DESIGNER

HANDBOOK

STAINLESS STEEL FOR MACHINING

Stainless Steel

The Value Option®

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ACKNOWLEDGEMENT

In reissuing this booklet, the Specialty Steel Industry of North America (SSINA) wishes to acknowledge that the contents were prepared by the Committee of Stainless Steel Producers, American Iron and Steel Institute. SSINA stainless steel producers were represented on this Committee. A number of member companies of the SSINA have reviewed this data and believe it to reflect an accurate representation of current stainless machining information on generic grades.

NOTE: Several stainless steel producers market proprietary or trademarked grades for improved machinability. These grades are not included in this handbook.

PREFACE

Reference to stainless steel is often made in the singular sense as if it were one material. Actually there are approximately 150 separate and distinct compositions, each one formulated to serve specific end-use and/or manufacturing requirements.

Stainless steels are only one segment of the steel spectrum, but they serve a multitude of applications from brightly polished consumer products to machinery and equipment for tough industrial environments. The variety of stainless steels available today provides a wide variety of properties, from specially formulated alloys capable of performing in the most difficult environments to a selection of types ideally suited for machining or other fabrication operations.

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WHY UPGRADE TO STAINLESS STEELS?

Upgrading to stainless steels rewards both manufacturer and user. Among the more obvious benefits are:

Corrosion and Heat Resistance — Stainless steels, depending upon the composition, resist corrosion by many acids, moisture, atmospheric conditions, and other aggressive environments at low or high temperatures.

Strength — Parts often can be made stronger and tougher with stainless steels than with mild steels or nonferrous metals . . . including parts exposed either to high temperatures or to hundreds of degrees below freezing.

Durability — The combined qualities of corrosion resistance and strength result in products capable of providing a lifetime of useful, trouble-free service. Accordingly, manufacturers' reputations are enhanced by products made of stainless.

Low Maintenance — Homeowners and industrial users alike prefer stainless steels because there is no need for protective coatings or other special surface treatments that can deteriorate or necessitate periodic maintenance.

Appearance — Whether a product is highly polished or just routinely made on a screw machine to a 63 RMS as-machined finish, its surface presents an enduring bright, metallic lustre.

Fabrication Flexibility — Stainless steels can be machined, cold formed, forged, extruded, or welded by contemporary fabricating tools and techniques. Designers will find among the stainless steels, properties capable of meeting a wide range of manufacturing and end-use requirements.

SELECTING A STAINLESS STEEL

Early uses of stainless steels were limited to such applications as gun barrels, cutlery, and nitric acid tanks. As industry began to exploit the full potential of these corrosion resistant metals, new compositions were developed to accommodate requirements for greater resistance to corrosion, greater strength levels, different fabricating characteristics, resistance to elevated temperature, etc.

For example, Type 304, one of the most frequently used stainless steel compositions having application in a broad range of products from cookware to chemical plant equipment, has several variations. For greater resistance to corrosion, especially in marine environments, specifiers often select Type 316, which has a higher alloy content than Type 304. Type 305, on the other hand, has a lower work-hardening rate than Type 304 and is better suited to cold forming operations, while Type 303 is the more machinable variation of Type 304.

Selection of the proper stainless steel from the many types available requires an evaluation based upon four important criteria. Listed in order of importance, they are:

Corrosion or Heat Resistance — the primary reason for specifying stainless steel. The specifier needs to know the nature of the environment and the degree of corrosion or heat resistance required.

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.

Fabrication Operations — and how the product is to be made is a third-level consideration. This includes machining, forming, welding, etc. For parts requiring more than one fabrication operation, the most difficult usually takes precedence.

Total Cost* — To put everything into proper perspective, a total value analysis is appropriate which will consider not only material and production costs, but the cost-saving benefits of a maintenance-free product having a long life expectancy as well.

With respect to machining, this handbook helps to explain the differences between stainless steels and other metals, and the differences from one stainless steel to another. It identifies the stainless steel types that were developed to improve machining production, and it demonstrates that stainless steels are readily machinable . . . even on high-volume, high-speed automatic screw machines.

* The Specalty Steel Industry of North America (SSINA) has a software program available called Life Cycle Costing For Stainless Steel. Contact the SSINA for information on this program.

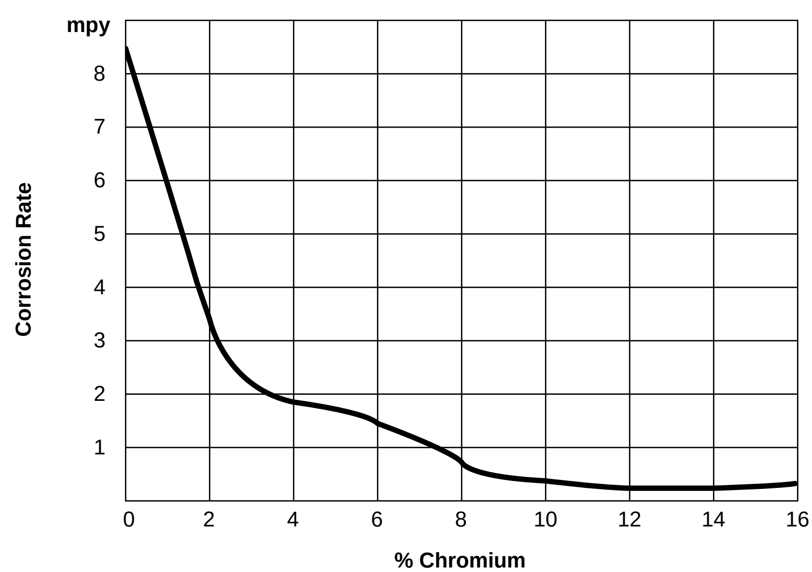
INTRODUCTION TO STAINLESS STEELS

Stainless steels are iron-base alloys containing 10.5 percent or more chromium. Chromium is the alloying element that imparts to stainless steels their corrosion-resistance qualities. It does this by combining with oxygen to form a thin, transparent chromium-oxide protective film on the metal surface (Figure1).

