STAINLESS STEELS FOR PUMPS VALVES AND FITTINGS

A DESIGNERS' HANDBOOK SERIES
Nº 9008

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Originally, this handbook was published in 1978 by the Committee of Stainless Steel Producers, American Iron and Steel Institute.

The Nickel Institute republished the handbook in 2020. Despite the age of this publication the information herein is considered to be generally valid.

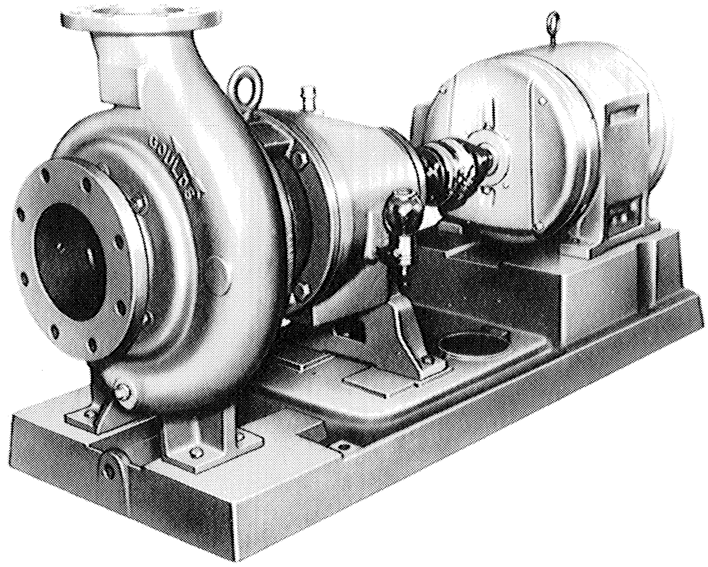
Nickel Institute

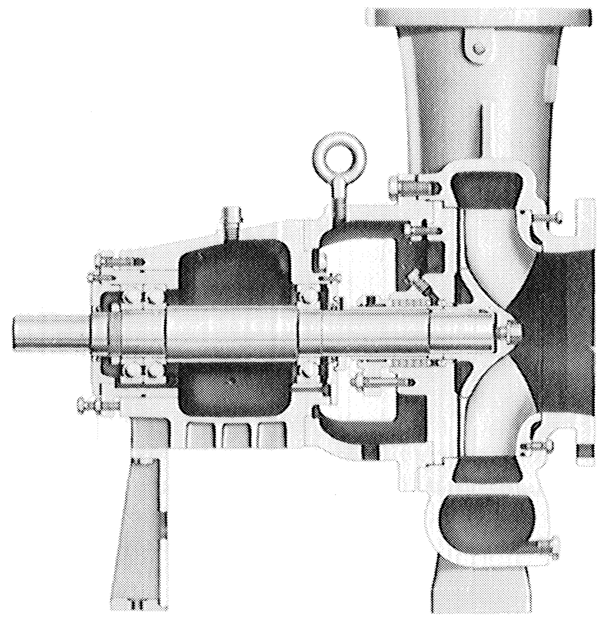
communications@nickelinstitute.org
www.nickelinstitute.org

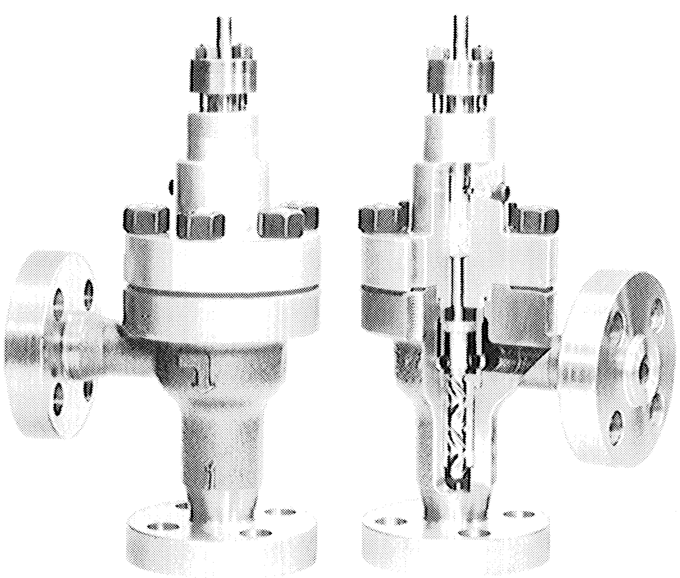
Stainless Steels for Pumps, Valves, and Fittings

Centrifugal pump, 2,800 GPM maximum capacity, 320 feet maximum head, 5,400 pounds total weight. Typical service: textiles, food processing, pollution control (water), chemical, petroleum, and metals production.

Source: Goulds Pumps, Inc.







High-pressure control valve, with carbon steel body, features internal components made of stainless steel to resist erosion/corrosion.

Source: Yarway Corporation

Contents

Introduction

It is difficult to imagine an oil refinery, a pharmaceutical plant, a petrochemical or chemical plant, a dairy or other food processing facility, or a power generating station without pumps and valves to move and control fluids. In fact, throughout all industries, pumps, valves and fittings are used so extensively, and they have become so familiar, that they are at times taken for granted.

As technology advances and plant capacities grow, and processes become more sophisticated, these fluid-handling devices become larger, more complex, and more expensive; and it becomes increasingly important to be more than casual in the selection of this equipment.

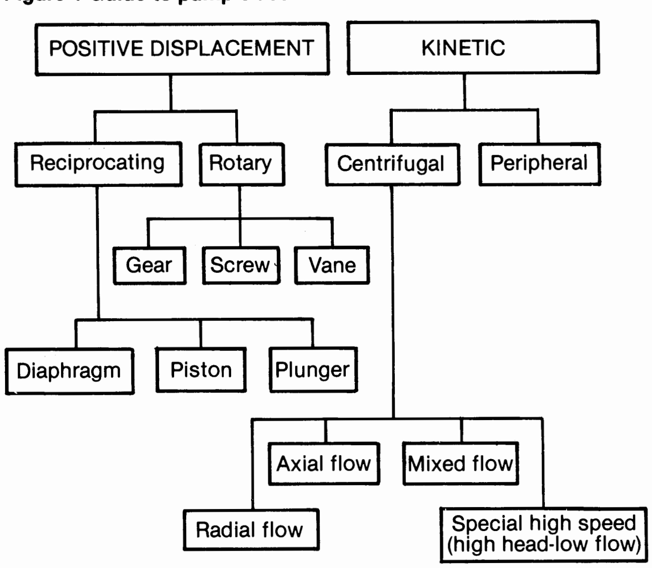
The selection of equipment for moving and controlling fluids involves many factors: equipment type and capacities, operating environment, materials of construction, availability, and, ultimately, cost. The selection of pumps, valves, and fittings is thoroughly discussed in published literature, and at the end of this booklet is a list of several outstanding references on the subject.

The purpose of this booklet, therefore, is to single out one aspect of equipment selection which is generally not discussed in great detail—namely construction materials—and to focus on a group of alloys that are recognized as the foremost materials in pumps, valves, and fittings. These materials are stainless steels.

