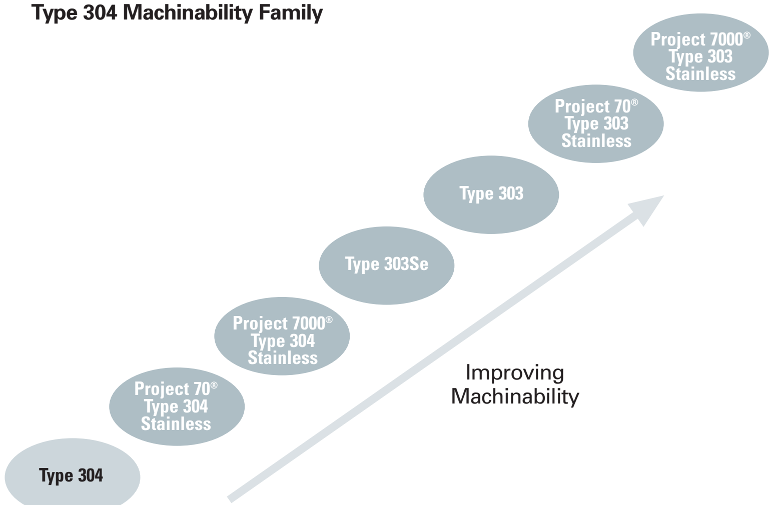
This is why there are so many different stainless alloys. In most cases, the 11 listed alloys are the most common and versatile stainless of the groups they represent. This may best be demonstrated through examples.

A good example is our basic and most popular stainless grade—Type 304. Suppose Type 304 was our choice for the best combination of corrosion resistance and strength. The next question to answer is how will the part be fabricated. Will it be machined, forged, welded, cold headed, etc.?

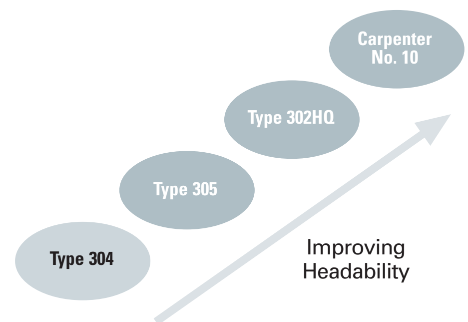
Suppose that you have a difficult machining problem. As you can see by the **Type 304 Machinability Family Chart,** there are enhanced machining alloys related to Type 304 with about the same corrosion-resistant characteristics and approximately the same mechanical properties.

As you move up and to the right, you see that Project 70® stainless Type 304 and Project 7000® stainless Type 304 are easier to machine than standard Type 304. Type 303Se and Type 303 are further improvements and Project 70 stainless Type 303 and Project 7000 stainless Type 303 possess the highest degree of machinability at this particular strength and corrosion resistance.

Type 304 Machinability Family



Type 304 Cold Heading Family



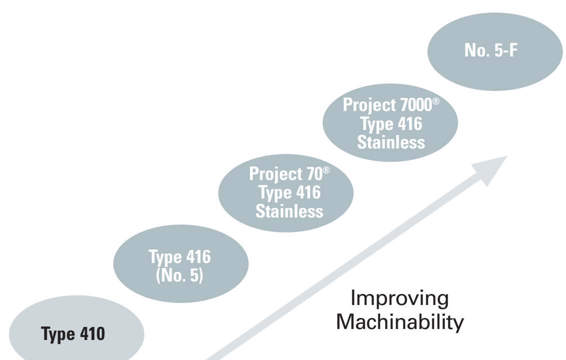
On the other hand, if the primary concern were to cold head the material, refer to the **Type 304 Headability Family Chart.**

Moving in the direction of better cold headability, we find Type 305 is an improvement over the basic Type 304, and Type 302HQ is even easier to cold head. No. 10 (Type 384) is the easiest stainless grade to head at that combination of corrosion and mechanical strength.