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

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.

Figure 1
Effect of Chromium Content on Corrosion Rate
(In Normal Atmosphere)



Other alloying elements may be added during melting, such as nickel, molybdenum, columbium, or titanium, which serve to change or enhance certain properties or characteristics.

IDENTIFICATION

Several methods are commonly used to identify stainless steels. They are:

1. Classification by metallurgical structure — austenitic, ferritic, martensitic, precipitation hardening, or duplex
2. The AISI numbering system — namely 200, 300, and 400 series numbers
3. The Unified Numbering System, which ASTM and SAE developed to apply to all commerical metals and alloys
4. Trade names — which are generally used with proprietary or special analysis stainless steels (Note: These are not included in this handbook)

METALLURGICAL STRUCTURE

The five categories of stainless steel according to metallurgical structure are:

1. Austenitic
2. Ferritic
3. Martensitic
4. Precipitation Hardening
5. Duplex

Following is a characterization of each group and identification of the typical stainless steel(s) in each. Understanding the characteristics of each category is basic to a better understanding of all stainless steels.

Austenitic stainless steels are those containing chromium, nickel and manganese or just chromium and nickel as the principal alloying elements. They are identified as AISI 200 series or 300 series types, respectively.

The austenitic stainless steels can be hardened only by cold working; heat treatment serves only to soften them. In the annealed condition, they are not attracted to a magnet although some may become slightly magnetic after cold working.

The 200 and 300 series stainless steels are characterized as having excellent corrosion resistance, unusually good formability, and the ability to develop excellent strength characteristics by cold working. Annealed, they possess maximum corrosion resistance, ductility, good yield and tensile strength, high impact strength, and freedom from notch effect.

Typical of this group is Type 304, also widely known as 18-8 stainless steel (which refers to 18 percent chromium, 8 percent nickel). It is a general-purpose stainless of which there are numerous modifications. In these variations,

1. The chromium/nickel ratio is modified to change the cold forming characteristics such as in Types 301 and 305.
2. The carbon content is decreased to prevent carbide precipitation in weldments such as in Types 304L and 316L.
3. Columbium or titanium can be added to stabilize the structure for service at high temperature such as in Types 347 and 321. They also serve to prevent carbide precipitation during welding.
4. Molybdenum is added or the chromium and nickel contents increased to improve corrosion or oxidation resistance such as in Types 316 and 317, with molybdenum, and Types 309 and 310 with higher alloy content.
5. Sulfur is adjusted to improve machining characteristics such as in Type 303. (The use of selenium to enhance machining characteristics has, for the most part, been discontinued. Type 303 Se, however, is still produced.)
6. Calcium additions are sometimes used to improve machinability, particularly deep hole drilling characteristics.
7. Nitrogen content is increased to enhance strength characteristics such as in Types 304N and 316N.
8. The 200 series stainless steels, namely Types 201, 202, 203, and 205, are counterparts to the 300 series Types 301, 302, 303, and 305. In the 200 series manganese replaces some of the nickel.

Ferritic stainless steels are straight-chromium types identified by 400 series numbers. The low carbon-to-chromium ratio in the ferritics eliminates effects of thermal transformation, which simply means that they are not hardenable by heat treatment. (They can be hardened slightly by cold working, however.)

The ferritic 400 series stainless steels are strongly attracted to a magnet, have good ductility, and have good resistance to corrosion and oxidation. The corrosion resistance of ferritic stainless steels is improved by increased chromium and molybdenum contents, while ductility, toughness, and weldability are improved by reducing carbon and nitrogen contents. The base composition is Type 430, with nominally 17 percent chromium. The free-machining ferritic is Type 430F.

There are several new ferritic stainless steels with improved characteristics, which can be classified as follows; those with about 18 percent chromium having corrosion resistance similar to Type 304, such as Type 444, and those with more than 18 percent chromium with resistance to corrosion comparable or superior to Type 316 in many media.

Martensitic stainless steels are also straight-chromium types bearing AISI 400 series numbers, but having a carbon-to-chromium ratio higher than the ferritic group. Consequently, when cooled rapidly from high temperature, they do harden, and in some cases to tensile strengths exceeding 200,000 psi.

The martensitic 400 series types resist corrosion in mild environments (atmosphere, fresh water, weak acids, etc.); they have fairly good ductility; and they are always strongly magnetic. Typical of the martensitic grades is Type 410 with 12 percent chromium. Some of the martensitics have been modified to improve machinability, such as Types 416, 420F and 440F.