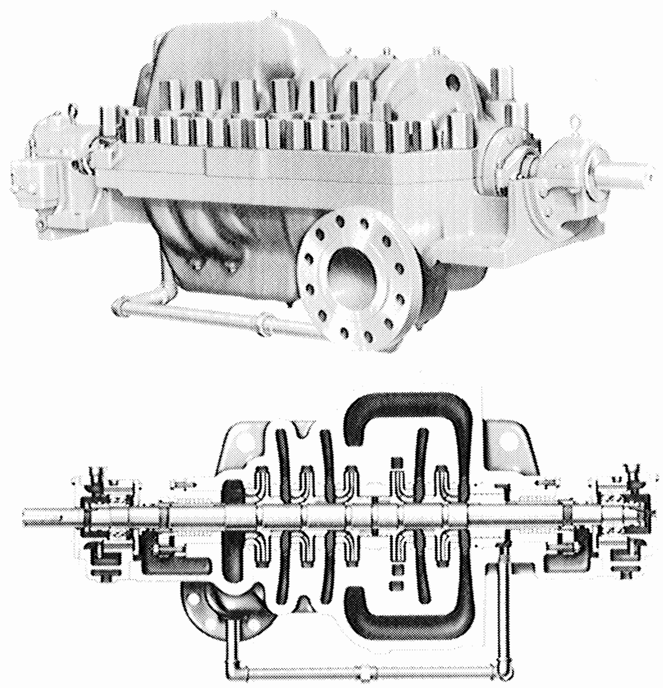
Stainless steels are modern metals developed to serve a modern world. From chemical plants to oil refineries, from dairy farms to food processing plants, stainless steels lend their unique properties to a variety of conditions imposed by the manufacture and use of pumps, valves, and fittings. These steels, for example, withstand corrosive attack in a broad range of aggressive environments. They possess strength and toughness at both extremes of the temperature scale, and they can be readily fabricated into the intricate shapes that make up the many components in pumps, valves, and fittings.

This booklet should provide a better understanding of stainless steels so designers and manufacturers, as well as the ultimate users, can specify the most effective alloy with a high degree of confidence.

Figure 1 Guide to pump classifications



Source: CHEMICAL ENGINEERING, October 11, 1971



Centrifugal pump, 2,500 GPM maximum capacity, 5,000 feet maximum head, 9,250 pounds total weight. Typical service: boiler feed, crude oil, lean oil, high-pressure processes. The cut-away view of the pump shows that many components are fabricated of bar, and for most services, the material is stainless steel—even if the body of the pump is carbon steel.

Note: Many of the photographs in this booklet show pumps and values that are available in different materials according to service requirements. All are available in stainless steel.

Source: Goulds Pumps, Inc.

Pumps

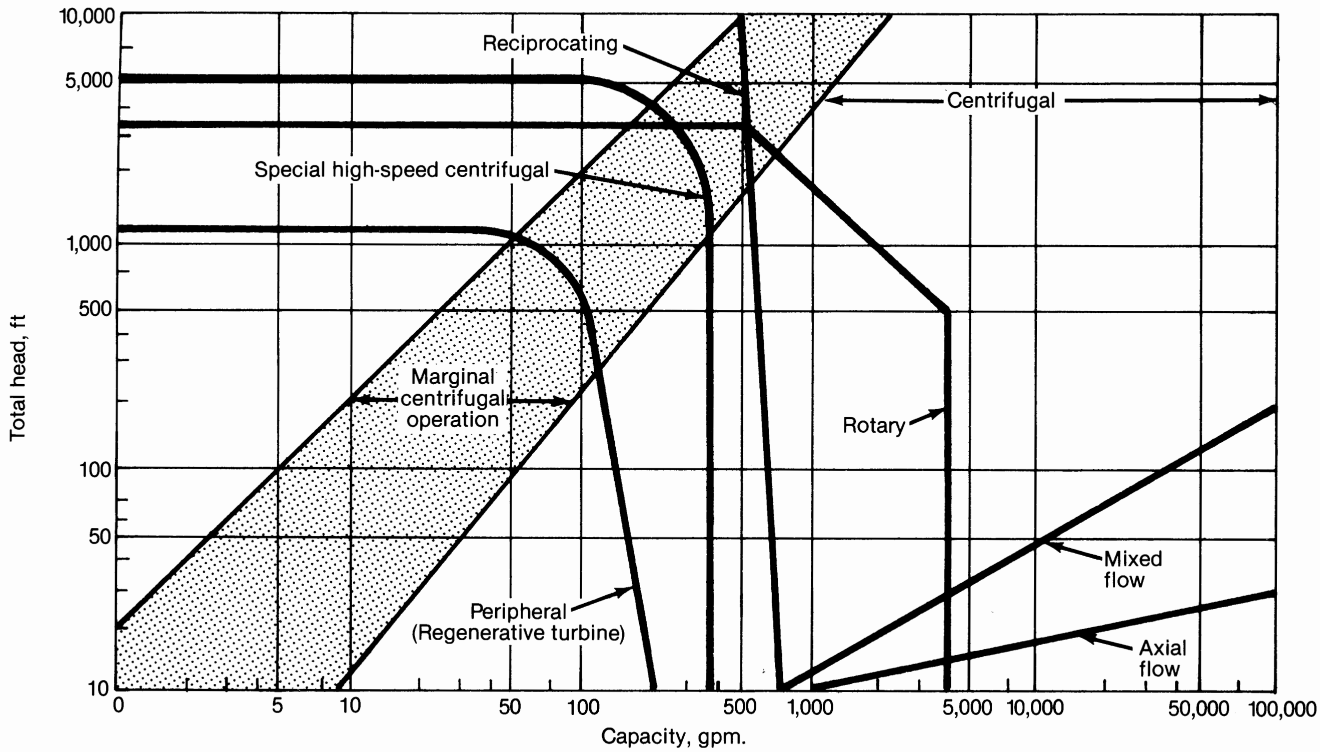
Pumps may be classified into two general types: *positive-displacement* and *kinetic* (or *dynamic*). Positive-displacement pumps are those in which energy is imparted to a liquid by an alternating increase and decrease of volume within the pump body, such as by the rotary motion of gears, screws, or vanes, or by reciprocating pistons or plungers.

Kinetic (or dynamic) pumps, such as centrifugal pumps, are those in which energy is imparted to the liquid by means of a moving impeller or a propeller rotating on a shaft. Velocity energy, imparted to the fluid by the rotating impeller, is converted to kinetic energy (or pressure) as the liquid leaves the impeller. Higher heads or greater velocity can be achieved by larger impeller diameter or higher rotating speed. Figure 1 shows pump categories schematically represented, and Figure 2 shows approximate capabilities of the various pump categories.

As a result of the wide range of available types and styles, pump capacities vary from several milliliters an hour, such as used for metering or in a laboratory, to 1 ¾ million gallons per minute in irrigation service. Some small gear pumps in aircraft weigh but a few ounces and consume only 1/250 horsepower (hp) while the largest have impellers weighing 137 tons that require 102,000 hp. As for temperatures, modern pumps are applied to cryogenic service or to high-temperature service approaching 1,500F.