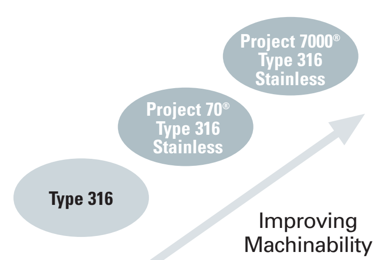
Choosing a stainless grade according to the necessary fabrication qualities is a matter of selecting a modification or refinement of one of the basic 11 alloys. In effect, you are moving about within the basic fabrication families searching for a suitable alloy modification. As you move away from the basic alloy (Type 304) towards the ultimate in a particular fabrication family, there is a tendency to lose certain other fabrication qualities. For instance, in moving towards better machinability, the alloy somewhat loses its ability to be cold worked.

The charts for the **Type 410 Machinability Family** and **Type 316 Machinability Family** can be used in the same manner.

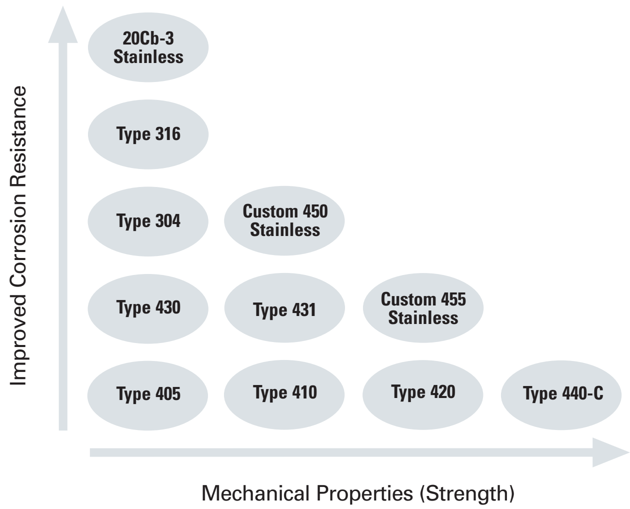
Type 410 Machinability Family



Type 316 Machinability Family



Review and Application of the Selectaloy Method



The Carpenter Selectaloy Method is a simple two-step selection system.

Step 1 — Select the level of corrosion resistance required.

Step 2 — Then select level of strength. These two determine the alloy.

Review

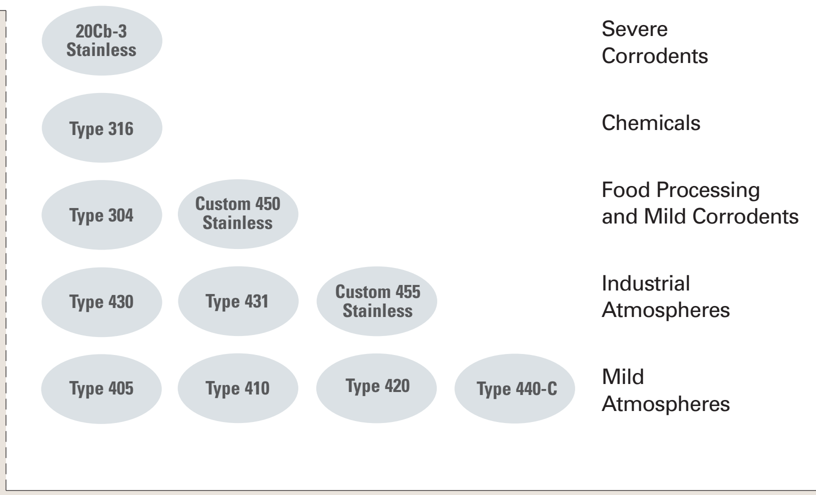
The Selectaloy method utilizes 11 basic stainless alloys. The first five alloys: 20Cb-3 stainless, Types 316, 304, 430, and 405 are plotted vertically and are placed in order of resistance to corrosion, the most important criterion in choosing stainless grade. 20Cb-3 stainless is the most corrosion resistant of the steels listed. Type 405 has the least resistance to corrosion with Type 304 midway between them on the corrosion scale.

Reading across the lowest level of corrosion, the representative alloys increase in strength as you move away from Type 405. Simple additions of carbon plus chromium increase the strength of Types 410, 420, and 440-C while maintaining corrosion resistance.