Precipitation Hardening. As just noted, cold working of the austenitics and rapid cooling from high temperature of the martensitics are two methods for increasing strength and hardness of stainless steels. In precipitation hardening stainless steels tensile and yield strengths (in some cases exceeding 300,000 psi) can be achieved by a low-temperature (about 900F) aging treatment in combination with cold working.

The precipitation hardening stainless steels are especially useful because fabrication can be completed in an “annealed” condition and then the component uniformly hardened without the requirement of cold working or the necessity of dealing with the problems of distortion and heavy scaling associated with high temperature thermal treatments.

Typical of the precipitation hardening grades, identified by UNS numbers (which also serve as AISI numbers), are Types S13800, S15500, S17400 and S17700.

Prior to hardening, the machinability of the precipitation hardening stainless steels is about equal to or slightly less than Type 304 in the annealed condition. For example, Type S17700 has a machinability rating of 45, in comparison to Type 416 stainless steel at 100 percent. The corrosion resistance of these steels in the hardened condition is about equal to that of Type 304.

Duplex stainless steels are dual phase materials with austenite and ferrite in a close to 50-50 balance. Typical characteristics include excellent strength and corrosion resistance and good fabrication properties, especially the nitrogen containing grades.

Type 329 is a duplex stainless steel that contains 26 percent chromium, which gives it good resistance in chloride environments. The newer duplex materials with nitrogen (S31803 and S32550) are readily weldable, which frequently was a problem with Type 329. They are used extensively in oil and gas production and chemical processing.

Table I lists the standard and enhanced machinability types of stainless steel.

Table I TABLE 1 LISTS THE STANDARD AND ENHANCED MACHINABILITY TYPES OF STAINLESS STEEL				
Metallurgical Standard			Enhanced Machinability	
Type	Type	UNS No.	Type	UNS No.
Austenitic	304	S30400	303	S30300
	304	S30400	303Se	S30323
	—	—	203	S20300
	304	S30400	304Ca	—
	316	S31600	316F	S31620
Ferritic	430	S43000	430F	S43020
Martensitic	410	S41600	416	S41600
	420	S42000	420F	S42020
	440C	S44004	440F	S44020

MATERIAL SELECTION FOR CORROSIVE ENVIRONMENTS

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

One of the three most widely used stainless steels (Type 304, 430, or 410) is a good starting point in the selection process, because these types are the most readily available.

Type 304 serves a wide range of applications. It withstands ordinary rusting in architecture, it is strongly resistant in 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 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, 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 percent 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 percent molybdenum and more chromium than Type 316 for even better resistance to pitting.

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.

Note: The Specialty Steel Industry of North America (SSINA) has a handbook on the "*Selection and Use of Stainless Steel*" with details on corrosion resistance, chemical and mechanical properties, high and low temperature properties and other information. Contact the SSINA for information on how to obtain a copy of this handbook.

CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES

Table II lists the chemical composition and the mechanical properties of the standard enhanced machinability types. A complete listing of all types is available in the SSINA Handbook "*Selection and Use of Stainless Steel.*"

Table III shows the physical properties of the standard and enhanced machinability types.

GENERAL GUIDELINES

The characteristics of stainless steels that have a large influence on machinability include:

- Relatively high tensile strength
- High work-hardening rate, particularly for the austenitic alloys
- High ductility

These factors explain the tendency of the material to form a built-up edge on the tool during traditional machining operations. The chips removed in machining exert high pressures on the nose of the tool; these pressures, when combined with the high temperature at the chip/tool interface, cause pressure welding of portions of the chip to the tool. In addition, the low thermal conductivity of stainless steels contributes to a continuing heat buildup.

The difficulties involved in the traditional machining of stainless steels can be minimized by observing the following points:

- Because more power is generally required to machine stainless steels, equipment should be used only up to about 75% of the rating for carbon steels
- To avoid chatter, tooling and fixtures must be as rigid as possible. Overhang or protrusion of either the workpiece or the tool must be minimized. This applies to turning tools, drills, reamers, and so on
- To avoid glazed, work-hardened surfaces, particularly with austenitic alloys, a positive feed must be maintained. In some cases, increasing the feed and reducing the speed may be necessary. Dwelling, interrupted cuts, or a succession of thin cuts should be avoided
- Lower cutting speeds may be necessary, particularly for nonfree-machining austenitic alloys, precipitation-hardenable stainless steels, or higher-hardness martensitic alloys. Excessive cutting speeds result in tool wear or tool failure and shutdown for tool regrinding or replacement. Slower speeds with longer tool life are often the answer to higher output and lower costs
- Tools, both high-speed steel and carbides, must be kept sharp, with a fine finish to minimize friction with the chip. A sharp cutting edge produces the best surface finish and provides the longest tool life. To produce the best cutting edge on high-speed steel tools, 60-grit roughing should be followed by 120- and 150-grit finishing. Honing produces an even finer finish
- Cutting fluids must be selected or modified to provide proper lubrication and heat removal. Fluids must be carefully directed to the cutting area at a sufficient flow rate to prevent overheating

For additional information contact the companies listed as bar producers on the back cover.