Virtually every pump type, in any capacity, is available either as a complete stainless steel unit or with stainless steel in critical operating components, and more often than

Figure 2 Operating ranges of common process pumps



Source: CHEMICAL ENGINEERING, October 11, 1971

not the buyer can specify a particular stainless steel depending on service requirements. The stainless steels most frequently used in pumps are Types 304 and 316, although some higher-alloyed materials, such as Alloy 20Cb-3, are also available.

Valves

Valves, by their nature, do the opposite of pumps; they present a restriction to fluid flow. However, they are selected on the same basic considerations as pumps, namely equipment type and capacities, environment, materials of construction, availability and cost. Once the function and type of service have been established, a valve type can be selected according to its construction.

The principal features and most common uses of the various valve types are:

Gate valves—Minimum resistance to line flow. Used full open or full closed. Infrequent operation.

Plug valves—Tight shutoff. Full open or closed.

Ball valves—Flow path is unobstructed. Used for viscous fluids and slurries. Positive shutoff. Used full open or full closed.

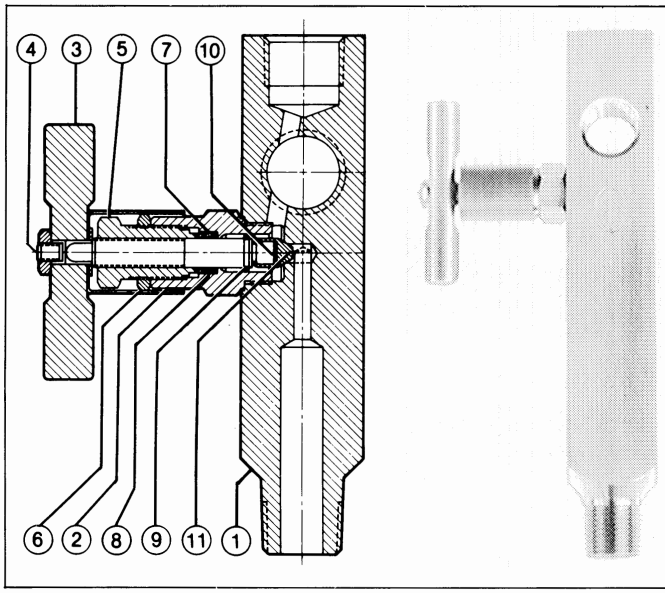
Butterfly valves—Mainly used for on-off and throttling services for large flows of gases and liquids at low pressures. Straight-through, open disk design prevents any buildup of solids and yields low pressure drop.

Globe valves—Infrequent operation. Positive shutoff. Seat generally placed parallel to flow direction.

Needle valves—Needle valves are basically globe valves having tapered needle-like plugs, fitting precisely within a seat. Used for accurate throttling of small flows.

Y-valves—Essentially globe valves with lower pressure drop.

Angle valves—Globe valve but with 90-degree turn.



Needle valve for gauge service in Type 316 features six different stainless steel types each selected for a specific purpose:

1. *Body—Type 316 for maximum corrosion resistance*
2. *Housing—Type 316*
3. *Handle—Type 303 for machineability*
4. *Hex Nut—Type 304 for corrosion resistance and machineability*
5. *Packing Nut—Type 416 for economy and machineability*
6. *Lock Nut—Type 303 for machineability*
7. *Packing*
8. *Stem—Type 316 for maximum corrosion resistance*
9. *Retaining Ring—Type 316 for maximum corrosion resistance and strength*
10. *Disc—S17700 for hardness, corrosion resistance, and galling resistance*
11. *Stem Point—S17400 for hardness and corrosion resistance*

Even with a carbon steel body for noncorrosive service, the internal components are made of stainless steel for resistance to rust and corrosion.

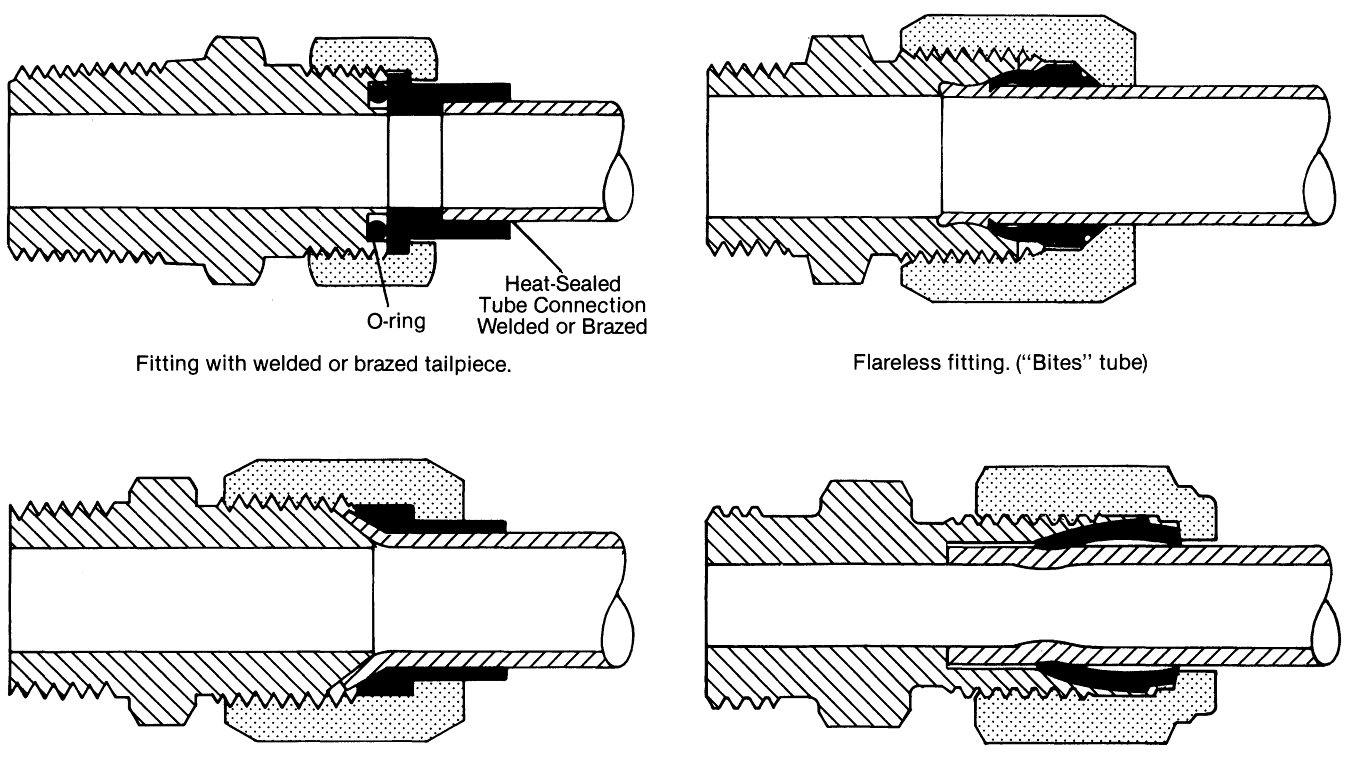
Source: Hoke Inc.

