STAINLESS STEELS FOR MACHINING

A DESIGNERS' HANDBOOK SERIES
Nº 9011

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Originally, this handbook was published in 1985 by the Committee of Stainless Steel Producers, American Iron and Steel Institute.

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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 pro- ducts to machinery and equipment for tough industrial environments.

The variety of stainless steels available today provides a veritable palette of properties, from specially formulated alloys capable of per- forming in the most difficult environments to a wide selection of types ideally suited for machining or other fabrication operations.

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 temperature.

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 five 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.
Availability–The final step in the selection /specification process is to determine the availability of the candidate material(s). Depending on the quantity involved, an inquiry can be prepared and submitted to a steel service center or directly to a mill that produces stainless steel. (A list of producers participating in this booklet appears on the back cover.) Direct contact with one or more producers can be beneficial because possible alternative, lower-cost materials might be suggested.

Although selection is based primarily on the ability of the material to meet end-use requirements, specifiers and buyers should not overlook manufacturing, especially machining, which can be improved by material selection.

With respect to machining, this booklet 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 through illustrative examples that stainless steels are readily machinable . . . even on high-volume, high-speed automatic screw machines.

INTRODUCTION TO STAINLESS STEELS

Stainless steels are iron-base alloys containing 10.5 percent or more chromium. 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. Designation by the AISI numbering system–namely 200, 300, and 400 series numbers
3. Designation by the Unified Numbering System, which ASTM and SAE developed to apply to all commercial metals and alloys
4. Trade names–which are generally used with proprietary or special analysis stainless steels
5. Abbreviated composition

Table 1 lists all AISI-designated stainless steels, and it shows the corresponding UNS designation for each. Following is a discussion of how stainless steels are classified by metallurgical structure. While somewhat technical in nature, a basic knowledge of metallurgical classification is helpful because stainless steels in each category tend to have many common characteristics.

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.

Table 1
AISI AND UNS NUMBERS

AISI TYPE	*UNS NUMBER*	*AISI TYPE*	*UNS NUMBER*
	Austenitic		
201	S20100	310S	S31008
202	S20200	316	S31600
205	S20500	316H	S31609
301	S30100	316F	S31620
302	S30200	316L	S31603
302B	S30215	316LN	S31652
303	S30300	316N	S31651
303Se	S30323	317	S31700
304	S30400	317L	S31703
304H	S30409	321	S32100
304L	S30403	321H	S32109
304Cu	S30430	329	S32900
304LN	S30453	330	N08330
304N	S30451	332	S33200
305	S30500	334	S33400
308	S30800	347	S34700
309	S30900	347H	S34709
309S	S30908	348	S34800
310	S31000	348H	S34809
		384	S38400
	Ferritic		
405	S40500	434	S43400
409	S40900	436	S43600
429	S42900	439	S43900
430	S43000	442	S44200
430F	S43020	444	S44400
431	S43100	446	S44600
	Martensitic		
403	S40300	420F	S42020
410	S41000	422	S42200
410S	S41008	440A	S44002
414	S41400	440B	S44003
416	S41600	440C	S44004
420	S42000		
	Precipitation Hardening		
S13800	S13800	S17400	S17400
S15500	S15500	S17700	S17700

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 has been modified to change the cold forming characteristics such as in Types 301 and 305.
2. The carbon content has been decreased to prevent carbide precipitation in weldments such as in Types 304L and 316L.
3. Columbium or titanium has been 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 has been added or the chromium and nickel contents have been 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 has been 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. Nitrogen content is increased to enhance strength characteristics such as in Types 304N and 316N. The 200 series stainless steels, namely Types 201, 202, and 205, are counterparts to the 300 series types 301, 302, and 305. In the 200 series manganese replaces some of the nickel.

Up Productivity,
Reduce Rejects

A manufacturer of sleeves for solenoid activated hydraulic control valves found that, by using Type 304 of foreign manufacture, it was experiencing excessive tool wear and unacceptable downtime. A switch to domestically produced Type 304 stainless steel reduced tool wear and increased machining speeds. Consequently, production went from 1,000 to 3,000 pieces per 8-hour shift, and rejection rates dropped from approximately 30 percent to less than 1 percent.

Sleeves are machined on 1-¼ -inch six-spindle Acme screw machines, with drilling, forming, turning, and reaming.

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.

The development of new melting and refining processes, such as argon-oxygen decarburization (AOD), has resulted in 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. Some of the high-chromium ferritic types (or super ferritics) have resistance to chlorides previously obtainable only in high-nickel and titanium alloys.

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 and 420F.

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 900ºF) 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. (The UNS numbers closely resemble original PH numbers such as 13-8PH*, 17-4PH*, etc.)

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.

* Trademark, Armco, Inc.

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 newer nitrogen containing grades.

Type 329 is a duplex stainless steel that has wide application in nitric acid service. It 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.

Receptacle

TYPE 303 STAINLESS STEEL

PRODUCT	Nuclear Connector
COMPONENT	Receptacle Shell
MATERIAL:	Type 303 Stainless Steel
BAR STOCK:	Hollow Bar 2½Inch Square OD and 1 3/16 Inch ID
MACHINE TOOL:	Acme 3½Inch Automatic
PRIMARY OPERATIONS:	Turn, Form, Bore, and Cut-Off
GROSS PRODUCTION:	76 Parts Per Hour
SFPM:	161 (Smallest Diameter)
RPM:	471
TOLERANCES:	±0.002 Inch
FINISH:	63 Micro-Inch

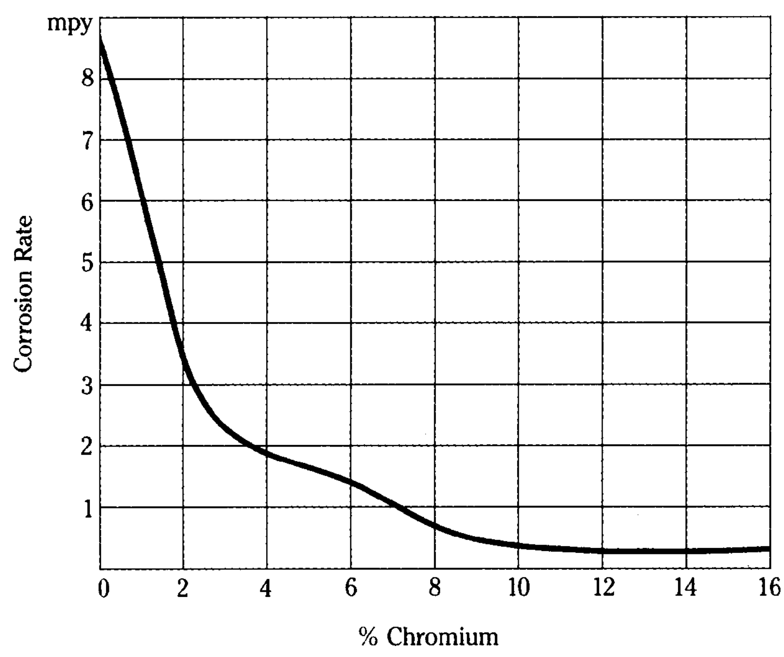
CORROSION RESISTANCE

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 (Figure 1).

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, however, 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)



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.

Table 2 lists the relative corrosion resistance of the AISI-numbered stainless steels in seven broad categories of corrosive environments. Table 3 details more specific environments in which various grades a used, such as acids, bases, organics, and pharmaceuticals.

Table 2
RELATIVE CORROSION RESISTANCE OF AISI STAINLESS STEELS

TYPE NUMBER	UNS NUMBER	MILD ATMOSPHERIC AND FRESH WATER	ATMOSPHERIC		SALT WATER	CHEMICAL		
			INDUSTRIAL	MARINE		MILD	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		
304	(S30400)	x	x	x		x	x	
304L	(S30403)	x	x	x		x	x	
304 Cu	(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	x
316F	(S31620)	x	x	x	x	x	x	x
316L	(S31603)	x	x	x	x	x	x	x
316N	(S31651)	x	x	x	x	x	x	x
317	(S31700)	x	x	x	x	x	x	x
317L	(S31703)	x	x	x	x	x	x	
321	(S32100)	x	x	x		x	x	
329	(S32900)	x	x	x	x	x	x	x
330	(N08330)	x	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						
420	(S42000)	x						

Table 2 continued on next page

Table 2 Continued
RELATIVE CORROSION RESISTANCE OF AISI STAINLESS STEELS

TYPE NUMBER	UNS NUMBER	MILD ATMOSPHERIC AND FRESH WATER	ATMOSPHERIC INDUSTRIAL	ATMOSPHERIC MARINE	SALT WATER	CHEMICAL MILD	CHEMICAL OXIDIZING	CHEMICAL REDUCING
420F	(S42020)	x						
422	(S42200)	x						
429	(S42900)	x	x			x	x	
430	(S43000)	x	x			x	x	
430F	(S43020)	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 American Iron and Steel Institute, the Committee of Stainless Steel Producers, or any of the member companies represented on the Committee. 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.

Type 303 =
Long Tool Life
Good Surface Finish
Excellent Parts Production

Type 303 stainless steel spray gun nozzles are machined on six-spindle automatic screw machines and lathes with high-speed tools. Machining operations range from rough forming to roll form threading. A Poly Gun attachment is used to machine the square. Secondary machining is done in two steps–four holes each. The nozzle tip is tapered on a bench lathe.

The nozzles are designed for use with potentially corrosive liquids, such as vitreous enamel or heavy alkaline paints. These paints flow through the gun into the nozzle where they are introduced to air intake. At the nozzle tip, air helps to atomize the paint, producing the desired spray.

Type 303 is supplied in 1 1/8 inch bars.

Table 3
WHERE DIFFERENT GRADES ARE USED

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 than Type 316. At concentrations up to 85%, the metal temperature should not exceed 212ºF (100ºC) 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 120ºF (50ºC) if the solutions are aerated; the attack is greater in airfree solutions. Type 317 may be used at temperatures as high as 150ºF (65ºC) 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 as 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 120ºF (50ºC). 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

Table 3 continued on next page

Table 3 Continued
WHERE DIFFERENT GRADES ARE USED

ENVIRONMENT	*GRADES*
Acetic acid *continued*	handling glacial acetic acid, which would be discolored by Type 304. Type 316 is likewise applicable for parts having temperatures above 120ºF (50ºC), 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 to about 300ºF (150ºC), Type 304 is resistant to fats and fatty acids but Type 316 is needed at 300 to 500ºF (150 to 260ºC) 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 minimize offcolor product.
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 (pulp 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 475ºF (245ºC), but Type 317 will probably be required at high 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.

The foregoing comments on the use of stainless steels in certain 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 upsets, can affect corrosion rates. For instance, there is a rule of thumb that states the corrosion rate of a material doubles for each 30ºC rise in temperature.

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 shut-down. For instance, sulfuric, sulfurous and polythionic acid condensates formed in some processes during shutdown 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 *ASH 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. Misapplications of stainless steels are rare and are usually avoided by specifiers and users who recognize conditions detrimental to stainless steels and understand how to specify to avoid problems. The types of corrosion and nature of environments that are more likely to be of concern are: pitting, crevice attack, stress-corrosion cracking, and intergranular corrosion.

Pitting occurs when the protective chromium-oxide film breaks down in small isolated spots, such as when halide salts contact the surface. Once started, the attack may accelerate because of differences in electric potential between the large area of passive surface vs. the active pit.

Pitting is avoided in many environments by using stainless steels containing molybdenum, such as Type 316 or 317.

S18200 for Meat Processing Trolley Stud

A manufacturer of meat processing trolleys had been using Type 303 stainless for Sani-Trolley studs, which hold the trolley wheels and brackets. Machining of the part was difficult, however, so the company looked for a stainless that would machine more freely, yet provide corrosion resistance matching or exceeding that of Type 303.

A test program of salt spray bath and in-service use resulted in the selection of S18200 stainless steel. The machining sequence is: form cut, shave cut, roll threads, drill, wobble broach, and cutoff.

Crevice corrosion results from local differences in oxygen concentration associated with deposits on the metal surface, gaskets, lap joints, or crevices under bolt or rivet heads where small amounts of liquid can collect and become stagnant.

The material responsible for the formation of a crevice need not be metallic. Wood, plastics, rubber, glass, concrete, asbestos, wax, and living organisms have all been reported to cause crevice corrosion. Once attack begins within the crevice, its progress is very rapid, and it is frequently more intense in chloride environments. For this reason, the stainless steels containing molybdenum are often used to minimize the problem. Notwithstanding, the best solution to crevice corrosion is a design that eliminates crevices.

Stress-Corrosion Cracking is caused by the combined effects of temperature, tensile stress and corrosive environment. Many metal systems have been known to experience stress-corrosion cracking– brass in ammonia, carbon steel in nitrate solutions, titanium in methanol, aluminum in sea water, and gold in acetic acid. Stainless steels are susceptible to stress-corrosion cracking in chloride environments. (Cracking may also occur in other aggressive environments, such as hydrogen sulfide.)

It is necessary for tensile stress, chlorides and elevated temperature all to be present for stress-corrosion cracking to occur. Wet-dry or heat transfer conditions, which promote the concentration of chlorides, are particularly aggressive with respect to initiating stress-corrosion cracking.

While the mechanism of stress-corrosion cracking is not fully understood, laboratory tests and service experience have resulted in methods to minimize the problem. For instance, the duplex stainless steels exhibit superior resistance to chloride stress-corrosion cracking; plus having good resistance to pitting.

The ferritic stainless steels, such as Types 405, 430 and 444 should also be considered when the potential exists for stress-corrosion cracking.