Also refer to the American Society for Metals (ASM) publication: *"Machining of Stainless Steel."*

Table II
STAINLESS STEELS CHEMICAL COMPOSITIONS AND MECHANICAL PROPERTIES

	Chemical Analysis % (Max. unless noted otherwise)									Mechanical Properties (Annealed bar unless noted otherwise)			
AISI Type (UNS No.)	**C**	**Mn**	**P**	**S**	**Si**	**Cr**	**Ni**	**Mo**	**Other**	**Tensile Strength ksi, min.**	**Yield Strength (0.2% offset) ksi, min.**	**Elongation in 2" (50.80mm) %, min.**	**Hardness (Rockwell) max.**
Austenitic													
203 (S20300)	0.08	5.00/ 6.50	0.040	0.18/ 0.35	1.00	16.00/ 19.00	5.00/ 6.50	0.50	1.75/ 2.25 Cu	75	30	40	262 (Brinell)
303 (S30300)	0.15	2.00	0.20	0.15 (min)	1.00	17.00/ 19.00	8.00/ 10.00			75	30	35	262 (Brinell)
303Se (S30323)	0.15	2.00	0.20	0.060	1.00	17.00/ 19.00	8.00/ 10.00		0.15 (min) Se	75	30	35	262 (Brinell)
304 (S30400)	0.08	2.00	0.045	0.030	0.75	18.00/ 20.00	8.00/ 10.50		0.10 N	75 (125)[a]	30 (100)[a]	40 (10)[a]	
316 (S31600)	0.08	2.00	0.045	0.030	0.75	16.00/ 18.00	10.00/ 14.00	2.00/ 3.00	0.10 N	75 (125)[a]	30 (100)[a]	40 (12)[a]	
316H (S31609)	0.04/ 0.10	2.00	0.045	0.030	0.75	16.00/ 18.00	10.00/ 14.00	2.00/ 3.00		75	30	40	
316F (S31620)	0.08	2.00	0.20	0.10 (min)	1.00	16.00/ 18.00	10.00/ 14.00	1.75/ 2.50		75	30	40	262 (Brinell)
Ferritic													
430 (S43000)	0.12	1.00	0.040	0.030	1.00	16.00/ 18.00	0.75			70	40	20	
430F (S43020)	0.12	1.25	0.060	0.15 (min)	1.00	16.00/ 18.00				70	40	20	262 (Brinell)
Martensitic													
416 (S41600)	0.15	1.25	0.060	0.15 (min)	1.00	12.00/ 14.00				75	40	22	262 (Brinell)
420 (S42000)	Over 0.15	1.00	0.040	0.030	1.00	12.00/ 14.00				75	40	25	241 (Brinell)
420F	Over	1.25	0.060	0.15	1.00	12.00/				75	40	22	262
440C (S44004)	0.95 (min)	1.25	0.40	0.030 (min)	1.00	16.00/ 18.00				110	65	14	262 (Brinell)
440F (S44020)	0.95 (min)	1.25	0.040	0.10 (min)	1.00	16.00/ 18.00				110	65	14	262 (Brinell)

Notes: Data are for information only and should not be used for design purposes. For design and specification, refer to appropriate ASTM specifications. Data were obtained from various sources, including AISI Steel Products Manuals, ASTM specifications, and individual company literature.
a = Cold finished, for sizes up to ¾ in. inclusive, A276 Condition B.

Table III
PHYSICAL PROPERTIES OF STAINLESS STEELS

Stainless Steel Type	Density Lb/Cu. In.	Modulus of Elasticity psi x 10^6	Specific Electrical Resistance at 68F Microhm-Cm	Specific Heat Btu/Lb/F 32-212F	Thermal Conductivity BTU/ft/hr/F (68-212F)	Mean Coefficient of Thermal Expansion, in/in/F x 10^{-6}					Magnetic Perme-ability max.	Annealing Tempera-ture
						32-212F	32-600F	32-1000F	32-1200F	32-1600F		
Austenitic												
203	0.29	28.0	74	—	9.5	9.4	—	—	—	11.6	1.02	1850-2050[a]
303	0.29	28.0[a]	72	0.12	9.4	9.6	9.9	10.2	10.4	—	(1.02)	1850-2050[a]
303Se	0.29	28.0[a]	72	0.12	9.4	9.6	9.9	10.2	10.4	—	(1.02)	1850-2050[a]
304	0.29	28.0[a]	72	0.12	9.4	9.6	9.9	10.2	10.4	11.0	1.02	1850-2050[a]
316	0.29	28.0[a]	74	0.12	9.4	8.9	9.0	9.7	10.3	(11.1) (32-1500F)	1.02	1850-2050[a]
316H	0.29	28.0[a]	74	0.12	9.4	8.9	9.0	9.7	10.3	(11.1) (32-1500F)	1.02	1850-2050[a]
316F	0.29	29.0	74	0.116	8.3	9.2	9.7	10.1	—	—	—	2000[a]
Ferritic												
430	0.28	29.0	60	0.11	13.8	5.8	6.1	6.3	6.6	6.9 (32-1500F)	—	1250-1400
430F	0.28	29.0	60	0.11	15.1	5.8	6.1	6.3	6.6	6.9	—	1250-1400[c]
Martensitic												
416	0.28	29.0	57	0.11	14.4	5.5	6.1	6.4	6.5	—	—	1500-1650[b] 1200-1400[c]
420	0.28	29.0	55	0.11	14.4	5.7	6.0	6.5	—	—	—	1550-1650[b] 1350-1450[c]
420F	0.28	29.0	55	0.11	14.5	5.7	—	—	—	—	—	1550-1650[b] 1350-1450[c]
440C	0.28	29.0	60	0.11	14.0	5.6	—	—	—	—	—	1550-1650[b]
440F	0.28	29.0	60	0.11	14.0	5.6	—	—	—	—	—	1350-1450[c]

a = Cool rapidly from these annealing temperatures.
b = Full annealing — cool slowly.
c = Process annealing.