Although different in resistance to corrosion, the representative alloys 20Cb-3 stainless, Types 316, 304, 430, and 405 are of similar mechanical strength. Types 405, 410, 420, and 440-C differ in mechanical strength but have generally similar corrosion resistance.

Since corrosion resistance is read vertically and strength is calculated horizontally, it can easily be seen that Type 431 is stronger than Type 430 and similar in corrosion resistance; weaker than Type 420 with a greater resistance to corrosion. Type 431 is strengthened by the same simple mechanism used for Types 410, 420, and 440-C, that is, by adding carbon to the analysis.

Representative alloys Custom 455 stainless and Custom 450 stainless also follow the chart projection, being more corrosion resistant than those alloys below them on the scale and stronger than those alloys to their left. Neither Custom 455 stainless nor Custom 450 stainless is strengthened by the simple addition of carbon, but instead, achieve high strength and hardness levels through age hardening.



Using the diagram to select the proper alloy for your application

Of the 11 representative stainless alloys used in the Selectaloy Method Type 304 is the basic reference alloy. Since Type 304 and its modifications lend themselves to so many practical uses and are used in up to 50% of all stainless alloy applications, it should generally be used as the starting point when attempting to determine the optimal grade for a specific application.

In selecting a stainless alloy, ask yourself, "Can I use Type 304 with its specialty properties of corrosion resistance and strength?" If the answer is "no," you should investigate one of the other basic 11 alloys.

Remember, resistance to corrosion is the primary reason for choosing a stainless alloy. Every time you use the 11-alloy Selectaloy projection, therefore, you should first determine the level of corrosion resistance required before considering strength. While an article's strength may be a function of either mechanical strength, physical size, or both, there is no substitute for adequate corrosion resistance.

Once the level of corrosion resistance is ascertained, you can then look to the right as far as possible for the required strength. With experience you will be able to mentally jump back and forth, up and down in making your selection.

For example, moving up to Type 316 from Type 304 increases the corrosion resistance while maintaining the same strength level. A move over to Custom 450 stainless from Type 304 increases the strength while maintaining the corrosion resistance.

If a lower level of corrosion resistance is required—but with increased strength—you would move down to Type 430 or Type 405 depending upon the level desired, then move right to obtain the necessary strength.

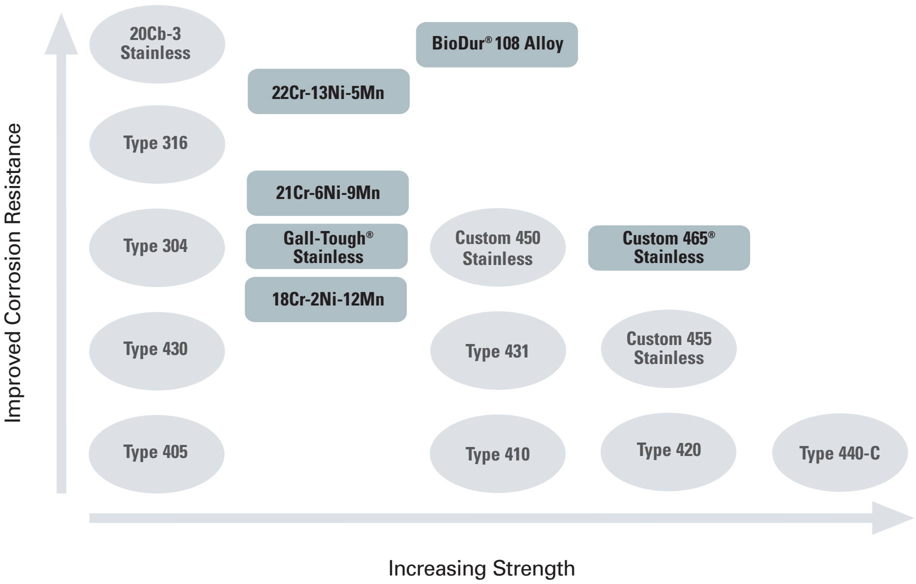
Selecting the proper representative alloy for your particular application becomes very simple if you remember the following:

1. Move up for higher corrosion resistance.
2. Move right for increased alloy strength.

Accurate alloy selection is arrived at using these two primary factors. One of the 11 basic grades shown on the Selectaloy projection will generally offer the best combination of properties for your application. In many cases, once you have found this combination, your selection is complete—you have found the stainless grade that should handle the service requirements. While one of the basic 11 grades will be the right alloy type for your application, you may want to improve fabrication characteristics by selecting different modifications of the basic Selectaloy stainless grades (see pages 18 and 19).