Fastener

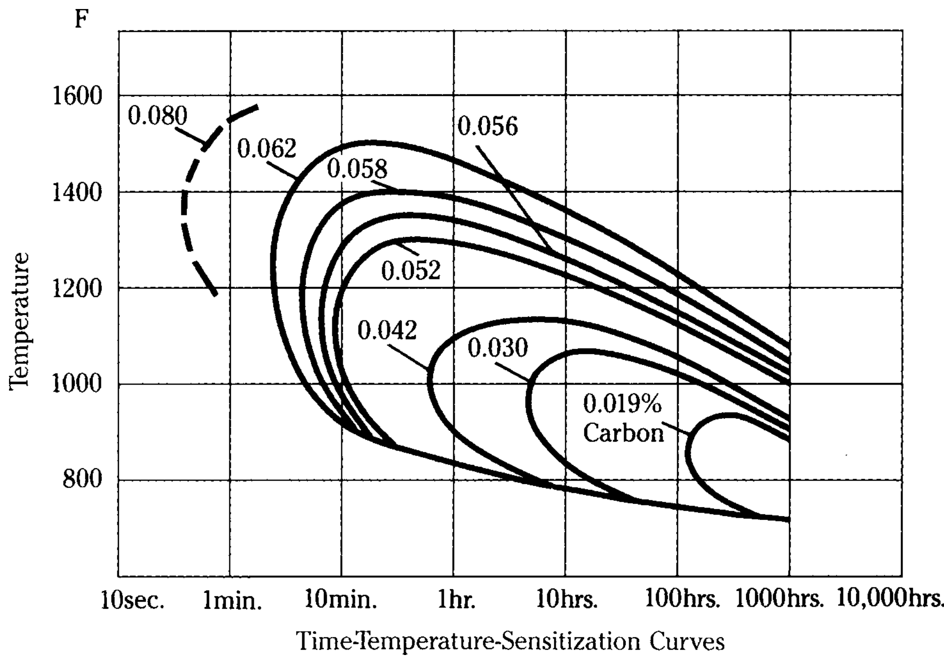
TYPE 430 STAINLESS STEEL

PRODUCT:	Anchor Bolts
COMPONENT:	Threaded Fastener
MATERIAL:	Type 430 Stainless Steel
BAR STOCK:	0.681 Inch Round Bar, Centerless Ground
OPERATIONS:	Form, Thread, and Cut-Off
SFPM:	90
RPM:	500
TOLERANCES:	±0.0015 Inch

Intergranular Corrosion. When austenitic stainless steels are heated or cooled through the temperature range of about 800-1650ºF, the chromium along grain boundaries tends to combine with carbon to form chromium carbides. Called carbide precipitation, or sensitization, the effect is a depletion of chromium and the lowering of corrosion resistance in areas adjacent to the grain boundary. This is a time-temperature dependent phenomenon, as indicated in Figure 2.

Figure 2

EFFECT OF CARBON CONTENT ON CARBIDE PRECIPITATION



Time required for formation of carbide precipitation in stainless steels with various carbon contents. Carbide precipitation forms in the areas to the right of the various carbon-content curves. Within time-periods applicable to welding, chromium-nickel stainless steels with 0.05% carbon would be quite free from grain boundary precipitation.

Sensitization may result from slow cooling from annealing temperatures, stress-relieving in the sensitization range, or welding. Due to the longer time at temperature of annealing or stress-relieving, it is possible that the entire piece of material will be sensitized, whereas the shorter time at temperature characteristic of welding can result in sensitization of a band, usually 1/8 to ¼ inch wide, adjacent to but slightly removed from the weld. This region is known as the heat-affected-zone or HAZ.

Intergranular corrosion depends upon the magnitude of the sensitization and the aggressiveness of the environment to which the sensitized material is exposed. Many environments do not cause intergranular corrosion in sensitized austenitic stainless steels.

Carbide precipitation and subsequent intergranular corrosion in austenitic stainless steels have been thoroughly investigated; the causes are understood and methods of prevention have been devised. These methods include:

1. Use of stainless steel in the annealed condition.
2. Selection of the low-carbon (0.030 percent maximum) stainless steels for weld fabrication. Low-carbon grades are Types 304L, 316L, and 317L. The less carbon available to combine with the chromium, the less likely is carbide precipitation to occur. However, the low-carbon grades may become sensitized at extremely long exposures to temperatures in the sensitization range.
3. Selection of a grade stabilized with titanium or columbium. The protection obtained is based upon the greater affinity of titanium and columbium for carbon as compared to chromium.

   Columbium stabilization is preferred because its carbides are more readily retained in welds and it is easier to add in the steelmaking process. However, the use of columbium stabilized steel requires additional care in welding.
4. Redissolving carbides by annealing parts after fabrication, although this is not always practical.

The excellent machining properties of Types 316 and 416 are responsible for long tool life and a minimum number of rejects in the production of gland nuts, which are one of four parts used in valve body assemblies of Union-type superpressure connectors. High strength, excellent corrosion resistance, and good machining characteristics are very important in this application.

The gland nut is 1-¼ inch hexagonal by 1- inch overall length, with 1- inch-12 UNF-2A threads. It is produced on Warner & Swasey five spindle automatic equipment with the fabrication sequence as follows: spot drill and rough turn; undersize drill and form for threads; drill inch diameter for through hole; ream inch diameter for through hole; roll threads; counterbore with 2 lip carbide tool; and cutoff.

It should be understood that the above steps are necessary only if the service environment is known to be capable of causing intergranular corrosion.

Although sensitization can also occur in the ferritic stainless steels heated to 1700ºF and water quenched or air cooled, it is far less likely to occur than with austenitic grades; and intergranular corrosion has not been a problem in these steels–except for a narrow band in the heat-affected-zone close to welds. (Several ferritic stainless steels either have low carbon content or are stabilized to prevent sensitization during welding.)

HIGH TEMPERATURE CORROSION RESISTANCE

Stainless steels have been widely used for elevated-temperature service, so fundamental and practical data concerning their resistance to corrosion are available.

When stainless steels are exposed at elevated temperatures, changes can occur in the nature of the protective chromium-oxide film. For example, at mildly elevated temperatures in an oxidizing gas, a protective oxide film is formed. In an environment containing sulfur-bearing gases, the film will be in the form of sulfides, which may also be protective.

In more aggressive environments, with temperatures above 1600ºF, the surface film may break down with sudden increase in scaling. Depending on alloy content and environment, the film may be self healing for a period of time followed by another breakdown.

Under extreme conditions of high temperature and corrosion, the surface film may not be protective at all.

For these reasons, the following data should serve only as a starting point for material selection, not as a substitute for service tests.

Machining Consistency Makes Manufacturer Competitive

Very close tolerance and critical surface finish are musts in the manufacture of these connector parts for electronic cable assemblies. So are high production rates.

Using Type 303 stainless steel, average production time per part is 140 seconds; critical tolerances are held to 0.0005 inch; and surface finishes of 32 RMS are achieved.

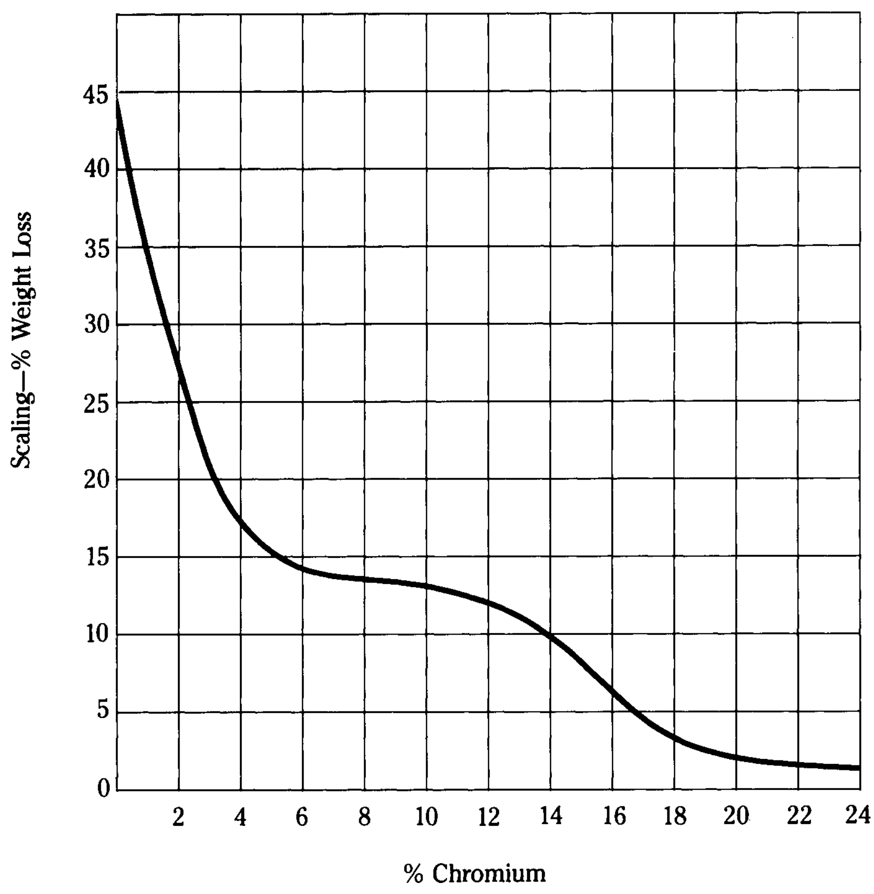
Connector bodies are machined from inch round stock on a Brown and Sharpe Ultramatic screw machine. Production sequence involves forming, drilling, boring, and tapping. Threading and knurling are also required.

Oxidation

In nonfluctuating-temperature service, the oxidation resistance (or scaling resistance) of stainless steels depends on chromium content, as indicated by the curve in Figure 3. Steels with less than 18 percent chromium (ferritic grades primarily) are limited to temperatures below 1500ºF. Those containing 18-20 percent chromium are useful to temperatures of 1800ºF, while adequate resistance to scaling at temperatures up to 2000ºF requires a chromium content of at least 25 percent, such as Type 309, 310, or 446.

Figure 3

EFFECT OF CHROMIUM CONTENT ON SCALING RESISTANCE (At 1800 ºF)



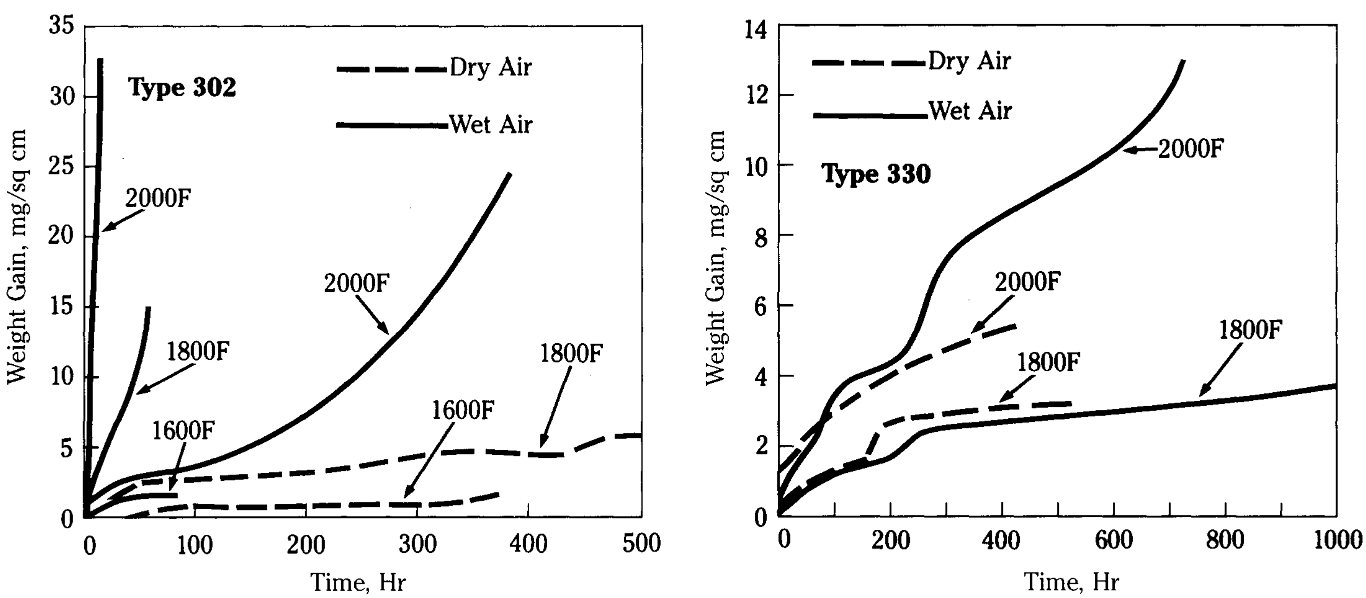
In many processes, isothermal (constant temperature) conditions are not maintained and process temperatures vary. Expansion and contraction differences between the base metal and the protective film (or scale) during heating and cooling may cause cracking and spalling of the protective scale. This allows the oxidizing media to attack the exposed metal surface.

The spalling resistance of the austenitic stainless steels is greatly improved at higher nickel levels. Nickel reduces the thermal expansion differential between alloy and oxide film and thereby reducing stresses at the alloy-oxide interface during cooling. Also, the ferritic chromium- molybdenum stainless steels have a fairly low coefficient of thermal expansion, which tends to reduce the spalling tendency.

An increase in corrosion rates can be expected in the presence of water vapor. Figure 4 illustrates the effect of moist air on the oxidation of Types 302 and 330. Type 302 undergoes rapid corrosion in wet air at 2000ºF, whereas a protective film is formed in dry air. The higher nickel Type 330 is less sensitive to the effects of moisture, so it is assumed that increased chromium and nickel permit higher operating temperatures in moist air. Types 309 and 310 are superior at temperatures greater than 1800ºF, and Type 446 is usable at temperatures approaching 2000ºF.

Figure 4

OXIDATION OF TYPES 302 AND 330 IN WET AND DRY AIR



A note of caution about stainless steels at high temperatures in stagnant oxidizing environments. The protective film breaks down in the presence of certain metal oxides, causing accelerated attack. For instance, austenitic types are susceptible to attack in the presence of lead oxide at temperatures as low as 1300ºF. Vanadium oxide, found in fuel ash, may cause failure of Types 309 and 310 at 1900ºF when water vapor is present. Molybdenum oxide behaves in a similar manner.