THE MACHINABLE FAMILY OF STAINLESS STEELS

What is Machinability?

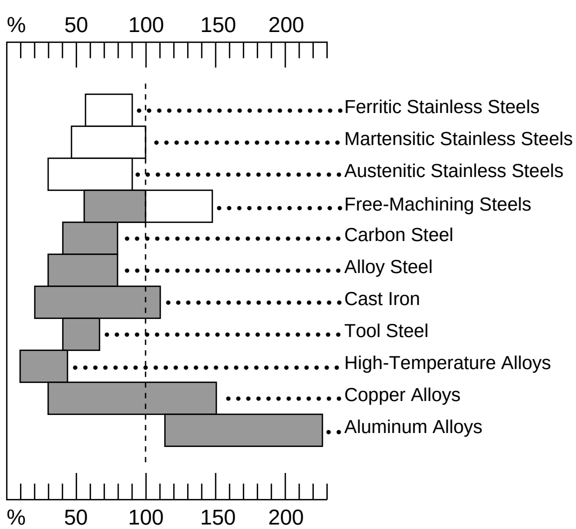
Machine shop operators have differing opinions as to what machinability really is. Some are interested only in the speed at which a material can be cut, others consider tool life at a reasonable speed to be most important, while others rate machinability on the surface finish produced. Obviously, all factors are important — cutting speed, tool life, and surface finish — and all are considered in rating the machinability of a metal.

The machinability of stainless steels is substantially different from that of carbon or alloy steels and other metals, as illustrated in the chart, "Comparative Machinability of Common Metals" (Figure 2). In varying degree, most standard stainless steels are somewhat more difficult to machine. That is why there are enhanced or free-machining stainless steel types.

In fact, stainless steels are routinely machined on high-production equipment. The best way to get maximum machinability, wherever end-use conditions permit, is to specify a free-machining stainless steel.

The 400 series stainless steels are the easiest to machine, but they do produce a stringy chip that can slow productivity. The 200 and 300 Series, on the other hand, are characterized as being the most difficult to machine, primarily because of their gumminess and, secondarily, because of their propensity to work harden at a very rapid rate. However, the difficulty is not so great as to be a deterrent to selecting a stainless steel for a machined part.

Figure 2
Comparative Machinability of Common Metals

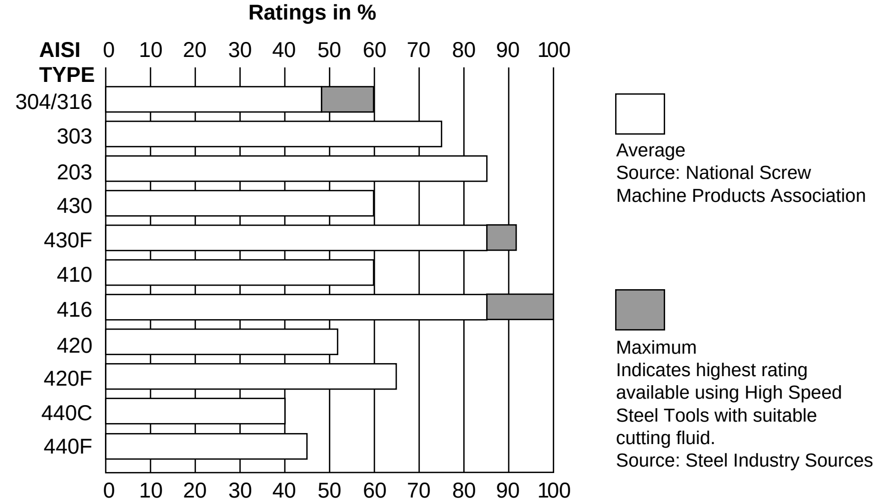


100% Type 416 Stainless Steel

Free-Machining Stainless Steels

Certain alloying elements in stainless steels, such as sulfur, selenium, lead, copper, aluminum, calcium, or phosphorus can be added or adjusted during melting to alter the machining characteristics. These alloying elements serve to reduce the friction between the workpiece and the tool thereby minimizing the tendency of the chip to weld to the tool. Also, sulfur forms inclusions that reduce the friction forces and transverse ductility of the chips, causing them to break off more readily. The improvement in machinability in the free-machining stainless steels — namely Types 303, 303 Se, 203, 430F, 416, and 420F — is clearly evident in the chart, "Comparative Machinability of Frequently Used Stainless Steels" (Figure 3).

Figure 3
Comparative Machinability of Frequently Used Stainless Steels and Their Free-Machining Counterparts



% based on 100% for AISI Type 416 free-machining Stainless Steel

Should a designer select Type 304 on the basis of corrosion resistance and strength but recognizes a need for the best possible machining rate, he may elect to use free-machining Type 303. The chromium, nickel, and sulfur contents of Type 303 are slightly different than that of Type 304, but its physical and mechanical properties are quite similar. Type 303 can be machined at speeds about 25-30 percent faster than Type 304.