Figure 3 Valve Selection Guide

Valve Type	Size Range, in.	Pressure Rating, psi.	Temperature Rating, F.	Materials of Construction	Service
Globe	½ to 30	to 2,500	to 1,000	Stainless steel, bronze, iron, steel and special alloys.	Throttling & shut-off on clean fluids.
Angle	⅛ to 10	to 2,500	to 1,000	Stainless steel, bronze, iron, steel and special alloys.	Throttling & shut-off on clean, viscous or slurry services.
Gate	½ to 48 (larger in some designs)	to 2,500	to 1,800	Stainless steel, bronze, iron, steel and special alloys.	Shut-off (limited throttling) clean & slurry services.
Butterfly	2 to several feet	to 2,000 (limited pressure drop)	to 2,000 (limited to lower temperature if liners or soft seats are used)	Castable or machinable materials. Liners can be plastic, rubber or ceramic.	Throttling (shut-off only with special designs or seats) clean & slurry services.
Plug	to 30	to 5,000	to 600	Stainless steel, iron, steel & various alloys. Complete rubber or plastic lined valves are available.	Shut-off (throttling with some designs)
Ball	⅛ to 42	to 10,000	cryogenic to 1,000	Stainless steel, iron, steel, brass, bronze, plastic and special alloys for nuclear applications, complete plastic lined valves.	Throttling & shut-off on clean, viscous or slurry services.
Relief	½ thru 6 (inlet)	to 10,000	cryogenic to 1,000	Stainless steel, iron, bronze, steel, nickel steel & special alloys.	Pressure limiting.
Needle	⅛ to 1	to 10,000	cryogenic to 500	Stainless steel, bronze, iron, steel.	Fine flow throttling & shut-off clean services.
Check	⅛ to 24	to 10,000	to 1,200	Stainless steel, bronze, iron, steel and special alloys.	Prevent flow reversal (special designs prevent excess flow)

Source: CHEMICAL ENGINEERING, October 11, 1971

Figure 4



Fitting with welded or brazed tailpiece.

Flareless fitting. ("Bites" tube)

Flared fitting.

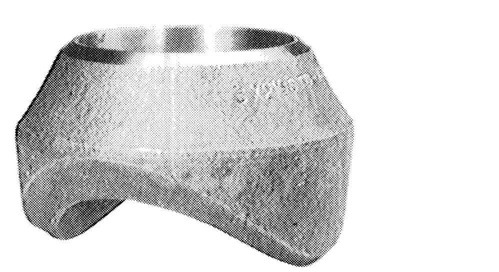
Flareless fitting. (Crimps tube)

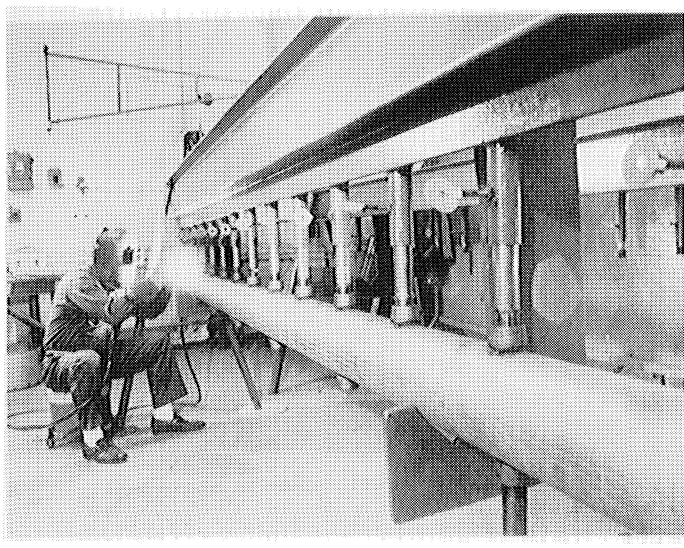
Pipeline fabricators use forged Weldolet fittings (top photograph) in making branch connections to a main pipe run. For example, the photograph (lower left) shows a typical fixture for attaching the forged fittings to a pipe section. The fixture serves a dual purpose: It holds the fittings in position for welding, and it clamps the pipe to prevent deflection caused by the weld heat.

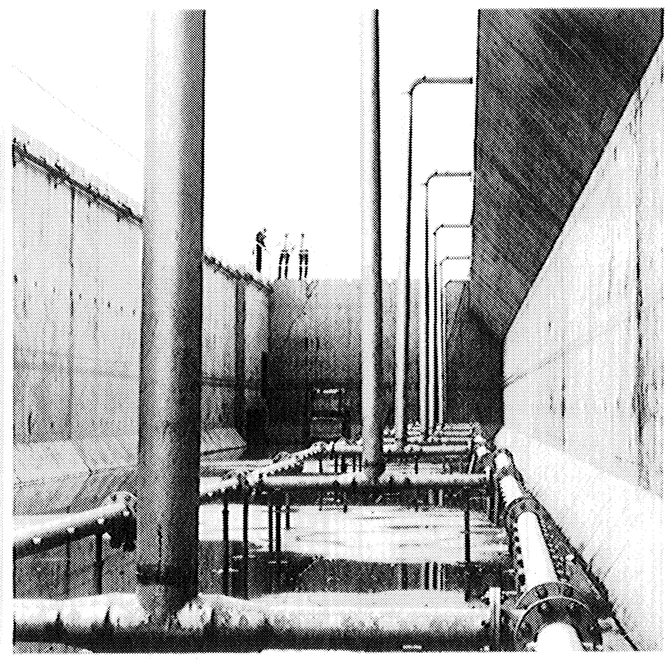
The other photograph shows an installation in a municipal sewage treatment plant. The fittings are attached to the horizontal pipe tee sections. Attached to each fitting will be a small-diameter pipe and porous ceramic air diffuser. When operating, air will be forced out through the diffusers to bubble up through the raw sewage in the tank.

By forging the fitting, optimum mechanical properties are achieved and minimum machining is required for the intricate shape. Stainless steel Types 304 and 316 provide strength and resistance to corrosion.

Source: Bonney Forge Division, Gulf + Western Manufacturing Company







There are other valves for special requirements of controlling or restricting fluid flow.

Figure 3 lists several of the most common valve types and shows typical size, pressure and temperature rating, and construction materials. In every case, stainless steel is one of the principal materials.

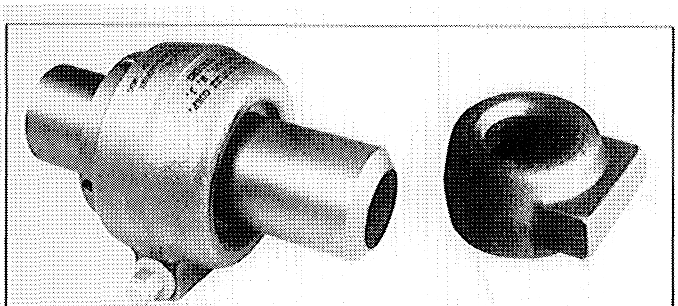
Fittings

Fluid handling systems have many accessory items in addition to pumps and valves. These accessories include flanges and other pipe coupling devices, lubrication and seal water lines, and pressure or vacuum instrument lines, all of which are lumped together under the general heading of fittings. Most prominent of these items are tube fittings of various descriptions. Figure 4 illustrates the most common types of tube fittings: flared, flareless, brazed or welded.