Sulfidation

Sulfur in various forms and even in relatively small quantities accelerates corrosion in many environments. Sulfur dioxide, hydrogen sulfide, and sulfur vapor are among the most corrosive forms. Sulfur vapor and hydrogen sulfide are considerably more aggressive than sulfur dioxide.

Sulfur attack, although closely related to oxidation, is more severe. Metal sulfides melt at lower temperatures than comparable oxides, and they may fuse to metal surfaces. Also, sulfides are less likely to form tenacious, continuous, protective films. Fusion and lack of adherence result in accelerated corrosion.

The resistance of stainless steels to sulfidation depends on chromium content.

Other High Temperature Environments

Data are available on the corrosion-resistance of stainless steels in other high-temperature environments, such as their use for liquid-metal environments. Designers are referred to the following publications for additional data on high-temperature applications: *Selection of Stainless Steels,* ASM Engineering Bookshelf. *Corrosion Resistance of the Austenitic Stainless Steels in High-Temperature Environments,* by International Nickel Inc. *High-Temperature Characteristics of Stainless Steels,* Committee of Stainless Steel Producers, American Iron and Steel Institute.

MECHANICAL AND PHYSICAL PROPERTIES

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 may exhibit yield strengths between 30 and 200 ksi, depending on composition, amount of cold work and size. They also exhibit good ductility and toughness even at high strengths, and this good ductility and toughness is retained to cryogenic temperatures. The chemical compositions, nominal mechanical and physical properties of annealed austenitic stainless steels are given in Table 4.

TABLE 4
AUSTENITIC STAINLESS STEELS CHEMICAL COMPOSITIONS and MECHANICAL PROPERTIES

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.	Product Form
	Chemical Analysis % (Max. unless noted otherwise)									*Mechanical Properties (Annealed bar unless noted otherwise)*				
201 (S20100)	0.15	5.50/ 7.50	0.060	0.030	0.75	16.00/ 18.00	3.50/ 5.50		0.25 N	75	40	40		
202 (S20200)	0.15	7.50/ 10.00	0.060	0.030	0.75	17.00/ 19.00	4.00/ 6.00		0.25 N	75	40	40		
205 (S20500)	0.12/ 0.25	14.00/ 15.50	0.060	0.030	0.75	16.50/ 18.00	1.00/ 1.75		0.32/ 0.40 N	110	65	30	B98	
301 (S30100)	0.15	2.00	0.045	0.030	0.75	16.00/ 18.00	6.00/ 8.00			75 (185)[a]	30 (140)[a]	40 (9)[a]	B92 (C41)[a]	Sheet
302 (S30200)	0.15	2.00	0.045	0.030	0.75	17.00/ 19.00	8.00/ 10.00		0.10 N	75 (125)[b]	30 (100)[b]	40 (12)[b]		
302B (S30215)	0.15	2.00	0.045	0.030	2.00/ 3.00	17.00/ 19.00	8.00/ 10.00			75	30	40		
303 (S30300)	0.15	2.00	0.20	0.15	1.00	17.00/ 19.00	8.00/ 10.00			85	35	50	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	85	35	50	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)[b]	30 (100)[b]	40 (10)[b]		
304H (S30409)	0.04/ 0.10	2.00	0.045	0.030	0.75	18.00/ 20.00	8.00/ 10.50			75	30	40	B92	
304L (S30403)	0.030	2.00	0.045	0.030	0.75	18.00/ 20.00	8.00/ 12.00		0.10 N	70	25	40		
304Cu (S30430)	0.08	2.00	0.045	0.030	0.75	17.00/ 19.00	8.00/ 10.00		3.00/ 4.00 Cu	65-85	30	70	B70	
304LN (S30453)	0.030	2.00	0.045	0.030	0.75	18.00/ 20.00	8.00/ 12.00		0.10/ 0.16 N	75	30	30	B92	
304N (S30451)	0.08	2.00	0.045	0.030	0.75	18.00/ 20.00	8.00/ 10.50		0.10/ 0.16 N	80	35	30		
305 (S30500)	0.12	2.00	0.045	0.030	0.75	17.00/ 19.00	10.50/ 13.00			75	30	40		

Table 4 continued on next page

TABLE 4 Continued
AUSTENITIC STAINLESS STEELS CHEMICAL COMPOSITIONS and MECHANICAL PROPERTIES

	Chemical Analysis % (Max. unless notedotherwise)									*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.*	*Product Form*
308 (S30800)	0.08	2.00	0.045	0.030	1.00	19.00/ 21.00	10.00/ 12.00			75	30	40		
309 (S30900)	0.20	2.00	0.045	0.030	1.00	22.00/ 24.00	12.00/ 15.00			75	30	40		
309S (S30908)	0.08	2.00	0.045	0.030	1.00	22.00/ 24.00	12.00/ 15.00			75	30	40		
310 (S31000)	0.25	2.00	0.045	0.030	1.50	24.00/ 26.00	19.00/ 22.00			75	30	40		
310S (S31008)	0.08	2.00	0.045	0.030	1.50	24.00/ 26.00	19.00/ 22.00			75	30	40		
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)[b]	30 (100)[b]	40 (12)b		
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	1.00	16.00/ 18.00	10.00/ 14.00	1.75/ 2.50		85	35	40	C20-28	
316L (S31603)	0.030	2.00	0.045	0.030	0.75	16.00/ 18.00	10.00/ 14.00	2.00/ 3.00	0.10 N	75	30	40		
316LN (S31653)	0.030	2.00	0.045	0.030	0.75	16.00/ 18.00	10.00/ 14.00	2.00/ 3.00	0.10/ 0.16 N	75	30	40	B95	Sheet
316N (S31651)	0.08	2.00	0.045	0.030	0.75	16.00/ 18.00	10.00/ 14.00	2.00/ 3.00	0.10/ 0.16 N	80	35	30		
317 (S31700)	0.08	2.00	0.045	0.030	0.75	18.00/ 20.00	11.00/ 15.00	3.00/ 4.00	0.10 N	75	30	40		
317L (S31703)	0.030	2.00	0.045	0.030	0.75	18.00/ 20.00	11.00/ 15.00	3.00/ 4.00	0.10 N	85	35	75		
321 (S32100)	0.08	2.00	0.045	0.030	0.75	17.00/ 19.00	9.00/ 12.00		5(C+N)(min)/ 0.70 (max) Ti 0.10 N	75	30	40		

321H (S32109)	0.04/ 0.10	2.00	0.045	0.030	0.75	17.00/ 19.00	9.00/ 12.00		4(C+N)(min)/ 0.70(max) Ti	75	30	40		
329 (S32900)	0.08	2.00	0.040	0.030	0.75	23.00/ 28.00	2.50/ 5.00	1.00/ 2.00		105	80	25		
330 (N08330)	0.08	2.00	0.040	0.030	0.75/ 1.50	17.00/ 20.00	34.00/ 37.00			70	30	30		
332 (S33200)	0.08	2.00	0.040	0.030	0.75	19.00/ 23.00	30.00/ 34.00		0.60 Ti 0.60 A1	80-120	35-90	50-25	140-217 (Brinell)	
334 (S33400)	0.08	1.00	0.040	0.030	0.75	18.00/ 22.00	18.00/ 22.00		0.60 Ti 0.60 Al	80	30	38		Strip
347 (S34700)	0.08	2.00	0.045	0.030	0.75	17.00/ 19.00	9.00/ 13.00		10 xC(min)/ 1.00(max) Cb+Ta	75	30	40		
347H (S34709)	0.04/ 0.10	2.00	0.045	0.030	0.75	17.00/ 19.00	9.00/ 13.00		8xC(min)/ 1.00(max) Cb+Ta	75	30	40		
348 (S34800)	0.08	2.00	0.045	0.030	0.75	17.00/ 19.00	9.00/ 13.00		10xC(min)/ 1.00(max)Cb +Ta 0.10 Ta, 0.20 Co	75	30	40		
348H (S34809)	0.04/ 0.10	2.00	0.045	0.030	0.75	17.00/ 19.00	9.00/ 13.00		8xC(min)/ 1.00(max)Cb+Ta 0.10 Ta, 0.20 Co	75	30	40		
384 (S38400)	0.08	2.00	0.045	0.030	1.00	15.00/ 17.00	17.00/ 19.00			60-80				

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 = Full hard condition.
b = Cold finished, for sizes up to ¾ in. inclusive, A276 Condition B.
c = ASTM A276-Condition H.
d = A565 Condition HT, heat treated 1900ºF, air or oil quench and tempered at 1150ºF minimum for 2 hours minimum.
e = Solution treated condition.

Table 4 Continued
PHYSICAL PROPERTIES OF AUSTENITIC STAINLESS STEELS

Stainless Steel Type	*Density Lb/Cu.In.*	*Modulus of Elasticity psi x 10^6*	*Specific Electrical Resistance at 68ºF Microhm-Cm*	*Specific Heat Btu/Lb/F 32-212ºF*	*Thermal Conductivity BTU/ft/hr/ºF (68-212ºF)*	*Mean Coefficient of Thermal Expansion, in/in/F x 10^{-6}* 32-212ºF	32-600ºF	32-1000ºF	32-1200ºF	32-1600ºF	*Magnetic Perme-ability max.*	*Annealing Temperature*
201	0.28	28.6[a]	69	0.12	9.4	8.7	9.7	10.9	–	11.3	1.02	1850-2050[b]
202	0.28	–	69	0.12	9.4	(9.2) (68-212ºF)	10.2	(10.6) (32–900ºF)	(11.3) (32-1400ºF)	–	1.02	1850-2050 [b]
205	0.28	28.6	–	–	–	(9.4) (68-392ºF)	(10.4) (68–851ºF)	– –	(11.4) (68-1472ºF)	(11.7) (68-1700ºF)	1.005	1950 [b]
301	0.29	28.0[a]	72	0.12	9.4	9.4	9.5	10.1	10.4	11.0	1.02	1850-2050'[b]
302	0.29	28.0[a]	72	0.12	9.4	9.6	9.9	10.2	10.4	11.0	1.02	1850-2050 [b]
302B	0.29	28.0[a]	72	0.12	–	9.0	10.0	10.8	11.2	–	–	1850-2050 [b]
303	0.29	28.0[a]	72	0.12	9.4	9.6	9.9	10.2	10.4	–	(1.02)	1850-2050 [b]
303Se	0.29	28.0[a]	72	0.12	9.4	9.6	9.9	10.2	10.4	–	(1.02)	1850-2050 [b]
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 [b]
304H	0.29	28.0[a]	72	0.12	9.4	9.6	9.9	10.2	10.4	11.0	1.02	1850-2050 [b]
304L	0.29	28.0[a]	72	0.12	9.4	9.6	9.9	10.2	10.4	11.0	1.02	1850-2050 [b]
304Cu	0.29	28.0[a]	72	0.12	9.4	9.6	9.0	–	10.4	–	1.02	1850-2050 [b]
304LN	0.29	28.0[a]	72	0.12	9.4	9.6	9.9	10.2	10.4	–	1.02	1850-2050
304N	0.29	28.5[a]	72	0.12	9.4	–	–	–	10.5	–	–	1850-2050 [b]
305	0.29	28.0[a]	72	0.12	9.4	9.6	9.9	10.2	10.4	11.0	1.02	1850-2050 [b]
308	0.29	28.0	72	0.12	8.8	9.6	9.9	10.2	10.4	(10.9) (68-1832ºF)	1.02	1850-2050 [b]
309	0.29	29.0[a]	78	0.12	9.0	8.3	9.3	9.6	10.0	(11.5) (32-1800ºF)	1.02	1900-2050 [b]
309S	0.29	29.0[a]	78	0.12	9.0	8.3	9.3	9.6	10.0	(11.5) (32-1800ºF)	1.02	1900-2050 [b]
310	0.29	29.0	78	0.12	8.2	8.8	9.0	9.4	9.7	(10.6) (32-1800ºF)	1.02	1900-2100
310S	0.29	29.0	78	0.12	8.2	8.8	9.0	9.4	9.7	(10.6) (32-1800ºF)	1.02	1900-2100
316	0.29	28.0[a]	74	0.12	9.4	8.9	9.0	9.7	10.3	(11.1) (32-1500ºF)	1.02	1850-2050 [b]
316H	0.29	28.0[a]	74	0.12	9.4	8.9	9.0	9.7	10.3	(11.1) (32-1500ºF)	1.02	1850-2050 [b]

316F	0.29	29.0	74	0.116	8.3	9.2	9.7	10.1	–	–	–	2000[b]
316L	0.29	28.0[a]	74	0.12	9.4	8.9	9.0	9.7	10.3	(11.1) (32-1500ºF)	1.02	1850-2050[b]
316LN	0.29	28.0[a]	74	0.12	9.4	8.9	9.0	9.7	10.3	(11.1) (32-1500ºF)	1.02	1850-2050[b]
316N	0.29	28.5[a]	74	0.12	–	–	–	–	10.3	–	–	1850-2050[b]
317	0.29	28.0[a]	74	0.12	9.4	8.9	9.0	9.7	10.3	(11.1) (32-1500ºF)	1.02	1850-2050[b]
317L	0.29	29.0[a]	79	0.116	8.3	9.2	-–	10.1	10.3	(10.8) (68-1832ºF)	1.02	1900-2000[b]
321	0.29	28.0	72	0.12	9.3	9.3	9.5	10.3	10.7	(11.2) (32-1500ºF)	1.02	1750-2050[b]
321H	0.29	28.0	72	0.12	9.3	9.3	9.5	10.3	10.7	(11.2) (32-1500ºF)	1.02	1750-2050[b]
329	0.28	27	–	–	–	(5.6)	(6.5)	–	–	(8.0)	–	1750-1800[b]
						(75-200ºF)	(75-700ºF)	–	–	(700-1500ºF)	–	1750-1800[b]
330	0.29	28.5	102	0.11	7.2	–	–	–	–	9.3	–	1950-2150[b]
332	0.29	27.9	99	0.12	6.7	7.8	9.0	9.4	9.7	-	1.02	2050-2150
334	0.29	–	86	–	–	9.3	9.5	9.7	(10.1) (32-1472ºF)	(10.6) (32-1832ºF)	–	2050-2100
347	0.29	28.0	72	0.12	9.3	9.3	9.5	10.3	10.6	(11.1) (32-1500ºF)	1.02	1850-2050[b]
347H	0.29	28.0	72	0.12	9.3	9.3	9.5	10.3	10.6	(11.1) (32-1500ºF)	1.02	1850-2050[b]
348	0.29	28.0	72	0.12	9.3	9.3	9.5	10.3	10.6	(11.1) (32-1500ºF)	1.02	1850-2050[b]
348H	0.29	28.0	72	0.12	9.3	9.3	9.5	10.3	10.6	(11.1) (32-1500ºF)	1.02	1850-2050[b]
384	0.29	28.0	79	0.12	9.4	9.6	9.9	10.2	10.4	–	–	1900-2100[b]

Notes:
a = In tension. As cold worked, the modulus is lowered. By stress relief heat treatment the lowered modulus may be increased.
b = Cool rapidly from these annealing temperatures.
c = Full annealing–cool slowly.
d = Process annealing.
e = Physical properties in the H950 Condition.
f = Physical properties in the H900 Condition.
g = Physical properties in the CH900 Condition.