Specialized Alloys to Consider

Enhanced Selectaloy Diagram



To 50 ksi/	To 70 ksi/	To 175 ksi/	To 250 ksi/	Over 250 ksi/
345 MPa	482 MPa	1207 MPa	1724 MPa	1724 MPa

WHEN SEEKING GREATER STRENGTH WITH GOOD CORROSION RESISTANCE, THE SPECIFIER SHOULD CHECK THE FAMILY OF NITROGEN-STRENGTHENED AND OTHER ALLOYS SHOWN IN THE MODIFIED SELECTALOY DIAGRAM.

Nitrogen Strengthened Grades

Many applications require a balanced combination of improved strength and corrosion resistance. When seeking greater strength with good corrosion resistance, the specifier should check the family of nitrogen-strengthened alloys in the **Enhanced Selectaloy Diagram** shown on the left. The four alloys in the second column have comparable mechanical properties, with yield strength of 50 ksi (345 MPa) to 70 ksi (482 MPa) as annealed, and tensile strength levels in excess of 100 ksi (689 MPa) when cold worked.

A new nitrogen strengthened grade, BioDur® 108 alloy, discussed in the following "Other Grades to Consider" section, has an annealed yield strength in excess of 85 ksi (586 MPa) with a tensile strength in excess of 130 ksi (896 MPa).

These alloys are austenitic stainless grades with nitrogen added for improved strength and corrosion resistance. All of them, except Gall-Tough® stainless, remain nonmagnetic even after severe cold working.

The group starts with18Cr-2Ni-12Mn stainless, which has corrosion resistance similar to Type 430 stainless. It offers an excellent combination of toughness, ductility, corrosion resistance, strength and good fabricability. Farther up the scale are Gall-Tough stainless and 21Cr-6Ni-9Mn stainless. These two grades have corrosion resistance similar to that of Type 304 stainless with twice the yield strength and excellent high temperature strength.

Gall-Tough stainless, which is resistant to galling, may be considered for applications such as valve and pump components, shafts, bridge pins, fasteners, wire and orthodontic parts. 21Cr-6Ni-9Mn stainless has been used generally for airframe and aircraft engine parts, steam and autoclave components, parts exposed to reciprocating engine exhausts, etc.

The most corrosion resistant stainless in this family is 22Cr-13Ni-5Mn stainless. This alloy has better corrosion resistance than Type 316 stainless, and twice the yield strength. It provides high level resistance to pitting and crevice corrosion and very good resistance in many reducing and oxidizing acids and chlorides.

Other Grades to Consider

Custom 465® stainless is a premium melted, martensitic, age hardenable alloy capable of about 260 ksi (1793 MPa) ultimate tensile strength when peak aged. The alloy was designed to have excellent notch tensile strength and fracture toughness in this condition.

Overaging provides a superior combination of strength, toughness and stress corrosion cracking resistance compared with other high strength precipitation hardenable stainless alloys such as Custom 455 stainless or PH 13-8 Mo* stainless.

This alloy should be considered for medical instruments such as screwdrivers, nut drivers, and instruments for clamping, spreading and impacting; for a variety of aerospace applications including aircraft landing gear, engine mounts, flap tracts, actuators, tail hooks and other structural components; also for shafting subject to heavy stress, bolts, fasteners and other parts requiring an exceptional combination of high strength, toughness and corrosion resistance.

**PH 13-8 Mo stainless is a registered trademark of Armco Inc.*

BioDur 108 alloy is a fully austenitic stainless steel with less than 0.05% nickel that has been designed as a candidate to meet high standards for bio-compatibility in medical applications. Tests for cytotoxicity, irritation, acute systemic toxicity and pyrogenicity have indicated that the alloy is a good candidate for implanted medical devices.