The principal advantage of these small fittings is that they can be used with thin-wall stainless steel tubing, in sizes up to two inches in diameter, for high or low pressure or vacuum service. For service in corrosive environments, stainless steel Type 304 or 316 is usually specified.

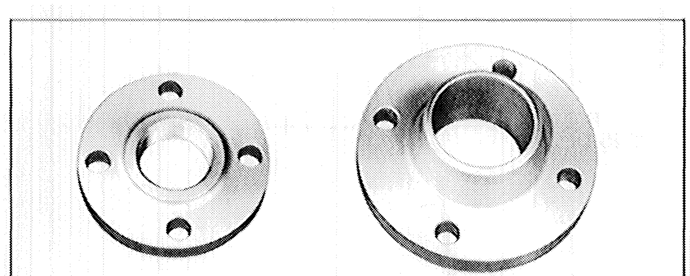
Straight tubular fittings are generally machined from stainless steel bar while the shaped bodies are machined from stainless steel forgings.

Other fitting types are shown in the photographs, such as forged fittings for making branch connections to a main pipe run and gear-powered unions that can be used in place of flanges or other bolted connections.



A gear-powered union is used instead of flanges or other bolted connections in high-pressure piping systems to save weight, space, and installation time. For instance, a stainless steel gear-powered union for a 4" pipe size weighs only 22 pounds, whereas its ASA bolted-flange counterpart weighs 30 pounds. Forging the collar gives the best possible strength and reduces the amount of machining needed to complete the part.

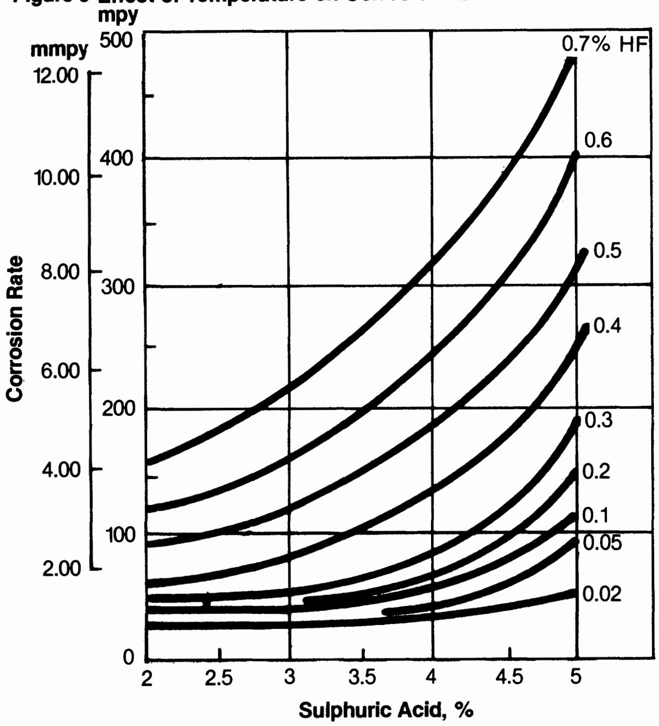
Source: McWillians Forge Company and Resistoflex Corporation



Pipeline flanges, fittings, and special components for nuclear power plants, refineries, chemical processing plants, and cryogenic service are routinely forged of Types 304, 304L, 316, and 316L stainless steels. Forging billets are supplied in seversl sizes: 4," 6," and 8" square. Because flanges are subjected to high stresses and corrosive environments, forged stainless steel flanges are preferred.

Source: Alloy Flange and Fittings Division, Gulf + Western Manufacturing Company

Figure 5 Effect of Temperature on Corrosion Rate



Small quantities of hydrofluoric and sulfuric acids can have a serious effect on Type 316 stainless in 25% P_2O_5 phosphoric acid with 1.5% F as H_2SiF_6 at 190 F (90 C).

Source: E. Pelitti, "Corrosion: Materials of Construction for Fertilizer Plants and Phosphoric Acid Service." Chemistry and Technology of Fertilizers. American Chemical Society Monograph Series. Reinhold Publishing Corp. (1960), pp. 576-632.

Factors in Selecting Construction Material

Having established the function and type of equipment needed for a particular application, the specifier must evaluate the materials available for construction of this equipment. There are numerous sources of information that will help in this evaluation.

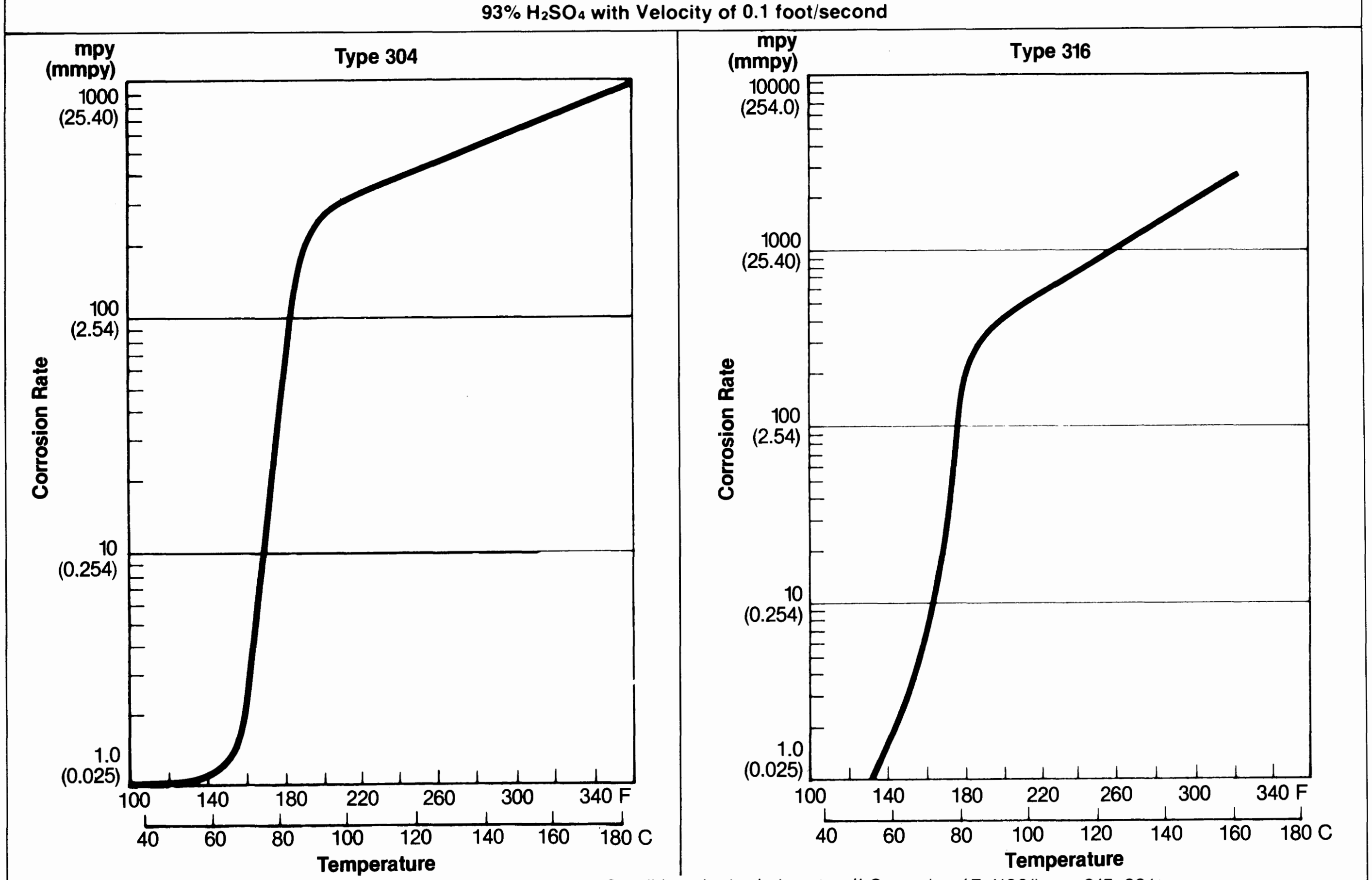
The best source is practical experience within one's own organization, especially in large companies having materials or corrosion specialists whose responsibilities include compiling data on the process equipment at the company's various plants.