Because austenitic stainless steels can be cold worked to high tensile and yield strengths, yet retain good ductility and toughness, they meet a wide range of design criteria. For example, Type 301 can be produced in the following tempers:

TABLE A

Temper	Tensile Strength Minimum ksi	Yield Strength Minimum ksi
¼-Hard	125	75
½-Hard	150	110
¾-Hard	175	135
Full-Hard	185	140

Ferritic Stainless Steels

Ferritic stainless steels contain approximately 12 percent chromium. The chemical composition, nominal mechanical and physical properties of the AlSl grades are shown in Table 5.

Solenoid Plunger

TYPE 434F STAINLESS STEEL

PRODUCT:	Hot and Cold Water Mix Valve
COMPONENT.	Solenoid Plunger
MATERIAL:	Type 434F Stainless Steel
BAR STOCK:	Coil Stock 0.1195 Inch Round
MACHINE TOOL:	Escomatic
PRIMARY OPERATIONS:	Form, Drill, and Cut-Off
GROSS PRODUCTION:	60 Parts Per Minute
TOLERANCES:	±0.001 Inch
FINISH:	40 Micro-Inch

TABLE 5
FERRITIC 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.*	*Product Form*
405 (40500)	0.08	1.00	0.040	0.030	1.00	11.50/ 14.50			0.10/ 0.30 Al	60	25	20		
409 (S40900)	0.08	1.00	0.045	0.045	1.00	10.50/ 11.75			6xC/ 0.75 Ti	65	35	25	B75	
429 (S42900)	0.12	1.00	0.040	0.030	1.00	14.00/ 16.00	0.75			70	40	20		
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	1.00	16.00/ 18.00				80	55	25	262 (Brinell)	
431 (S43100)	0.20	1.00	0.040	0.030	1.00	15.00/ 17.00	1.25/ 2.50			125	95	20	285 (Brinell)	
434 (S43400)	0.12	1.00	0.040	0.030	1.00	16.00/ 18.00		0.75/ 1.25		77	53	23	B83	Sheet
436 (S43600)	0.12	1.00	0.040	0.030	1.00	16.00/ 18.00		0.75/ 1.25	5 xC/ 0.70 Cb+Ta	77	53	23	B83	Sheet
439 (S43900) (S43035)	0.07	1.00	0.040	0.030	1.00	17.00/ 19.00	0.50		0.20+4(C+N) (min) Ti 0.15 Al	70	40	20	190 (Brinell)	
442 (S44200)	0.20	1.00	0.040	0.030	1.00	18.00/ 23.00				80	45	25	B90	
444 (S44400)	0.025	1.00	0.040	0.030	1.00	17.50/ 19.50		1.75/ 2.50	0.035 N 0.2+4(C+N)(min)/ 0.80 Ti+Cb	60	40	20	B95	Sheet
446 (S44600)	0.20	1.50	0.040	0.030	1.00	23.00/ 27.00			0.25 N	70	40	20		

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 = Full hard condition.

b = Cold finished, for sizes up to ¾ in. inclusive, A276 Condition B.

c = ASTM A276–Condition H.

d = A565 Condition HT, heat treated 1900ºF, air or oil quench and tempered at 1150ºF minimum for 2 hours minimum.

e = Solution treated condition.

Table 5 Continued
PHYSICAL PROPERTIES OF FERRITIC STAINLESS STEELS

Stainless Steel Type	*Density Lb/Cu.In.*	*Modulus of Elasticity psi x 10^6*	*Specific Electrical Resistance at 68ºF Microhm-Cm*	*Specific Heat Btu/Lb/F 32-212ºF*	*Thermal Conductivity BTU/ft/hr/ºF (68-212ºF)*	*Mean Coefficient of Thermal Expansion, in/in/F x 10^{-6}* 32-212ºF	32-600ºF	32-1000ºF	32-1200ºF	32-1600ºF	*Magnetic Perme-ability max.*	*Annealing Temperature*
405	0.28	29.0	60	0.11	15.6	6.0	6.4	6.7	-	7.5	-	1350-1500 [d]
409	0.28	29.0	–	0.11	14.4	(6.5) (68-212ºF)	(6.6) (68-500ºF)	(6.9) (68-900ºF)	(7.2) (68-1200ºF)	(7.5) (68-1500ºF)	-	1625
429	0.28	29.0	59	0.11	14.8	5.7	–	–	–	–	–	1450-1550[d]
430	0.28	29.0	60	0.11	13.8	5.8	6.1	6.3	6.6	6.9 (32-1500ºF)	–	1250-1400
430F	0.28	29.0	60	0.11	15.1	5.8	6.1	6.3	6.6	6.9	–	1250-1400 [d]
431	0.28	29.0	72	0.11	11.7	5.6	6.7	–	–	–	–	1150-1225 [a]
434	0.28	29.0	72	0.11	13.8	5.8	6.1	6.3	6.6	6.9 (32-1500ºF)	–	1400-1600
436	0.28	29.0	60	–	13.8	5.2	–	–	–	–	–	1400-1600
439	0.28	29.0	60	–	–	–	–	–	–	–	–	1450-1700
442[d]	0.28	29.0	64	0.11	12.5	5.6	–	–	–	–	–	1350-1500[d]
444	0.28	29.0	62	0.102	15.5	6.1	–	–	–	–	–	1500-1650
446	0.27	29.0	67	0.12	12.1	5.8	6.0	6.2	6.4	(6.7) (32-1800ºF)	–	1450-1600

Notes:
a = In tension. As cold worked, the modulus is lowered. By stress relief heat treatment the lowered modulus may be increased.
b = Cool rapidly from these annealing temperatures.
c = Full annealing–cool slowly.
d = Process annealing.
e = Physical properties in the H950 Condition.
f = Physical properties in the H900 Condition.
g = Physical properties in the CH900 Condition.

Ferritic stainless steels were once regarded as being difficult to weld. Weldability, ductility and toughness are improved by reducing carbon and nitrogen contents, such as in Type 444.

Martensitic Stainless Steels

The martensitic grades are so named because when heated above their critical temperature (about 1600ºF) 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 300-700ºF).

Table 6 gives the chemical composition, mechanical and physical properties of martensitic grades in the annealed and hardened conditions.

Spindles

TYPE 316 STAINLESS STEEL

PRODUCT:	Direct-Read Water Meters
COMPONENT:	Magnetic Coupling Drive Spindles
MATERIAL:	Type 316 Stainless Steel
BAR STOCK:	12 Foot Rod, 0.1562 Inch Diameter ±.0005 Inch, Ground and Polished, Hardness R_b 88-100
MACHINE TOOL:	#00 Brown and Sharpe Automatic
PRIMARY OPERATIONS:	Form, Knurl, Burnish, Mill, and Cut-Off
GROSS PRODUCTION:	144 Parts Per Hour
CYCLE TIME:	25 Seconds
SFPM:	107
RPM:	About 2000
TOLERANCES:	±0.0005 Inch
FINISH:	16 Micro-Inch

TABLE 6
MARTENSITIC STAINLESS STEELS CHEMICAL COMPOSITIONS and MECHANICAL PROPERTIES

	Chemical Analysis % (Max. unless noted otherwise)									*(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 Product (Rockwell) Form max.*
403 (S40300)	0.15	1.00	0.040	0.030	0.50	11.50 13.00				70	40	20	
410 (S41000)	0.15	1.00	0.040	0.030	1.00	11.50/ 13.50	0.75			70 (120)[c]	40 (90)[c]	20 (12)[c]	
410S (S41008)	0.08	1.00	0.040	0.030	1.00	11.50/ 13.50	0.60			70	35	30	B82
414 (S41400)	0.15	1.00	0.040	0.030	1.00	11.50/ 13.50	1.25/ 2.50			115	90	20	298 (Brinell)
416 (S41600)	0.15	1.25	0.060	0.15	1.00	12.00/ 14.00				75	40	30	262 (Brinell)
420 (S42000)	Over 0.15	1.00	0.040	0.030	1.00	12.00/ 14.00				95	50	25	241 (Brinell)
420F (S42020)	Over 0.15	1.25	0.060	0.15	1.00	12.00/ 14.00				95	55	22	262 (Brinell)
422 (S42200)	0.20/ 0.25	0.50/ 1.00	0.025	0.025	0.50	11.00/ 12.50	0.50/ 1.00	0.90/ 1.25	0.20/ 0.30 V 0.90/ 1.25 W	140[d]	110[d]	13[d]	302-352[d] (Brinell)
440A (S44002)	0.60/ 0.75	1.00	0.040	0.030	1.00	16.00/ 18.00		0.75		105	60	20	269 (Brinell)
440B (S44003)	0.75/ 0.95	1.00	0.040	0.030	1.00	16.00/ 18.00		0.75		107	62	18	269 (Brinell)
440C (S44004)	0.95/ 1.20	1.00	0.040	0.030	1.00	16.00/ 18.00		0.75		110	65	14	269 (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 = Full hard condition.
b = Cold finished, for sizes up to ¾ in. inclusive, A276 Condition B.
c = ASTM A276-Condition H.
d = A565 Condition HT, heat treated 1900ºF, air or oil quench and tempered at 1150ºF minimum for 2 hours minimum.
e = Solution treated condition.

TABLE 6 Continued
TYPICAL MECHANICAL PROPERTIES

As Quenched Hardness and Properties After Hardening and Tempering
1 in. (25.4 mm) Diameter Bars

Types	Hardening	As Quenched Hardness		Tempering	Tensile Strength	Yield Strength 0.2 percent	Elongation in 2" (50.80 mm)	Reduction of Area	Izod Impact V-Notch	Tempered Hardness	
UNS	Temperature °F	HB	HR	Temperature °F	ksi	Offset ksi	Percent	Percent	Ft.Lbs.	HB	HR
403	1800	410	C43	400	190	145	15	55	35	390	C41
(S40300)				600	180	140	15	55	35	375	C39
410				800*	195	150	17	55		390	C41
(S41000)				1000*	145	115	20	65		300	C31
				1200	110	85	23	65	75	225	B97
				1400	90	60	30	70	100	180	B89
416	1800	410	C43	400	190	145	12	45	20	390	C41
(S41600)				600	180	140	13	45	20	375	C39
				800*	195	150	13	50		390	C41
				1000*	145	115	15	50		300	C31
				1200	110	85	18	55	30	225	B97
				1400	90	60	25	60	60	180	B89
414	1800	425	C44	400	200	150	15	55	45	410	C43
(S41400)				600	190	145	15	55	45	400	C41
				800*	200	150	16	58		415	C43
				1000*	145	120	20	60		290	C30
				1200	120	105	20	65	50	250	C22
431	1900	440	C45	400	205	155	15	55	30	415	C43
(S43100)				600	195	150	15	55	45	400	C41
				800*	205	155	15	60		415	C43
				1000*	150	130	18	60		325	C34
				1200	125	95	20	60	50	260	C24

Table 6 continued on next page

TABLE 6 Continued
TYPICAL MECHANICAL PROPERTIES

As Quenched Hardness and Properties After Hardening and Tempering
1 in. (25.4 mm) Diameter Bars

Types UNS	*Hardening Temperature °F*	*As Quenched Hardness*		*Tempering Temperature °F*	*Tensile Strength ksi*	*Yield Strength 0.2 percent Offset ksi*	*Elongation in 2" (50.80 mm) Percent*	*Reduction of Area Percent*	*Izod Impact V-Notch Ft.Lbs.*	*Tempered Hardness*	
		HB	*HR*							*HB*	*HR*
420 (S42000)	1900	540	C54	600	230	195	8	25	10	500	C50
440A (S44002)	1900	570	C56	600	260	240	5	20	4	510	C51
440B (S44003)	1900	590	C58	600	280	270	3	15	3	555	C55
440C (S44004)	1900	610	C60	600	285	275	2	10	2	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 6 Continued
PHYSICAL PROPERTIES OF MARTENSITIC STAINLESS STEELS

Stainless Steel Type	Density Lb/Cu.In.	Modulus of Elasticity psi x 10^6	Specific Electrical Resistance at 68ºF Microhm-Cm	Specific Heat Btu/Lb/ºF 32-212ºF	Thermal Conductivity BTU/ft/hr/ºF (68-212ºF)	Mean Coefficient of Thermal Expansion, in/in/F x 10^{-6}					Magnetic Perme-ability max.	Annealing Temperature
						32-212ºF	32-600ºF	32-1000ºF	32-1200ºF	32-1600ºF		
403	0.28	29.0	57	0.11	14.4	5.5	6.3	(6.4) (32-1000ºF)	6.5	-	900	1500-1650[c] 1200-1400[d]
410	0.28	29.0	57	0.11	14.4	5.5	6.3	6.4	6.5	-	900	1500-1650[c] 1200-1400[d]
410S	0.28	29.0	57	0.11	14.4	5.5	6.3	6.4	6.5	-	900	1500-1650[c] 1200-1400[d]
414	0.28	29.0	70	0.11	14.4	5.8	6.1	(6.7) (32-1000ºF)	-	-	-	1200-1300[d]
416	0.28	29.0	57	0.11	14.4	5.5	6.1	6.4	6.5	-	-	1500-1650[c] 1200-1400[d]
420	0.28	29.0	55	0.11	14.4	5.7	6.0	6.5	-	-	-	1550-1650[c] 1350-1450[d]
420F	0.28	29.0	55	0.11	14.5	5.7	-	-	-	-	-	1550-1650[c] 1350-1450[d]
422	0.28	29.8	24.3	0.11	13.8	6.2	6.3	6.6	6.7	-	-	1350-1450
440A	0.28	29.0	60	0.11	14.0	5.7 (68-392ºF)	-	-	6.5 (68-1112ºF)	- -	- -	1550-1650[c] 1350-1450[d]
440B	0.28	29.0	60	0.11	14.0	5.7 (68-392ºF)	-	-	6.5 (68-1112ºF)	- -	- -	1550-1650[c] 1350-1450[d]
440C	0.28	29.0	60	0.11	14.0	5.7 (68-392ºF)	-	-	6.5 (68-1112ºF)	-	-	1550-1650[c] 1350-1650[d]

Notes:
a = In tension. As cold worked, the modulus is lowered. By stress relief heat treatment the lowered modulus may be increased.
b = Cool rapidly from these annealing temperatures.
c = Full annealing–cool slowly.
d = Process annealing.
e = Physical properties in the H950 Condition.
f = Physical properties in the H900 Condition.
g = Physical properties in the CH900 Condition.