Type 303 Se is a free-machining variation of Type 304 that contains selenium instead of sulfur. Type 303 Se is a better choice than Type 303 when a better machined surface finish is required or when cold working may be involved, such as staking, swaging, spinning, or severe thread rolling, in addition to machining.

Type 203 is an austenitic free-machining grade which is a modification of the 200 series stainless steels. Although it contains significant additions of manganese like the 200 series it also contains nickel and copper.

There are also free-machining alternatives to consider in the 400 series stainless steels. For instance, if end-use conditions call for Type 430 stainless, the specifier might select Type 430F. The composition of Type 430F is adjusted to enhance the machining characteristics while preserving to the extent possible the qualities of Type 430.

The free-machining variation of Type 410 is Type 416, and for Type 420, the specifier should consider Type 420F.

Specifiers should recognize that the alloying elements used to improve free-machining characteristics adversely affect corrosion resistance, transverse ductility, and other qualities, such as weldability. Free-machining stainless steels are normally not used if welding, cold forming or hot forging are to be done. However, the free-machining grades are often specified after evaluation as to their suitability for the intended corrosive environment in which they will serve. When they are specified, however, significantly higher production rates can be achieved.

There are other alternatives specifiers should consider, especially if there is concern over the use of a free-machining stainless steel. For example, composition of a stainless steel is often altered slightly by the producer to enhance certain fabrication characteristics, including machinability, but without changing other basic qualities. While the improvement may not be as great as with a "true" free-machining type, there is improvement.

Also, producers of stainless steel bar can provide a product that is in the best condition for machining. However, as experienced machinists know, the best condition for turning may not be the best condition for drilling, so specifiers are encouraged to discuss the machining application with a producer.

Other considerations for reduced machining are forgings or tubular products. Seamless or welded mechanical tubing is readily available in a broad range of compositions (carbon, alloy, and stainless steels), sizes and wall thicknesses — and shapes. Mechanical tubing for machining is often referred to as hollow bar.

Hollow bar is especially attractive for projects that require 30 percent or more metal removal from the center. Not only does hollow bar generally cost less per foot than solid bar of equal diameter (less cost because less weight), but it will require less machining, produce less scrap, improve cycle time, and allow more parts to be produced per hour.

Mechanical tubing is usually available from 1-inch diameter up to a 5-inch diameter. Check with suppliers for availability of sizes and shapes.

Rod and wire in coiled form are also available for coil-fed screw machines. Table IV describes the conditions and finishes in which stainless steel bars are normally available.

Table IV
CONDITIONS AND FINISHES FOR BAR

Conditions	Surface Finishes*
1. Hot worked only	(a) Scale not removed (excluding spot conditioning) (b) Rough turned** (c) Pickled or blast cleaned and pickled
2. Annealed or otherwise heat treated	(a) Scale not removed (excluding spot conditioning) (b) Rough turned (c) Pickled or blast cleaned and pickled (d) Cold drawn or cold rolled (e) Ground (f) Polished
3. Annealed and cold worked to high tensile strength***	(d) Cold drawn or cold rolled (e) Ground (f) Polished

* Surface finishes (b), (e) and (f) are applicable to round bars only.
** Bars of the 4XX series stainless steels which are highly hardenable, such as Types 414, 420, 420F, 431, 440A, 440B and 440C, are annealed before rough turning. Other hardenable grades, such as Types 403, 410, 416 and 416Se, may also require annealing depending on their composition and size.
*** Produced in Types 302, 303Se, 304 and 316.

Stainless Steels for Screw Machine Operations

Higher production rates are not the only benefits derived from the free-machining stainless steels. As shops become better acquainted with machining stainless steels they acquire confidence to use screw machines for increased productivity. This can be particularly important because many parts are being machined at higher cost than would be required to produce those same parts on automatic screw machines.

Low productivity can exist when the production department underestimates the practicality and feasibility of stainless steels for screw machine production. This situation will change as they become aware of the extreme versatility of the several types of automatic screw machines in use, and of the extreme versatility in stainless steel selection.

If the part meets the following six criteria, screw machining should be seriously considered for stainless steel:

1. The part to be produced should be in lots of 1,000 or more. This is more a function of time than number, however, and production runs should be at least as long as the set-up time.
2. Tolerances, in general, should be in the range of ±.001 inch.
3. The part has to be made from rod, bar, tubing, or hollow bar.
4. Turned or formed finishes in the range of 16 to 125 RMS should be acceptable.
5. Overall diameter of cross-section dimension should be between 1/64 inch and 8 inches.
6. Overall length of machined part is usually less than 10 stock diameters.

Machinability vs. Cost

Many factors influence the ratio of machinability to cost of screw machine products, including the choice of materials. Experience has clearly established that the "cheapest" material does not always yield the lowest cost. Metals having low machinability ratings require more frequent tool changing, longer downtime, and greater difficulty in maintaining good finish. This is particularly true when stainless steels are involved; machining costs tend to increase as machinability decreases. Accordingly, a stainless steel with improved machining characteristics is to be preferred. Even if there is a slight premium in the cost of such bar stock, it is generally more than offset by the resultant ease of machining.

When material specifications permit, it is to everyone's advantage to give the screw machine shop the opportunity to use a free-machining material.