Where such technical support is not available or a first-of-a-kind process is involved, corrosion data may be obtained through laboratory or pilot plant corrosion tests. Service tests are the most reliable in determining optimum material, and ASTM G-4-48 (1974) is a recommended practice for carrying out such tests. Tests should cover conditions both during operation and during shutdown. For instance, sulfuric, sulfurous or polythionic acid condensates formed in some processes during shutdowns may be more corrosive than the process stream itself. Tests should be conducted under the worst operating conditions anticipated.

The specifier can also be guided by equipment manufacturers' suggestions as well as information available in published literature. However, published data should not be taken as valid for the environments cited, because other conditions in actual service may affect the corrosion rate

Figure 6 Effect of Temperature on Corrosion Rate

93% H_2SO_4 with Velocity of 0.1 foot/second

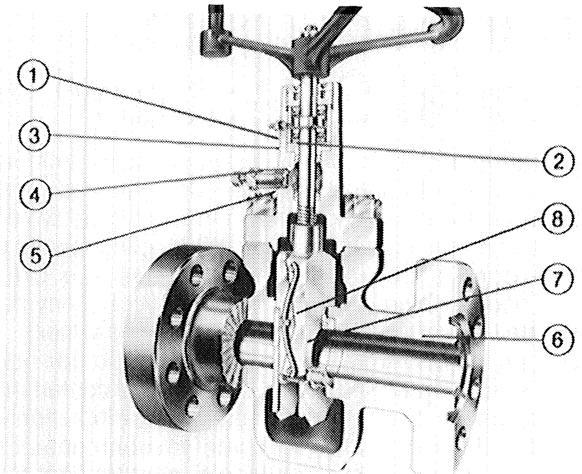


Source: A. O. Fisher, "New Methods of Simulating Corrosive Plant Conditions in the Laboratory." Corrosion 17, (1961), pp. 215t-221t.

and must be considered. For example, small differences in chemical content and temperature, such as might occur during processing upsets, can change corrosion rates considerably, as suggested by Figures 5 and 6. Figure 5 shows small quantities of hydrofluoric and sulfuric acids as having a serious effect on Type 316 stainless steel in an environment of 25% phosphoric acid. Figure 6 shows the effects of temperature on Types 304 and 316 in concentrated sulfuric acid. A rule of thumb is that the corrosion rate of a material doubles for each 30 degrees (C) rise in temperature.

Another critical factor is the presence of solids in the process stream. It is not uncommon for a given alloy to range from satisfactory to unsatisfactory in a given chemical process with hydraulic design being the only variable factor. Failure to cite the presence of solids on the data sheet for a solution is common. This oversight can be the cause of catastrophic erosion-corrosion failures of many pumps and valves if solids are actually present.

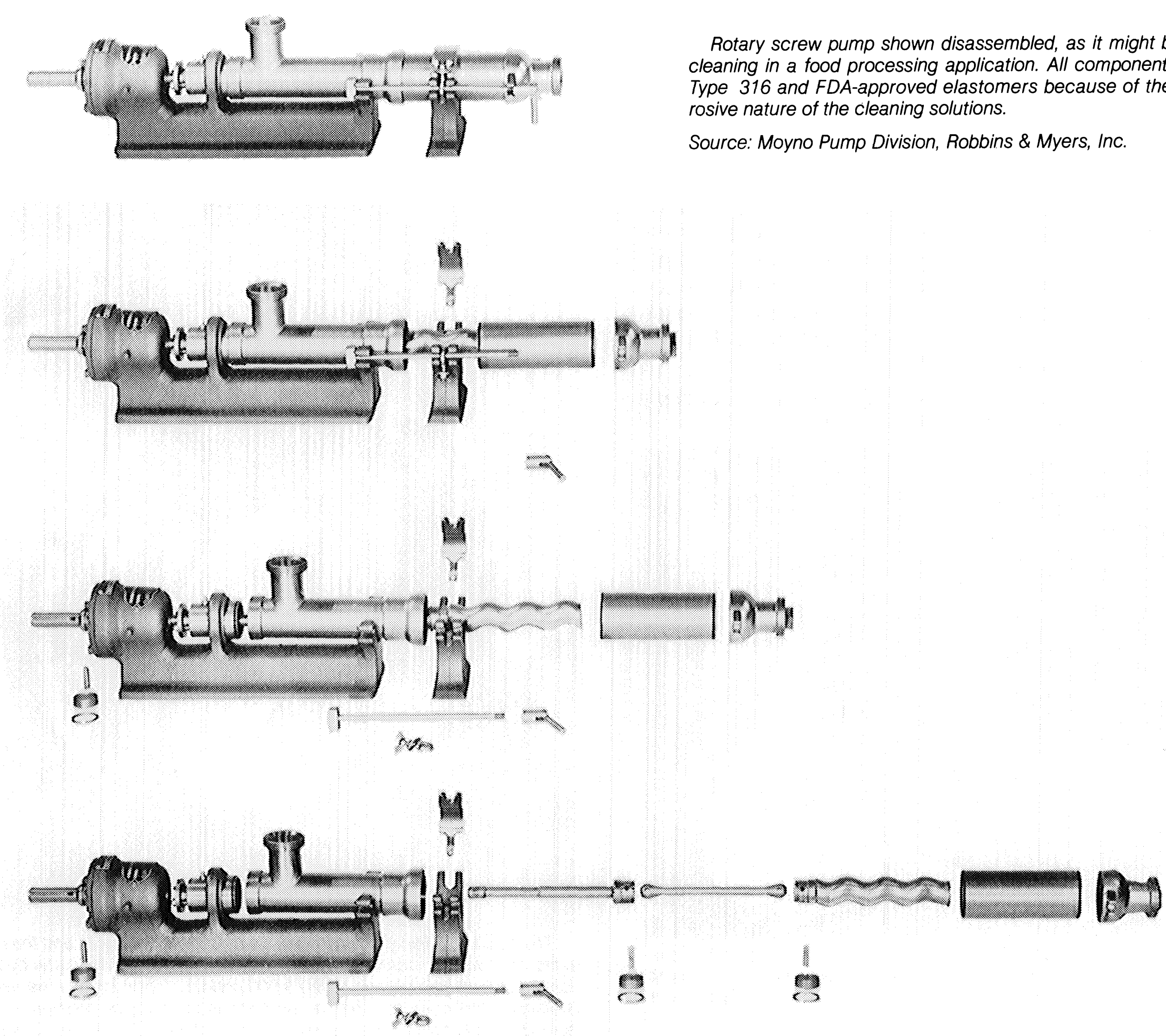
Air in a solution also can be quite significant. In some instances, the absence or presence of air is the difference between success and failure, in that it can conceivably convert a reducing solution into an oxidizing one. Under these circumstances an altogether different material may be required.