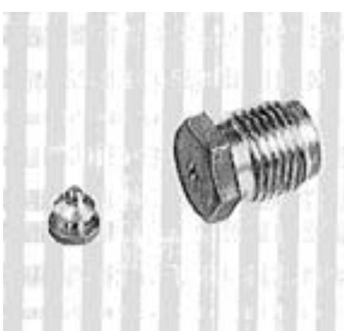
The martensitic stainless steels fall into two main groups that are associated with two ranges of mechanical properties; low-carbon compositions with a maximum hardness of about Rockwell C45 and the higher-carbon compositions, which can be hardened to Rockwell C60. (The maximum hardness of both groups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

Low-carbon content is associated with low-chromium content or the materials will not harden. At higher carbon levels, the chromium content can be raised to about 18 percent. However, because of potential problems of carbide precipitation (discussed in the section on corrosion) high-chromium martensitic stainless steels are not usually tempered to the same degree as the low-carbon types.

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 percent and is usually produced to a carbon specification of 0.3-0.4 percent. 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) is attained.



Steam Trap

TYPE 420F STAINLESS STEEL

PRODUCT:	Steam Trap
COMPONENT:	Points & Seats
MATERIAL:	Type 420F Stainless Steel
BAR STOCK:	$^5/_{16}$ Inch Round and $^9/_{16}$ Inch Hexagonal, Cold Rolled and Bright Hardened to R_c 50
MACHINE TOOL:	Brown & Sharpe Single-Spindle Automatic
PRIMARY OPERATIONS:	Form, Thread, Drill, Burnish, and Cut-Off
SECONDARY OPERATIONS:	Ream and Coin
GROSS PRODUCTION:	180 Parts Per Hour (Primary)
CYCLE TIME:	20 Seconds
SFPM:	100 ($^5/_{16}$ Inch Bar) and 120 ($^9/_{16}$ Inch Bar)
RPM:	1220-850
TOLERANCES:	±0.001 Inch
FINISH:	8-16 Micro-Inch

Martensitic stainless steels are subject to some temper brittleness and should not be tempered or used in the range of 800 to 1050ºF if optimum toughness is important.

Martensitic grades have a ductile-brittle transition temperature at which notch ductility drops very suddenly. The transition temperature is near room temperature, and at low temperature–about -300ºF–they become very brittle. 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 -100ºF, 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, for example, in a structure or the effect of a corrosive environment can do more to reduce fatigue limit than alloy content or heat treatment.

Precipitation Hardening Stainless Steels

The principle of precipitation hardening is that a supercooled solid solution (solution annealed) 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 900-1150ºF aging treatment, minimizing the problems associated with high-temperature treatments. Strength levels of up to 260 ksi (tensile) can be achieved–exceeding even those of the martensitic stainless steels–while corrosion resistance is usually superior to that of martensitics–approximately equal to that of Type 304 stainless. Ductility is similar to corresponding martensitic grades at the same strength level. Table 7 shows the chemical composition, the nominal mechanical and physical properties of four AISI precipitation hardening stainless steels in solution treated and age hardened conditions.

Production Increased 33 Percent

Tank adaptors, which hold steel tubing in position and house the valves and quick disconnects on soft drink tanks, were originally made with a foreign-produced Type 304 stainless steel. One problem was excessive downtime due to the need to remove chips during machining.

A switch to domestically produced Type 304 stainless steel provided significantly improved machinability, allowing the chips to break up easily. This enabled the manufacturer to machine the tank adaptors without interruption . . . thereby increasing production by one-third.

Machining is done on one-inch Acme Gridley Automatic screw machines, using Type 304 stainless in 11/16-inch and 13/16-inch diameter bars.

TABLE 7

PRECIPITATION HARDENING 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.*	*Product Form*
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	160[e]	120[e]	17[e]	C38[e]	
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	160[e]	145[e]	15[e]	C38[e]	
S17400	0.07	1.00	0.040	0.030	1.00	15.00/ 17.50	3.00/ 5.00		3.00/ 5.00 Cu 0.15/ 0.45 Cb+Ta	160[e]	145[e]	15[e]	C38[e]	
S17700	0.09	1.00	0.040	0.040	1.00	16.00/ 18.00	6.50/ 7.75		0.75/ 1.50 Al	150[e]	65[e]	25[e]	B100(min)[e]	Sheet

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 = Full hard condition.
b = Cold finished, for sizes up to ¾ in. inclusive, A276 Condition B.
c = ASTM A276-Condition H.
d = A565 Condition HT, heat treated 1900ºF, air or oil quench and tempered at 1150ºF minimum for 2 hours minimum.
e = Solution treated condition.

Table 7 Continued
PHYSICAL PROPERTIES OF PRECIPITATION HARDENING STAINLESS STEELS

Stainless Steel Type	Density Lb/Cu.In.	Modulus of Elasticity psi x 10^6	Specific Electrical Resistance at 68ºF Microhm-Cm	Specific Heat Btu/Lb/ºF 32-212ºF	Thermal Conductivity BTU/ft/hr/ºF (68-212ºF)	Mean Coefficient of Thermal Expansion, in/in/F x 10^{-6}					Magnetic Perme-ability max.	Annealing Tempera-ture
						32-212ºF	32-600ºF	32-1000ºF	32-1200ºF	32-1600ºF		
S13800[e]	0.28	29.4	102	0.11	8.1	5.9	6.2	6.6	–	–		–
S15500[f]	0.28	28.5	77	0.10	10.3	6.0	6.3	–	–	–	–	–
S17400[f]	0.28	28.5	80	0.11	10.6	6.0	6.4	–	–	–	–	–
S17700[g]	0.28	29.5	83	0.11	9.5	(8.6) (68-200ºF)	(9.7) (68-600ºF)	–	–	–	–	–

Notes:
a = In tension. As cold worked, the modulus is lowered. By stress relief heat treatment the lowered modulus may be increased.
b = Cool rapidly from these annealing temperatures.
c = Full annealing–cool slowly.
d = Process annealing.
e = Physical properties in the H950 Condition.
f = Physical properties in the H900 Condition.
g = Physical properties in the CH900 Condition.

Precipitation hardening stainless steels have high strength, relatively good ductility, and good corrosion resistance at elevated 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.

HIGH-TEMPERATURE MECHANICAL PROPERTIES

Stainless steels are used at temperatures up to about 2000ºF because they have good strength at elevated temperature and good resistance to corrosion and oxidation.

In steam power generation, for example, high allowable design stresses permit the use of thin sections and high operating temperatures. In aircraft and spacecraft design, the AISI numbered stainless steels are used for parts in which hot strength is crucial. Stainless steels are used extensively in heat exchangers in which there is need for both corrosion resistance and hot strength, especially for pressure service. In the nuclear power industry, there are high temperature applications for stainless steels in superheaters, boilers, feedwater heaters, valves, and main steam lines.

In analyzing high-temperature properties, hot strength and thermal stability (from the standpoint of softening or embrittlement) are important. Physical properties are also significant.

Figure 5 gives a broad concept of the hot-strength advantages of stainless steels in comparison to low-carbon unalloyed steel. Precipitation hardening stainless steels also have excellent hot strength at moderate temperatures, but their strength declines sharply as they overage at high temperature.

Thermal Stability

With time and temperature, changes in metallurgical structure can be expected for almost any steel or alloy. In stainless steels, the changes can be softening, carbide precipitation, or embrittlement.

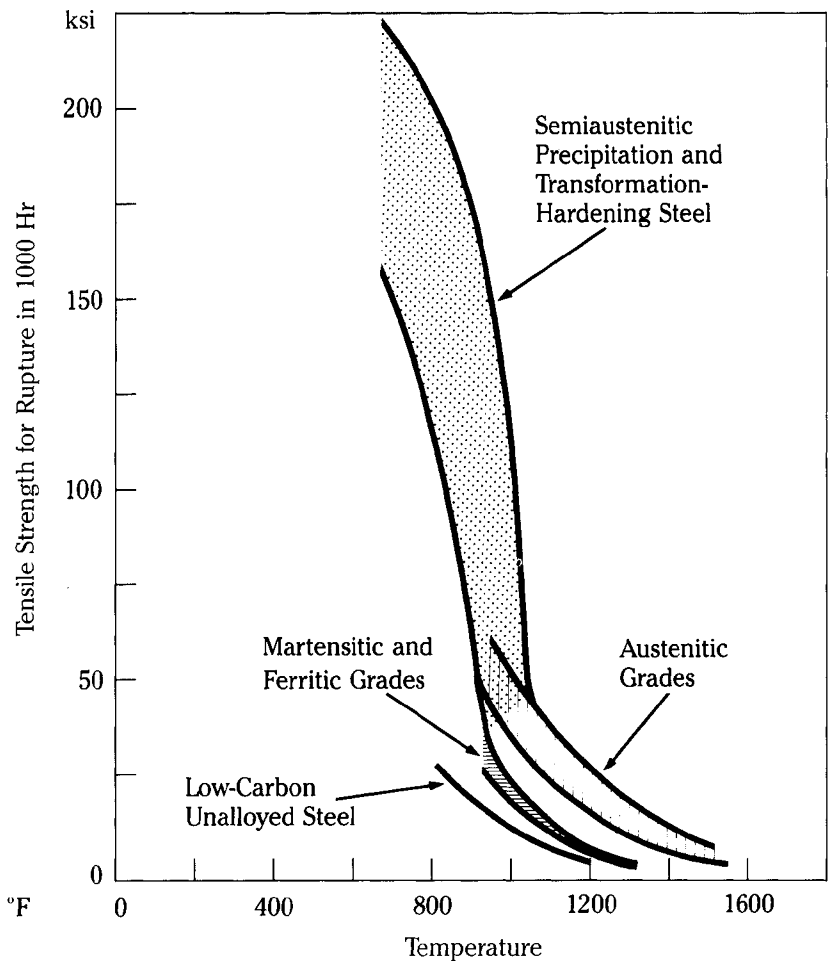
Softening occurs in the martensitic stainless steels when exposed to temperatures approaching or exceeding the original tempering temperature. Type 440C, for example, can be held at 900ºF for only short periods if the high hardness is to be retained. Cold-worked austenitic stainless steels may also soften at elevated temperature.

Embrittlement usually means the loss of room-temperature toughness. Embrittled equipment must be handled carefully to avoid impact when it is cooled down for maintenance. Embrittlement is rarely of concern with austenitic stainless steels.

Ferritic stainless steels are subject to embrittlement when exposed to temperatures of 700-950ºF over an extended period of time. Martensitic grades with 12 percent chromium also have been known to display brittle tendencies after extended periods in the same temperature range. This phenomenon is called 885ºF embrittlement because of the temperature at which embrittlement is most pronounced.

Figure 5

HOT-STRENGTH CHARACTERISTICS



General comparison of the hot-strength characteristics of austenitic, martensitic and ferritic stainless steels with those of low carbon unalloyed steel and semi-austenitic precipitation and transformation-hardening steels.

885ºF embrittlement results in low ductility and increased hardness and tensile strengths at room temperature, and the metal may fracture if not handled carefully. The metal, however, retains its desirable mechanical properties at operating temperature (500ºF and higher). The effect of 885ºF embrittlement can be removed by heat treatment at 1100ºF followed by air cooling.

Brittle failure under load is of concern, especially in welded fabrications. This type of embrittlement is largely a problem at temperatures of 1000-1500ºF, since strength and not ductility is the limiting factor at higher temperatures. Because of difficulty in evaluating data, and the variable conditions involved, designers are encouraged to seek technical assistance from stainless steel producers (listed on back cover).

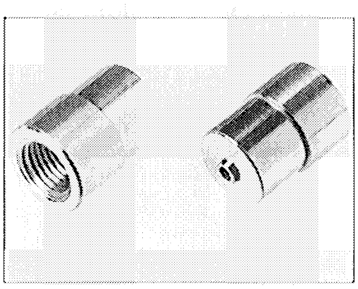
LOW-TEMPERATURE MECHANICAL PROPERTIES

Alloys for low-temperature service must have suitable engineering properties, such as yield and tensile strengths and ductility. Experience with brittle fracture of steel ships during World War II demonstrated that many metals may have satisfactory "room-temperature" characteristics but not perform adequately at low temperatures. Low-temperature brittle fracture can occur, sometimes with catastrophic failure, without any warning by stretching, sagging, bulging, or other indication of plastic failure. Alloys that are ordinarily ductile may suddenly fail at very low levels of stress.