GOOD SHOP PRACTICES

Of course, a good deal of success in machining and reducing production costs rests with the machine shop. Here are a few guidelines that may be useful when working with stainless steels:

1. Machine tools should be rigid, modern, and as much "overpowered" as possible. Best practice is to use the machine up to about 75 percent of its rated capacity.
2. The work-piece and tool should be held rigid. Tool overhang should be minimized and extra support used when necessary.
3. Tools, either high speed tool steels or carbide, should be kept sharp, preferably being sharpened at regular intervals rather than only when necessary.
4. A good lubricant is required, such as compounded sulfur-chlorinated mineral oil plus fatty oil for high-speed tools, and heavy duty emulsifiable oil for carbide tools.
5. Positive cuts are necessary. Care should be exercised to avoid dwelling so as not to work harden the material, especially the austenitic (300 Series) stainless steels.

PASSIVATION OF STAINLESS STEEL

On the surface of stainless steels there is an extremely thin transparent film. Nevertheless, it is tenacious, uniform, stable and passive. It imparts to the surface the property of passivity, normally associated with noble or inert metals and it is to this passive film that stainless steels owe their superior corrosion resistance.

The film will form spontaneously, or repair itself if damaged, both in air due to the presence of oxygen, or when immersed in solutions, provided there is sufficient oxygen or oxidizing elements present. The basic passivation treatment for stainless steel is exposure of a clean surface to air. However, there is much practical evidence which shows that passivity, and therefore corrosion resistance, is enhanced if the passive film is formed by the action of oxidizing acid solutions. Nitric acid is such an oxidizing acid, and is always used for passivation treatments. Nitric acid does not corrode stainless steel, does not alter critically dimensioned parts and will not remove heat tint, embedded iron or other embedded surface contamination. Nitric acid passivation is most useful in enhancing the corrosion resistance of freshly machined surfaces.

The standard nitric acid passivating solution is made up and used as follows:

10 to 15 percent by volume of nitric acid (HNO_3) in water. Quickest and best passivation results if used at 150°F for the austenitic (300 series) stainless steels, and 120°F for the ferritic and martensitic (400 series) plain chromium stainless steels. The immersion time is approximately 30 minutes, followed by thorough water washing.

CLEANING

Chemical cleaning is also important for the removal of "free-iron" from the machined surface. During machining, the stainless steel part can pick up minute particles of iron, which if not removed can form rust spots on the surface. These rust areas, which result from the cutting tool — not the stainless steel itself — can be prevented by immersing the finished part in a chemical solution.

The primary method of cleaning surfaces contaminated with embedded iron is nitric-HF pickling in 10% nitric 2% HF either warm or at ambient temperature.

For the stainless steel part to achieve maximum corrosion resistance, it should be cleaned to remove grease, oil, and fingerprints from the surface. The average shop degreasing solution is usually sufficient. Passivation in a 25-40% nitric acid solution is suggested for machined parts to remove microscopic particles of tooling, and to prevent staining.

THE FREE-MACHINING STAINLESS STEELS

TYPES 303 AND 303 Se STAINLESS STEELS		
Chemical Composition, Percent	**303**	**303 Se**
Carbon	0.15 Max.	0.15 Max.
Manganese	2.00 Max.	2.00 Max.
Phosphorus	0.20 Max.	0.20 Max.
Sulfur	0.15 Min.	0.060 Max.
Silicon	1.00 Max.	1.00 Max.
Chromium	17.00/19.00	17.00/19.00
Nickel	8.00/10.00	8.00/10.00
Selenium		0.15 Min.
Molybdenum	0.60 Max. (Optional)	

Description

Types 303 and 303 Se stainless steels are the free-machining variations of Type 304 (austenitic — 18Cr-8Ni) that are particularly well suited for screw machining operations. Their greatest benefit is higher productivity resulting from longer tool life and higher cutting speeds in comparison to Type 304.

Type 303 has wide application for shafting, valve bodies, valves, valve trim, fittings, etc. This stainless steel has desirable nongalling properties that make disassembly of parts easy — and help to prevent scratching or galling in moving parts.

Type 303 Se has applications similar to Type 303 except that it has slightly better corrosion resistance than Type 303 and better formability for applications involving hot or cold working operations.

Machining Characteristics

Types 303 and 303 Se stainless steels machine easily with a brittle chip. In turning operations they can be used at speeds of 102-130 surface feet per minute. Moderate cold working increases the machinability. Grinding and polishing operations can be very satisfactorily performed. In comparison to Type 416, their machinability rating average is 75 percent. Much higher speeds are possible if carbide tooling is used.

Corrosion Resistance

Types 303 and 303 Se stainless steels resist rusting from all normal atmospheric sources and are used in connection with sterilizing solutions, most of the organic chemicals and dyestuffs, and a wide variety of inorganic chemicals. They resist nitric acid well, the halogen acids poorly, and the sulfuric acids moderately.

For optimum corrosion resistance, all parts made of Types 303 or 303 Se should be entirely free from scale and foreign particles, such as iron particles picked up from tooling. It is suggested that after machining, all parts be cleaned and passivated. Also, if during fabrication, components are heated and cooled in the range of 800-1650F, a corrective thermal treatment is suggested to avoid chances of intergranular corrosion. Such a treatment consists of heating to about 1900F followed by quenching in water.