For underwater service this positive-sealing API gate valve features the following components in stainless steel:

1. *Locknut (Type 316)*
2. *Stem (Type S17400)*
3. *Bearing Retainer Nut (Type 316)*
4. *Grease Fitting*
5. *Packing Fitting*
6. *Lined Ring Groove*
7. *Seats*
8. *Gate (Nitrohardened stainless steel for galling resistance)*

Source: W-K-M Valve Group, ACF Industries, Inc.



Rotary screw pump shown disassembled, as it might be for cleaning in a food processing application. All components are Type 316 and FDA-approved elastomers because of the corrosive nature of the cleaning solutions.

Source: Moyno Pump Division, Robbins & Myers, Inc.

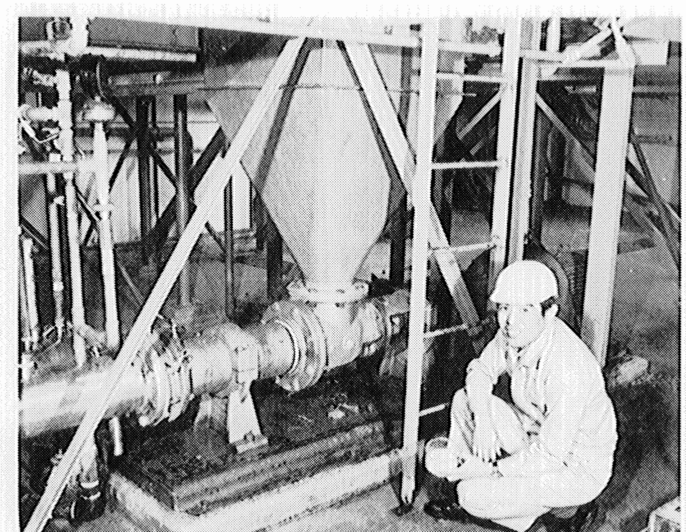
Other Factors in Material Selection(A)

Evaporation and recirculation of process streams can change the concentration of corrosive elements and cause a buildup of corrosives to aggressive levels. A typical system in which this condition can develop is in cooling towers or pollution control scrubbers. If chlorides are present in the cooling tower water or scrubber liquid, they can concentrate to levels which exceed those of sea water.

Where purity of product is essential, particular note should be made of any element that may cause contamination problems, whether it be discoloration, alteration of taste, or solution breakdown. In some environments, the pickup of only a few parts per billion of contaminant can create a serious problem. Fluid contamination is a particular concern in selecting materials for pumps and valves wherein the flow rate and presence of solids can cause erosion of metal surfaces, as opposed to other types of process equipment such as tanks where velocity and/or solids may have little or no effect. A good example of a process requiring the use of stainless steel to prevent product contamination by fluid handling equipment is the manufacture of paper. Although paper pulp may not be particularly aggressive toward carbon steel, traces of rust can cause severe discoloration of the product. Conversely, Type 304 stainless steel should not be used for pumps, valves, or other equipment handling glacial acetic acid because of the tendency of Type 304 to cause discoloration. Type 316 or 317 is a better choice for such service.

Whether the process is continuous or intermittent is also a factor affecting service life of pumps and valves. Intermittent duty in some environments can be more destructive than continuous duty, especially if the component retains corrosive fluid during downtime that could result in accelerated corrosion at the liquid interface. Perhaps of equal importance is whether or not the equipment is drained and/or flushed when not in service.

(Note A. Excerpted with special permission from *CHEMICAL ENGINEERING* February 18, 1974. Copyright 1974 by McGraw-Hill Inc.)



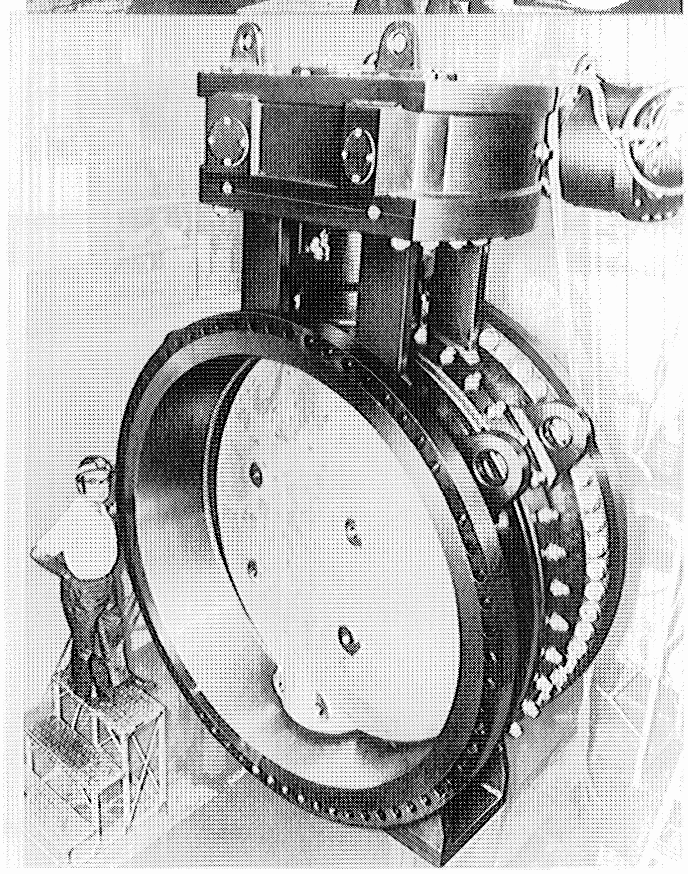
Rotary screw pump installed in food processing line handling a mixture of salt water, cooked soy bean grits and crushed whole wheat grain. Pump handles 50 tons per hour with a vertical discharge lift of 30 feet. Type 316 is used throughout.