In the handling and storage of liquid gases at cryogenic temperatures, few steels can be used. Austenitic stainless steels are among these few because they exhibit good ductility and toughness at the most severe of cryogenic temperatures–minus 423ºF.

Table 8 shows tensile properties of several stainless steels at cryogenic temperatures. Austenitic grades show not only good ductility down to -423ºF, but they also show an increase in tensile and yield strengths.

Toughness is also excellent as indicated by the impact strength values–although there is some decrease as temperature decreases.



Switching Nets
Lower Manufacturing Costs

A screw machine shop making fittings for energy related equipment, experienced many machining problems with imported Type 316 stainless steel bars. Inconsistent size and chemistry resulted in a high rate of snapped taps, and an upturn in downtime.

The switch to domestically produced Type 316 stainless steel produced immediate results. Machining time was cut by 3.8 seconds per piece, a 20 percent saving of time. Overall tap life was increased by 50 percent through more consistent machinability.

The Type 316, in ¾-inch rounds, is run on a Wickman six-spindle automatic screw machine with a basic production sequence that includes center drilling, two tap drills, tap and small-hole drilling with a speeder. Critical dimensions for the fitting include an end pipe thread truncation with a maximum limit of 0.005 inch.

Table 8

TYPICAL MECHANICAL PROPERTIES OF STAINLESS STEELS AT CRYOGENIC TEMPERATURES

	o				
304	- 40	34	155	47	110
	- 80	34	170	39	110
	-320	39	221	40	110
	-423	50	243	40	110
310	- 40	39	95	57	110
	- 80	40	100	55	110
	-320	74	152	54	85
	-423	108	176	56	
316	- 40	41	104	59	110
	- 80	44	118	57	110
	-320	75	185	59	
	-423	84	210	52	
347	- 40	44	117	63	110
	- 80	45	130	57	110
	-320	47	200	43	95
	-423	55	228	39	60
410	- 40	90	122	23	25
	- 80	94	128	22	25
	-320	148	158	10	5
430	- 40	41	76	36	10
	- 80	44	81	36	8
	-320	87	92	2	2

Auto Emission Parts With 303

Control valve parts for automotive emission systems require machining of three different angles, with a tolerance of ±6 minutes, a drilling operation, and a micro-inch finish of 16 or better.

Using Type 303 stainless steel, the manufacturer achieves consistent machinability, close tolerances, low tool breakage, few rejects and excellent surface finishes–without the need for grinding and polishing. Downtime is low, operating efficiency is high and profitability is good.

THE MACHINABLE FAMILY OF STAINLESS STEELS

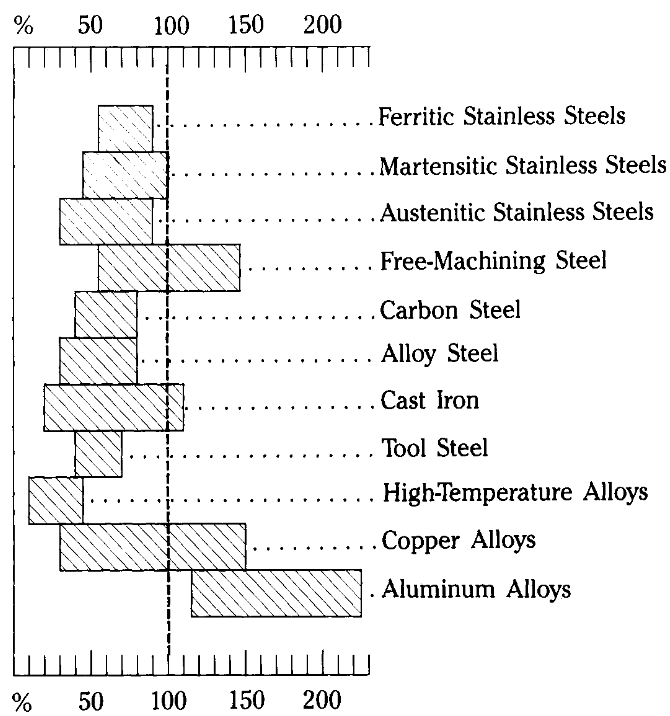
What is machinability?

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 6). In varying degrees, most stainless steels are tough, rather gummy, and they tend to seize and gall.

Figure 6

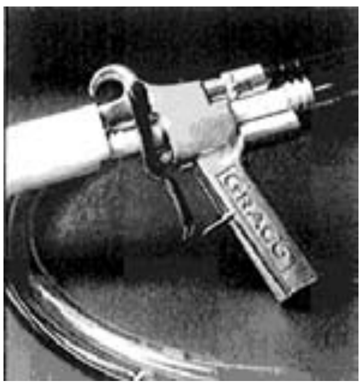
COMPARATIVE MACHINABILITY OF COMMON METALS



100% Type 416 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.

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



Air Valve

TYPE 416 STAINLESS STEEL

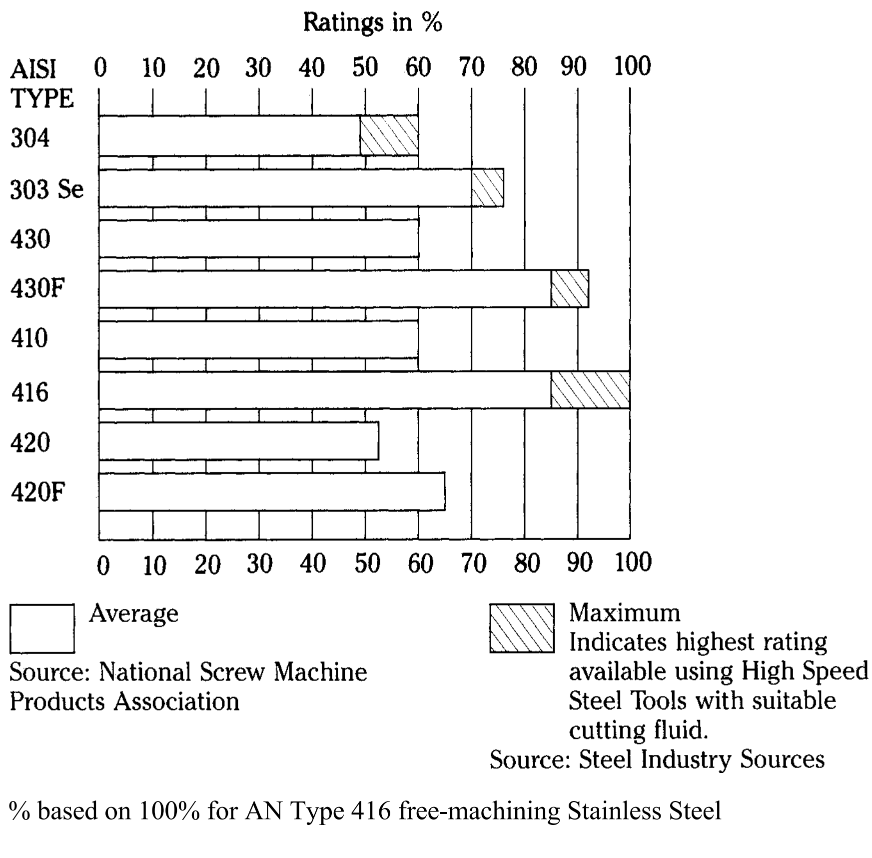
PRODUCT:	Solvent Spray Gun
COMPONENT:	Air Valve Seat
MATERIAL:	Type 416 Stainless Steel
BAR STOCK:	0.687 Inch (±0.002 Inch) Round, Annealed, Centerless Ground
MACHINE TOOL:	Acme Six-Spindle Bar Machine
PRIMARY OPERATIONS:	Form, Center Drill, Roll Thread, Form, Drill, and Cut-Off
SECONDARY OPERATIONS:	Countersink, Thread, Cross Drill, Mill, Deburr, and Electropolish
GROSS PRODUCTION:	96 Parts Per Hour
CYCLE TIME:	38 Seconds
SFPM:	120
RPM:	617
TOLERANCES:	±0.005 Inch
FINISH:	250 Micro-Inch

FREE-MACHINING STAINLESS STEELS

Certain alloying elements in stainless steels, such as sulfur, selenium, lead, copper, aluminum, or phosphorus can be added or adjusted during melting to alter the machining characteristics. These alloying elements serve to reduce the friction between the work-piece 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, 430F, 416, and 420F–is clearly evident in the chart, "Comparative Machinability of Frequently Used Stainless Steels" (Figure 7).

Figure 7

COMPARATIVE MACHINABILITY OF FREQUENTLY USED STAINLESS STEELS AND THEIR FREE-MACHINING COUNTERPARTS



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

It has been traditional in machining literature to compare the machinability of various metals to AISIB-1112 which is a free-machining carbon steel. However, since Type 416 stainless steel has a machining rating equal to that of B-1112, and since B-1112 is no longer on the market, comparisons in this booklet will be made with Type 416 as the base at 100%.

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.

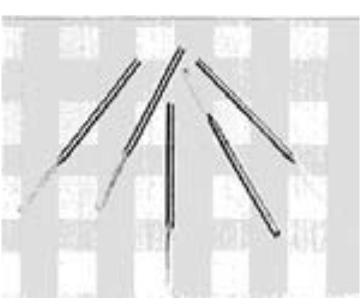
There are also free-machining alternatives to consider in the 400 series stainless steels. For instance, if end-use conditions call for Type 430 stainless, the specifier might select Type 430F. The composition of Type 430F is adjusted to enhance the machining characteristics while preserving as best 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 (Detailed descriptions of the free-machining stainless steels begin on page 60.)

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. 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.



Type 303 a "Cut Above"

Electronic surgical blades made of Type 303 stainless steel resist corrosion from atmospheric sources and sterilizing solutions. Disposable electronic surgical blades, fabricated from coils of 0.093/0.094-inch round stock in the annealed, cold drawn condition, are machined on precision coil fed automatics. With carbide tooling and sulfo-chlorinated cutting fluid, cycle time is eight seconds per part.

BUY A BETTER BAR

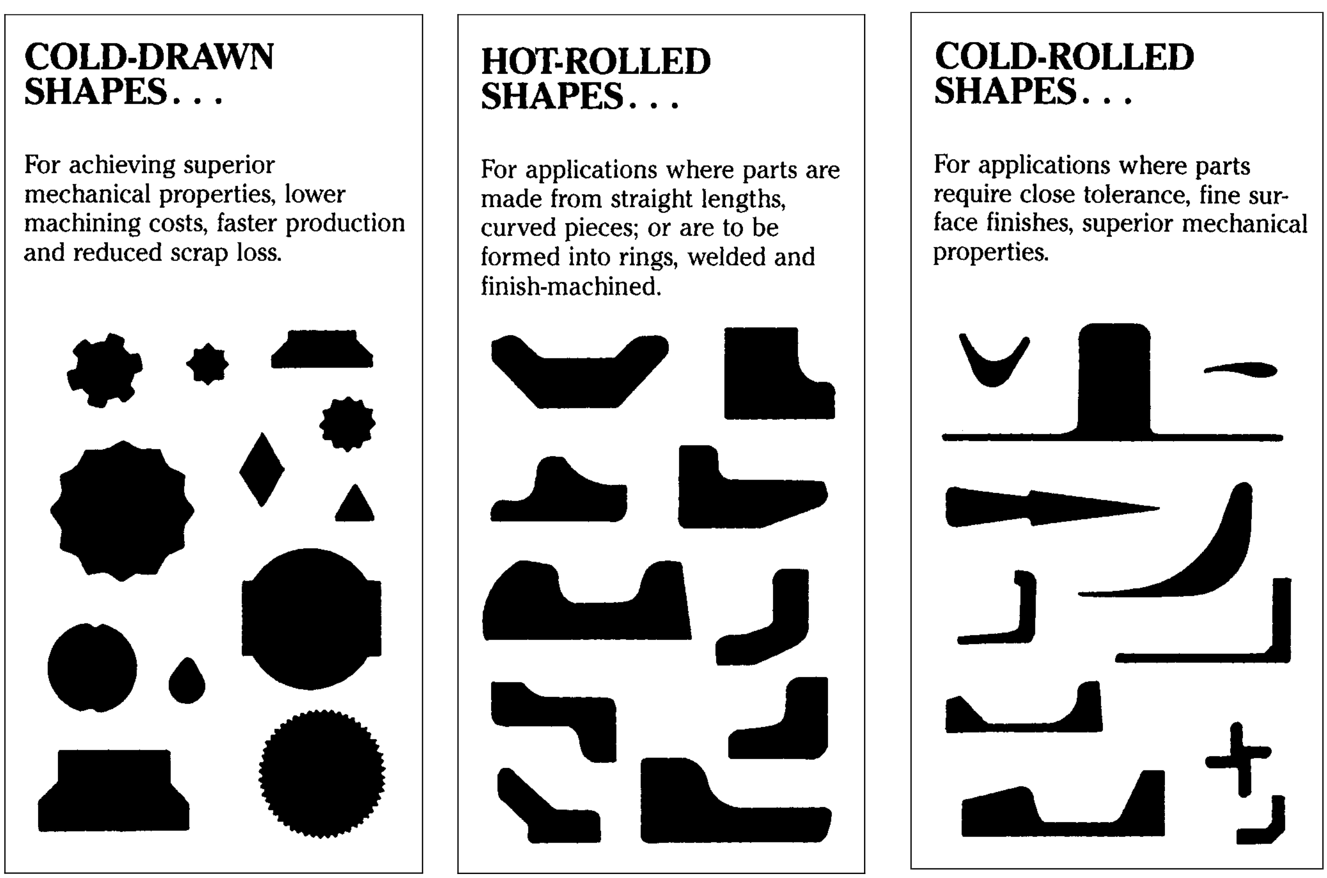
Among the various considerations for better machining efficiency in stainless steels are the purchase details of the basic bar stock. Discussed previously were the various conditions in which stainless steels are available–as free-machining types, as special analyses suitable for machining, and condition.