TYPE 203 STAINLESS STEEL	
Chemical Composition, Percent	**203**
Carbon	0.8 Max.
Manganese	5.00/6.50
Phosphorus	.04 Max.
Sulfur	.18/.35
Silicon	1.00 Max.
Chromium	16.00/18.00
Nickel	5.00/6.50
Molybdenum	.50 Max.
Copper	1.75/2.25

Description

Type 203 is an austenitic free-machining stainless steel containing higher levels of manganese in order to obtain maximum machining speeds. The grade is particularly suited for high production high volume automatic screw machine work. Machining speeds are somewhat higher than for Type 303.

Machining Characteristics

Type 203 stainless steel machines with chip characteristics similar to Type 303 but requires slightly higher machining speeds. Typical turning speeds are 125 to 155 surface feet per minute for high speed tools. Higher speeds are possible with carbide tooling. The machinability rating for this steel is about 85%.

Corrosion Resistance

The corrosion resistance of this grade is very similar to Type 303. It resists a wide variety of organic and inorganic compounds.

TYPE 430F STAINLESS STEEL	
Chemical Composition, Percent	**430F**
Carbon	0.12 Max.
Manganese	1.25 Max.
Phosphorus	0.060 Max.
Sulfur	0.15 Min.
Silicon	1.00 Max.
Chromium	16.00/18.00
Selenium	
Molybdenum	0.60 Max. (Optional)

Description

Type 430F stainless steel is suggested for faster cutting and reduced costs when making machined parts from a 16.00/18.00 percent straight-chromium stainless steel. Type 430F does not harden by heat treatment. It is used for parts requiring good corrosion resistance, such as solenoid valves, aircraft parts, gears, etc. Type 430F is not usually recommended for vessels containing gases or liquids under high pressure.

Machining Characteristics

Type 430F machines in turning operations at speeds of 124-155 surface feet per minute or at about the same as ASE 1120, 1030, etc.

Corrosion Resistance

Type 430F stainless steel is used to combat corrosion from atmosphere, fresh water, nitric acid, dairy products, etc. Parts must be entirely free from scale and foreign particles. As a final treatment, after the scale has been removed or after machining, all parts should be passivated.

TYPE 416 STAINLESS STEEL	
Chemical Composition, Percent	**416**
Carbon	0.15 Max.
Manganese	1.25 Max.
Phosphorus	0.060 Max.
Sulfur	0.15 Min.
Silicon	1.00 Max.
Chromium	12.00/14.00
Selenium	
Molybdenum	0.60 Max. (Optional)

Description

Type 416 is the most readily machinable of all stainless steels, and it is particularly well suited for good productivity on automatic screw machining operations because of the longer tool life that results. The uses for Type 416 are extensive and include fittings, gears, housings, lead screws, shafts, valve bodies, valve stems, and valve trim. In fact, this type is ideal for parts requiring considerable machining work. Its low frictional properties minimize galling in service. Threaded sections work freely without seizing, and disassembly is particularly easy. Pump shafts and valve stems work more smoothly in packing, and many metal-to-metal contacts withstand more pressure because of their anti-seizing characteristics.

Machining Characteristics

Type 416 stainless steel cuts very freely because of the sulfur content. In automatic screw machines Type 416 machines at about 165 surface feet per minute.

Corrosion Resistance

While not as corrosion resistant as an austenitic (300 series type) or Type 430F, Type 416 resists atmospheric environments, fresh water, mine water, steam, carbonic acid, gasoline, crude oil, blood, perspiration, alcohol, ammonia, soap, sugar solutions, etc. A high finish is helpful in providing optimum resistance to corrosion. It also resists scaling at elevated temperatures and can be used for continuous service up to about 1200F. (Maximum corrosion resistance is achieved in the heat treated condition.)

TYPE 420F STAINLESS STEEL	
Chemical Composition, Percent	**420F**
Carbon	0.15 Min.
Manganese	1.25 Max.
Phosphorus	0.060 Max.
Sulfur	0.15 Min.
Silicon	1.00 Max.
Chromium	12.00/14.00
Molybdenum	0.60 Max.

Description

Type 420F stainless steel is easy to machine, grind, and polish, and has certain anti-galling or nonseizing properties in service. It is used for parts made on automatic screw machines, such as valve trim, pump shafts, needle valves, ball check valves, gears, cams, pivots, etc. This free-machining hardenable steel is used mainly for machined parts requiring high hardness and good corrosion resistance.

Machining Characteristics

For automatic screw machines, Type 420F stainless steel machines like SAE 2315 and 2340. In single point turning operations employing heavy duty equipment, speeds of 90-110 surface feet per minute and feeds of 0.0008-0.0020 inch are suggested.

Corrosion Resistance

Since Type 420F stainless steel should always be used in the hardened condition for optimum corrosion resistance, surfaces must be free of all scale, which is achieved by pickling, or grinding and polishing. If pickled after hardening, the parts should be thoroughly baked at 250-300F for at least one hour to remove acid brittleness.

In the hardened condition, Type 420F stainless steel will resist corrosion from atmosphere, fresh water, mine water, steam, carbonic acid, crude oil, gasoline, blood, perspiration, alcohol, ammonia, mercury, sterilizing solutions, soap, etc. Passivation after machining is recommended. (It should be noted that Type 420F is not as resistant to corrosion as an austenitic grade or Type 430F.)