High nitrogen content gives this alloy improved levels of tensile and fatigue strength as compared with nickel-containing alloys such as BioDur 22Cr-13Ni-5Mn alloy and BioDur 734 alloy. The resistance of BioDur 108 alloy to pitting and crevice resistance is superior to Type 316L alloy and equal to that of BioDur 22Cr-13Ni-5Mn alloy and BioDur 734 alloy. The new alloy is produced by the ElectroSlag Remelting (ESR) process to assure its microstructural integrity and cleanness.

BioDur 108 alloy should be considered for use in applications requiring high levels of strength and corrosion resistance. Candidate applications include implantable orthopedic devices such as bone plates, bone screws, spinal fixation components, hip and knee components, jewelry, orthodontic applications and other medical components/instruments fabricated by forging and machining.

Type Analysis of 22Cr-13Ni-5Mn:

Carbon	0.06% max.	Nickel	11.50/13.50%
Manganese	4.00/6.00%	Molybdenum	1.50/3.00%
Silicon	1.00% max.	Columbium	0.10/0.30%
Phosphorus	0.040% max.	Vanadium	0.10/0.30%
Sulfur	0.030% max.	Nitrogen	0.20/0.40%
Chromium	20.50/23.50%		

Type Analysis of 21Cr-6Ni-9Mn:

Carbon	0.03% max.	Sulfur	0.030 % max.
Manganese	8.00/10.00%	Chromium	19.00/21.50%
Silicon	1.00% max.	Nickel	5.50/7.50%
Phosphorus	0.040% max.	Nitrogen	0.15/0.40%

Type Analysis of Gall-Tough® Stainless:

Carbon	0.15% max.	Chromium	15.00/18.00%
Manganese	4.00/6.00%	Nickel	4.00/6.00%
Phosphorus	0.040% max.	Nitrogen	0.08/0.20%
Sulfur	0.040% max.	Iron	Balance
Silicon	3.00/4.00%		

Type Analysis of 18Cr-2Ni-12Mn:

Carbon	0.15% max.	Sulfur	0.030% max.
Manganese	11.00/14.00%	Chromium	16.50/19.00%
Silicon	1.00% max.	Nickel	0.50/2.50%
Phosphorus	0.060% max.	Nitrogen	0.20/0.45%

Type Analysis of Custom 465® Stainless:

Carbon	0.02% max.	Chromium	11.00/12.50%
Manganese	0.25% max.	Nickel	10.75/11.25%
Phosphorus	0.015% max.	Titanium	1.50/1.80%
Sulfur	0.010% max.	Molybdenum	0.75/1.25%
Silicon	0.25% max.		

Type Analysis of BioDur® 108 Alloy:

Carbon	0.08% max.	Nickel*	0.10% max.
Manganese	21.00/24.00%	Molybdenum	0.50/1.50%
Silicon	0.75% max.	Copper	0.25% max.
Phosphorus	0.030% max.	Nitrogen	>0.90%
Sulfur	0.010% max.	Iron	Balance
Chromium	19.00/23.00%		

*0.05% max. nickel available upon request

Cost and Availability

Finally, consider the cost and availability selection criteria to arrive at a true overall picture of the factors involved.

Cost

Generally, the total cost of a stainless alloy is determined by the number and amount of alloying elements used, the fabrication steps necessary, the installed cost of the finished product and its expected service life.

Product Availability

Many of Carpenter's Selectaloy grades may be quickly available from service centers in the quantity, size, and shape you need. Alloys that may not be stocked are available through direct mill ordering, with corresponding lead time. Alloys which are ordered to special finishes, tolerances, and shapes require the most lead time for delivery.

Sales and Service/ Technical Support

For immediate information on availability and delivery of our full line of specialty alloys, call **1-800-654-6543.**

Technical support through our regional metallurgists and application engineers is also available through Carpenter Service Centers, when required. For International service, refer to the service centers listing on the back cover.

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