There is another aspect worth consideration that falls more in the realm of purchasing than design, but alert engineers do not want to overlook any angle to minimize costs.

Bar for machining is available in more than just a length of metal for the shop to cut up on a machine tool. Basic shapes, such as rounds, squares, hexagonals, and octagonals have always been available. It stands to reason that the closer you can come to the final shape in the starting bar material, the less machining will have to be performed.

Some forward looking domestic bar producers have carried the shape concept a number of steps forward by producing special shapes, the catch-word for which is "near net shape." Special shapes, such as illustrated in Figure 8, are hot rolled, cold drawn, or extruded. They are worthy of consideration because of the potential for reduced machining and handling.

Figure 8



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 with about a 0.125-inch wall thickness, up to a 5-inch diameter tubing with about a 3½-inch wall. Check with suppliers for availability of sizes and shapes.

Rod and wire in coiled form are also available for coil-fed screw machines. Table 9 describes the conditions and finishes in which stainless steel bars are normally available.

Table 9

CONDITIONS & 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) Centerless ground (f) Polished
3. Annealed and cold worked to high tensile strength* * *	(d) Cold drawn or cold rolled (e) Centerless 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 and 416, 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.

PH Packing Nuts

Packing nuts for instrumentation valves are used in natural gas process lines, which are exposed to a variety of corrosive chemicals at temperatures from -65ºF to +450ºF and pressures to 5000 psi. This requires the strength of Type 416 but with better corrosion resistance.

S45000 (UNS) martensitic, precipitation hardenable stainless steel combines the strength of Type 416 with the corrosion resistance of Type 304. Also, since the packing nut mates with Type 316, the choice of S45000 minimizes seizing and galling tendencies.

Packing nuts have dual threads; external threads for attaching to the valve housing and internal threads for operation of the valve stem.

The precipitation hardening stainless, which has a yield strength of 95, 000 psi (minimum) in the annealed condition, is machined like other martensitic stainless steels. Starting with 5/8 inch hexagonal, cold-drawn bars, the packing nuts are made on Greenlee Automatic Screw machines, and Reed Thread Rolling machines.

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.

Other Factors Affecting Cost

In addition to material selection, other considerations contribute to the machinability/cost ratio. When two or more types of machines can produce acceptable parts, cost per piece usually determines the final choice. Machining cost per piece is influenced most by cost of setup, cost of labor and burden (amortization) of machine tools. Experienced screw machine shops are more than qualified to determine the type of machine that will produce the part with the greatest degree of economy and dispatch.

Another factor affecting cost is brought to bear long before the order is placed for machining. This factor comes into play on the designer's drawing board. If screw machine parts are overdesigned and overspecified, machining expense will increase unnecessarily, especially on long production runs. The following several pages have been devoted to parts design hints to assist the design engineer in achieving the ultimate economy.

In the final analysis, the best way to control the machinability/cost ratio of any screw machine parts is to discuss every detail with the production engineer, to take advantage of his knowledge and experience in advance of actual production.

Tough Parts Made Easy

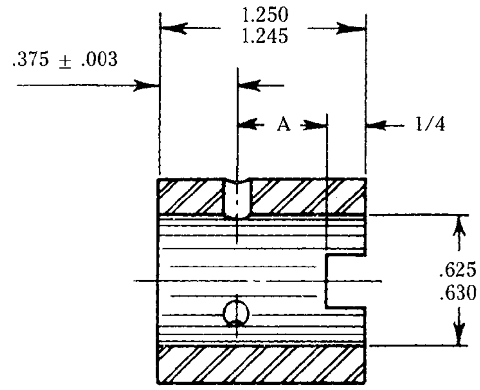
Precision screw machine components for military communications equipment have to be extremely reliable, possessing both strength and corrosion resistance. Free-machining Type 303 does both, and it minimizes tool breakage and machine downtime. A change from a *high manganese stainless steel to Type 303 also resulted in more uniform machinability.*

The shafts, screw assemblies, spacers, bushings, rivets, washers, and supports are fabricated on high speed Davenport and Swiss automatic screw machines.

DESIGN HINTS FOR SCREW MACHINE PARTS

Remove All Burrs

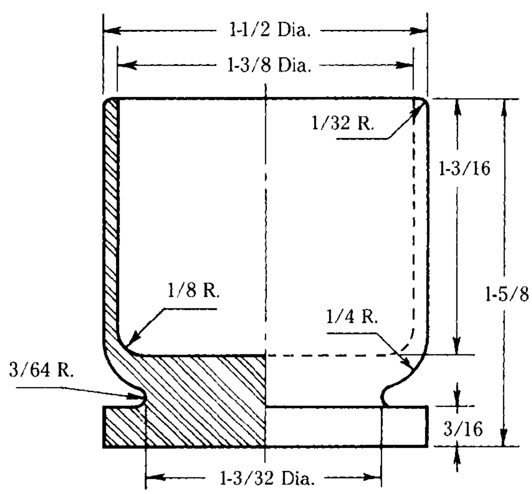
Such common notations as "Remove all burrs" are more often than not indicated as a matter of course on drawings, even when they are totally unnecessary. To avoid excessive machining expense, unnecessary notations should be omitted from specifications whenever possible. Burr removal should be specified only where needed, such as shown below.



Remove burrs from bore.
Slight burrs permissible on OD.

Tolerances

To the machine shop, this type of notation means all dimensions of the part are to be held to ±.005" (.127mm). The part is thus estimated and produced at an unnecessarily inflated cost. Tolerances should be tight only where they are required for satisfactory function.



Unless otherwise specified, all dimensions of this part to be held to ±.005.

Sharp Corners

A sharp corner may require extra machining so it should be specified only when necessary. If an inside or outside edge requires a break only, this should be specifically stated, leaving the radius or angle of the break to the discretion of production.

Concentricity

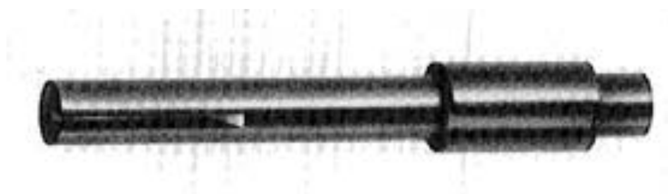
Concentricity of drilled holes to diameter can be held to 0.002 " TIR or better on some parts, but more liberal tolerances can reduce final costs significantly. Allowable eccentricity should be clearly stated on the specification.

Center Hole

If a screw machined part is to be held between lathe centers for further machining, holes must be provided for this purpose. A center hole is easily machined in the outer end of a part but at the rear of the part it is more difficult and costly. Specifications for such rear center holes are often left on drawings when they are not needed; an expensive oversight. The same is true of a 30 degree chamfer on the outer end of a hole.

Slots

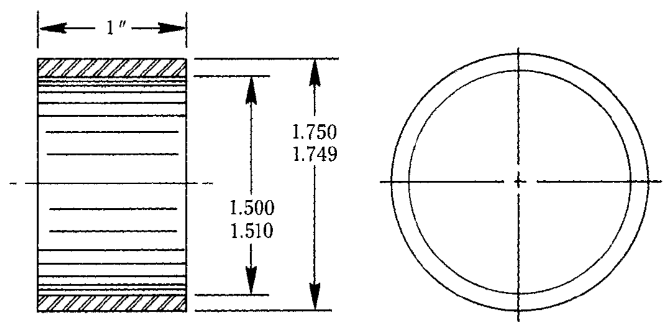
Attachments generally utilize circular milling cutters for slot cutting. This means that the radius produced at the bottom of a slot will correspond to the radius of the cutter used for this operation. A flat-bottomed slot can be cut, but at added expense. If the slot is specified for driving purposes, the drawing should indicate a bottom with an optional radius. Tooling for straddle milling is similar to that required for slotting. Whenever a radius is allowable at the junction of a milled or round area, the drawing should so state.



Heat Treating

If heat treating can be expected to affect the concentricity of a machined part, allowances for this possibility should be taken into consideration when drawing machining specifications.

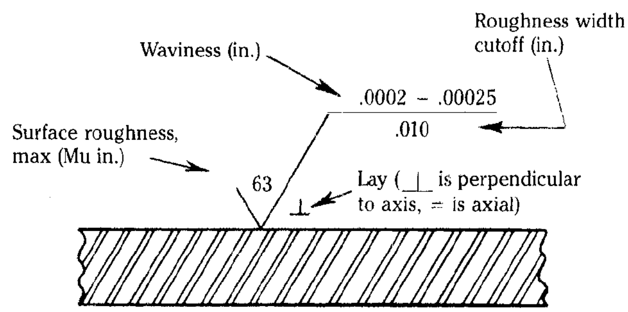
If a part is to be plated, plating thickness and tolerance must be indicated on the drawing.



Dimensions to be held after heat treating and plating
Harden: 40 to 44 Rockwell C
Cadmium plate: .0002 to .0003 thick

Finishes

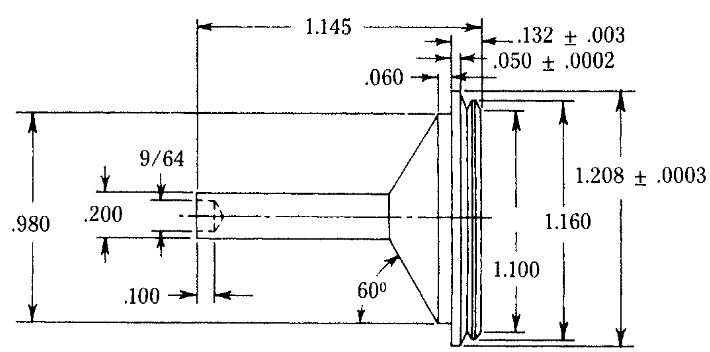
It is important that drawings show whether finishes are for function or appearance, whether tool marks are allowable, and whether waviness or lay are critical. The drawing submitted is the final authority on such details and should be so constructed.



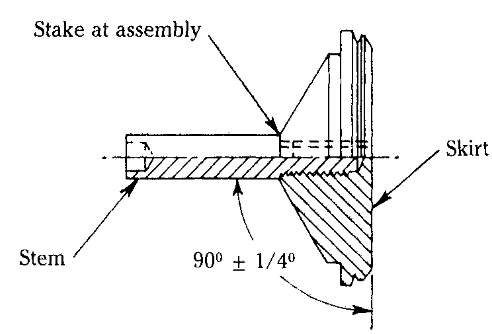
Secondary Operations

As a rule, the most economical product is made in one operation with no secondary work required on other equipment. Because secondary operations are less automated, they are often more costly than making the part in bland form on a screw machine.

There are exceptions to this rule, however, and the comparative illustration below is an example. The drastic reduction of material in the stem area of the part marked "A" created a heat problem, which lowered tool life and caused cracks in the finished part. By redesigning the part to be made in two pieces, as shown in the drawing marked "B", total cost of machining and joining the two components reduced the cost about 25 percent, and resulted in a better product.



A

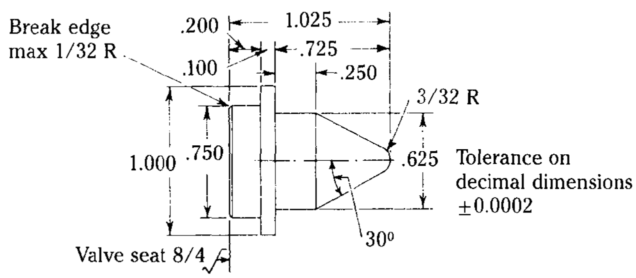


B

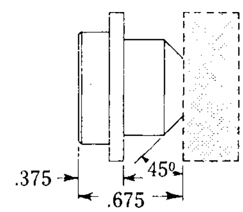
Shape and Orientation

When the parts designer regards function his prime objective, he can sometimes reduce costs even when tolerances cannot be changed. The next example illustrates this point.

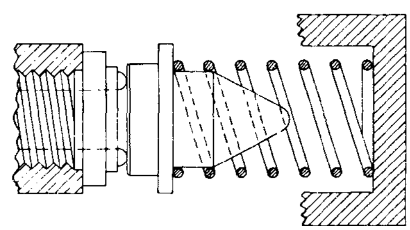
The shape of the valve seat shown in drawing A, combined with tolerances called for on the flat face, made a secondary operation necessary. The part was screw machined, rounded end out, then placed on a bench lathe to complete facing of the valve seat to the required flatness.



A



B



Since the rounded nose of the part served no function, the drawing was revised to allow the part to be made with the seat end out (drawing B), thus eliminating the secondary operation. The result: a 30 percent saving in material and a 55 percent reduction in overall cost.

Uniformity Helps

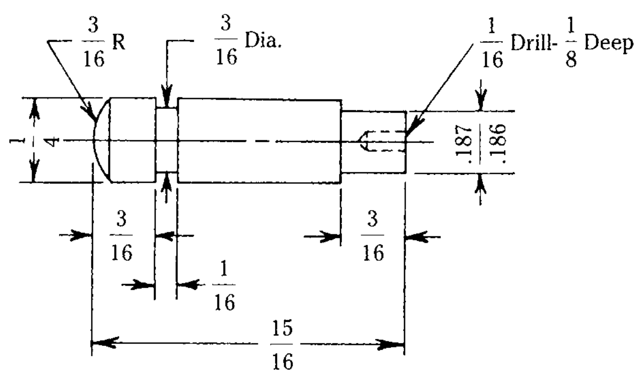
Producing terminal connection inserts of Type 303 includes an unusual configuration of a thin wall with threads on both inside and out. Nevertheless, machining on Acme Gridley 8-spindle automatics is accomplished with few rejects and minimum downtime.

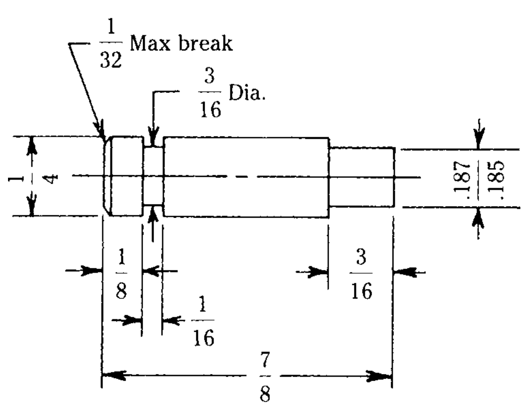
No-Frills Please

Here is another example where unnecessary design frills were eliminated to reduce part costs by a considerable margin.

Both parts shown here serve the same function. The one on the top includes an unnecessary hole in the rivet end of the shank, and a 3/16-inch radius on the head end which serves no specific purpose.

A change in material specification–plus redesign to eliminate the unnecessary hole and replace the 3/16-inch radius with an adequate corner break–created a part that provided the same function as the original part, at a cost saving of 37 percent.

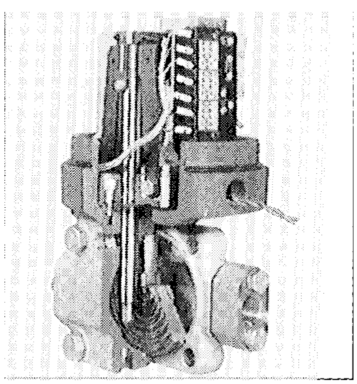




GOOD SHOP PRACTICES

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 sulfurchlorinated 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.



d/p Cell

TYPE 316 STAINLESS STEEL

PRODUCT:	Electronic Differential Pressure Cell
COMPONENT:	Cap-End Spacer
MATERIAL:	Type 316 Stainless Steel
BAR STOCK:	1¼ Inch Round, Cold Rolled, Annealed, Ground, Hardness R_b 95 (Maximum)
MACHINE TOOL:	Warner & Swasey Five-Spindle Bar Machine
PRIMARY OPERATIONS:	Turn, Drill, Form, Knurl, Ream, Tap, and Cut-Off
SECONDARY OPERATIONS:	Thread, Contour, Cross-Drill
GROSS PRODUCTION:	54 Parts Per Hour
CYCLE TIME:	59 Seconds
SFPM:	90
RPM:	272
TOLERANCES:	±0.0015 Inch
FINISH:	63 Micro-Inch

CLEANING AND PASSIVATING

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. Chemical cleaning is sometimes used interchangeably with passivation, which is another method for removing contamination from the metal surface. Properly cleaned stainless steel will passivate in contact with air, but for much better corrosion resistance, passivation should be done in appropriate solutions. For passivation procedures, it is best to consult technical literature available from stainless steel producers.

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. If not, the final chemical cleaning (passivating) solution can leave a tightly adhering brown stain on the metal surface.

Pilot Valve

TYPE 430F STAINLESS STEEL

PRODUCT:	Air Valve
COMPONENT.	Pilot Valve Plunger
MATERIAL:	Type 430F Stainless Steel
BAR STOCK:	0.500 Inch Bar, Annealed and Centerless Ground
MACHINE TOOL:	Acme 6-Spindle Bar Machine
PRIMARY OPERATIONS:	Form, Drill, Tap, and Cut-Off
SECONDARY OPERATIONS:	Drill, Form, Tap, and Broach
GROSS PRODUCTION:	133 Parts Per Hour
CYCLE TIME:	27 Seconds Per Part
SFPM:	105
RPM:	824
TOLERANCES:	±0.001 Inch
FINISH:	32 Micro-Inch

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-l8Cr-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.

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 800-1650ºF a corrective thermal treatment is suggested to avoid chances of intergranular corrosion. Such a treatment consists of heating to about 1900ºF followed by quenching in water.

PHYSICAL PROPERTIES

Specific gravity	8.00
Density-lb/in^3	0.29
Mean coefficient of thermal expansion	
in/in/F x 10^{-6} (32-1200ºF)	10.4
mm/mm/C x 10^{-6} (0-649ºC)	18.7
Electrical resistivity	
ohm-cir mil/ft	433
microhm-cm	72
Specific heat	
Btu/Ib/F(32-212ºF)	0.12
J/kg• K (0-100ºC)	502

MECHANICAL PROPERTIES (Typical)

Test for 1 " (25.4 mm) Round Bar

	Annealed	Annealed & Cold Drawn
Yield Strength 0.2% offset		
ksi	35	60
MPa	241	414
Tensile Strength		
ksi	85	100
MPa	621	689
Elongation in 2" (50.8mm), %	50	40
Reduction of area %	55	53
Brinell hardness	160	228
Impact resistance, Izod		
ft-lb	80	
Joules	108	

THERMAL TREATMENT

Initial forging temperature	2100-2350ºF (1149-1288ºC)
Annealing temperature	1850-2050ºF (1010-1121ºC) Followed by rapid cooling

Hardening

Cannot be hardened by heat treatment. Upon being cold worked, Types 303 and 303 Se stainless steel increase in strength and hardness.

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

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.

PHYSICAL PROPERTIES

Specific gravity	7.75
Density–lb/in^3	0.28
Mean coefficient of thermal expansion	
in/in/F x 10^{-6}(32-1200ºF)	6.6
mm/mm/C x 10^{-6} (0-649ºC)	11.9
Electrical resistivity	
ohm-cir mil/ft	361
microhm-cm	60
Specific heat	
Btu/lb/F (32-212ºF)	0.11
J/kg• K	460

MECHANICAL PROPERTIES (Typical)

Test for 1 " (25.4 mm) Round Bar

	Annealed	Annealed & Cold Drawn
Yield Strength 0.2% offset		
ksi	55	80
MPa	379	552
Tensile Strength		
ksi	80	90
MPa	552	621
Elongation in 2" (50.8mm), %	25	15
Reduction of area %	60	55
Brinell hardness	170	190

THERMAL TREATMENT

Initial forging temperature	1950-2100ºF (1066-1149ºC)
Annealing temperature	1250-1400ºF (677-760ºC)

Hardening

Not appreciably hardenable by thermal heat treatment, but can be slightly hardened by cold working.

The Ultimate in Cylinder Rods

While other manufacturers use chrome-plated carbon steel for air cylinder piston rods, this company uses Type 416 stainless steel because it provides the corrosion resistance necessary to help maintain a uniformly smooth surface on the piston rod. This, in turn, reduces wear on the "O" ring seal, assuring a tight seal for the life of the cylinder.

Machining operations for the piston rods are critical, especially in the final stage of fabrication. The manufacturer requires consistently uniform threads that cannot rip the "O" ring when assembled. Since threading is one of the last steps in fabricating, the success of the part hinges on this operation.

Type 416 is supplied as precision ground and polished rounds in diameters ranging from 5/16 inch to 1-½ inches. The material is machined on Brown and Sharpe single-spindle automatics. The fabrication sequence includes box turning, machining of piston diameter, cutting grooves in the piston, cutting thread diameters, cutoff and end chamfering. Secondary operations include threading one end of the rod, then broaching.

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 1200ºF (Maximum corrosion resistance is achieved in the heat treated condition.)

PHYSICAL PROPERTIES

Specific gravity	7.75
Density-lb/in^3	0.28
Mean coefficient of thermal expansion	
in/in/F x 10^{-6} (32-1200ºF)	6.5
mm/mm/C x 10^{-6}	11.7
Electrical resistivity	
ohm-cir mil/ft.	343
microhm-cm.	57
Specific heat	
Btu/lb/F (32-212ºF)	0.11
J/kg• K	460

MECHANICAL PROPERTIES (Typical)

Test for 1 "(25.4 mm) Round Bar

	Annealed	Tempered & Cold Drawn
Yield Strength 0.2% offset		
ksi	40	85
MPa	276	586
Tensile Strength		
ksi	75	100
MPa	517	689
Elongation in 2 " (50.8mm) %	30	13
Reduction of area %	60	50
Brinell hardness	155	205
Impact resistance, Izod		
ft-lb	70	20
Joules	95	27

THERMAL TREATMENT

Initial forging temperature	2100–2300ºF (1149–1260ºC) Retard Cooling
Annealing temperature	Cool slowly from 1500–1650ºF (816–899ºC)
Hardening	Cool rapidly from 1700–1850ºF (927–1010ºC)
Tempering	400–1400ºF(204–760ºC)

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.)

PHYSICAL PROPERTIES

Specific gravity	7.75
Density-lb/in^3	0.28
Mean coefficient of thermal expansion	
in/in/ºF x 10^{-6} (32-1200ºC)	6.8
mm/mm/C x 10^{-6} (0-649)	12.2
Electrical resistivity	
ohm-cir mil/ft	331
microhm-cm	55
Specific heat	
Btu/lb/F (32-212ºF)	0.11
J/kg• K	460

MECHANICAL PROPERTIES (Typical)

Test for 1 " (25.4 mm) Round Bar

	Annealed	*Annealed & Cold Drawn*
0.2% Yield Strength		
ksi	55	100
MPa	379	689
Tensile Strength		
ksi	95	110
MPa	655	758
Elongation in 2 " (50.8mm), %	22	14
Reduction of area %	50	40
Brinell hardness	220	228

THERMAL TREATMENT

Initial forging temperature 2050-2250ºF (1130-1231ºC)
Annealing temperature............................ Cool slowly from 1550-1650ºF (843-899ºC)
Hardening

Heat to 1800-1900ºF (982-1038ºC)– soak at heat and quench in warm oil.

Table 11

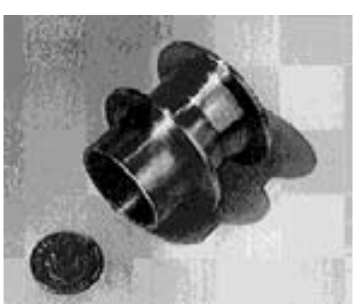
FREE-MACHINING STAINLESS STEELS TRADE NAME DIRECTORY

TYPE	*ARMCO*	*ATLAS STEELS*	*CARPENTER TECHNOLOGY*	*LTV STEEL*	*SLATER STEELS*	*CYTEMP DIV. CYCLOPS*
			302 HQ-FM*			
303	RP 303	303 MX	303 Project 70	Multicut 303	303 MM**	303
			Project 70 303DQ	303 FQ	303 FQ	303 FQ
			303			
			303 Forging Quality			
			303 Al Modified*			
303Se			303Se			
304[a]	304	304	304 Project 70	Multicut 304	304 MM**	304
				304 FQ		
316[a]	316		316 Project 70	Multicut 316	316MM**	316
				316 FQ		
316F			316F			
			347F Se*			
416	RP 416	416 MF	416 Project 70	Multicut 416	416 MM**	416
		416 MH	No. 5	416 FQ	416 FQ	416 HH
		416 MX	No. 5F*		416 XF	416 HT
		4 MX	No. 5 BQ			416 FQ
			416 Forging Quality			
416 Se			No. 5 Se			
420F	420F		420F	420F	420FM	
430F	430F		430F	430F	430 FM	
			430 FR*		430 FS	
			430F Bushing Quality			
			430F Modified S+Se*			
			434F*			
			440F*			
			440F Se*			
			Project 70 182-FM*			

* Denotes special analysis not within AlSl composition range. Compositions of special analysis grades are listed in Table 12.
** MM= Maximum machinability
a Types 304 and 316 are not free-machining stainless steels but they are listed because of their wide use for machining applications.

Table 12
FREE-MACHINING SPECIAL ANALYSIS STAINLESS STEELS

ALLOY	*C*	*Mn*	*P*	*S*	*Si*	*Cr*	*Ni*	*Mo*	*Other*
302 Hq-FM	0.06	2.00	0.040	0.20	1.00	16.00/ 19.00	9.00/ 11.00	-	1.20/2.40 Cu
303 Al Mod.	0.15	2.00	0.050	0.11/ 0.16	1.00	17.00/ 19.00	8.00/ 10.00	0.40/ 0.60	0.60/1.00 Al
347F Se	0.080	2.00	0.045	-	1.00	17.00/ 19.00	9.00/ 13.00	-	10XC Min. Cb 0.15 Min. Se
No. 5F	0.10	1.00	0.060	0.30 Min.	1.00	13.00/ 19.50	0.50	0.40/ 0.60	
430 FR	0.060	0.050	0.020	0.30	1.25	17.50	-	0.30	
430F Mod. S+Se	0.12	1.25	0.040	0.10 Min.	1.00	16.00/ 18.00	-	0.60	0.15 Min. Se
434F	0.12	1.00	0.040	0.15/ 0.40	1.00	16.00/ 18.25	0.50	0.75/ 1.25	0.35 Cu
440F	0.95/ 1.20	1.00	0.040	0.07 Min.	1.00	16.00/ 18.00	0.50	0.75	
440F Se	0.95/ 1.20	1.00	0.040	0.030	1.00	16.00/ 18.00		0.75	0.070 Min. Se
182-FM	0.080	1.25/ 2.50	0.040	0.15/ 0.40	1.00	17.50/ 19.50	-	1.50/ 2.50	



Film-Guide

TYPE 303 STAINLESS STEEL

PRODUCT:	Cine Processor
COMPONENT:	Film-Guide Roller
MATERIAL:	Type 303 Stainless Steel
BAR STOCK:	1½ Inch Round by 12 Feet Long Annealed, Centerless Ground
MACHINE TOOL:	Numerical Control Tape Lathe 33A
PRIMARY OPERATIONS:	Form, Drill, Bore, Hone, and Cut-Off
GROSS PRODUCTION:	28 Parts Per Hour
SFPM:	700 Maximum-190 Minimum
RPM:	1800 Maximum-580 Minimum
TOLERANCES:	±0.0005 Inch
FINISH:	32 Micro-Inch