Source: Moyno Pump Division, Robbins & Myers, Inc.

Types of Corrosion in Pump, Valves, and Fittings

The corrosion mechanisms to which pumps and valves are susceptible are similar to those encountered by other process equipment. However, because pumps and valves are more intricate and exposed to more severe hydraulic conditions, such as higher velocities and pressures, corrosion problems are frequently more prevalent. It is not the intent here to describe in detail these corrosion mechanisms, but only to mention them briefly so that they can be recognized.

1. General or uniform corrosion is the most common type that is characterized as having the same rate of deterioration over the entire wetted or exposed surface. Predicting the incidence and rate of general corrosion in a pump or valve, however, can be difficult because of the varying

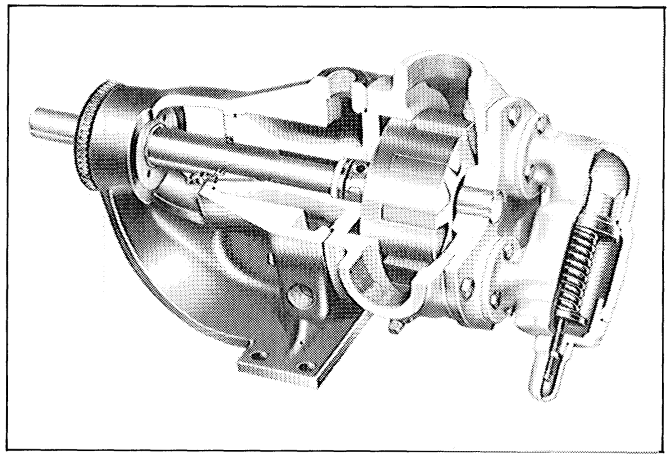


The operating disc of this butterfly valve is 96" in diameter, and the complete valve weighs more than 30 tons. The shaft is 14 ¾" in diameter by 173" long, and it weighs approximately 9,000 pounds. A precipitation hardening stainless steel gives the shaft a combination of corrosion resistance, high strength, and abrasion resistance. About 45 of these valves are scheduled for fresh-water service.

velocities, temperatures and pressures of the process streams within the component. To avoid problems, stainless steels are specified because of their excellent resistance to general or uniform corrosion in most chemical environments.

2. Unlike general corrosion, concentration-cell or crevice corrosion is a very localized attack caused when small quantities of stagnant solution become trapped in such areas as threads, gasket surfaces, holes, crevices, surface deposits (especially of an uneven or spotty nature), and under fastener heads. When there is a difference in the concentration of metal ions or oxygen in the stagnant area, as compared to that of the main body of the fluid, crevice corrosion is likely to occur. This difference causes an electrical current to flow between the two areas, resulting in rapid attack in the stagnant area. Usually this form of corrosion does not occur in pumps or valves unless their design has ignored the factors which contribute to concentration-cell corrosion.

3. Pitting corrosion is an insidious, destructive and often unpredictable form of corrosion. It is extremely localized showing up as small or large holes (usually small) on the surface. Although the weight loss from pitting may be an insignificant percentage of the weight of the part, failure can be total if a pit perforates the section, as for example the wall

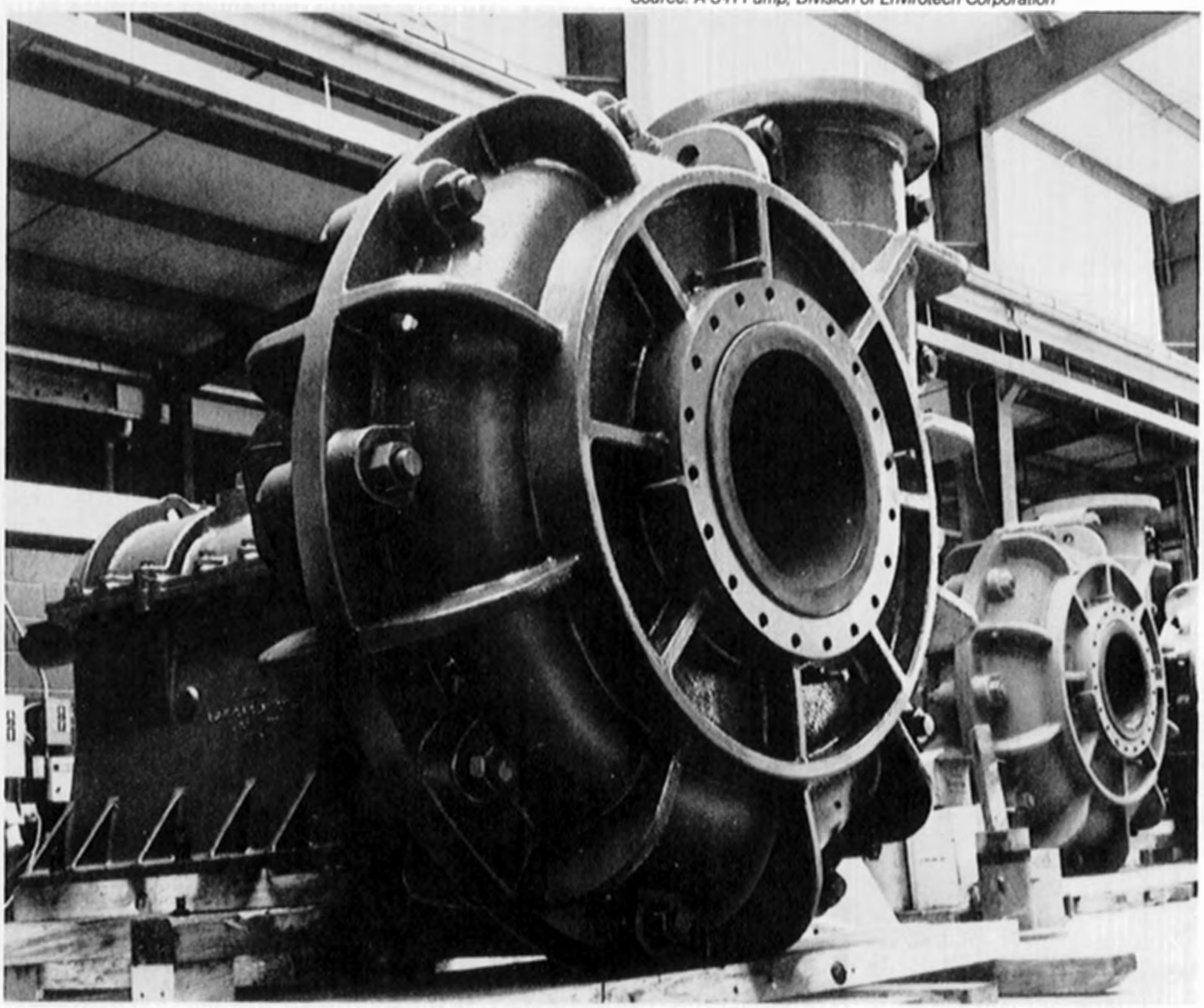


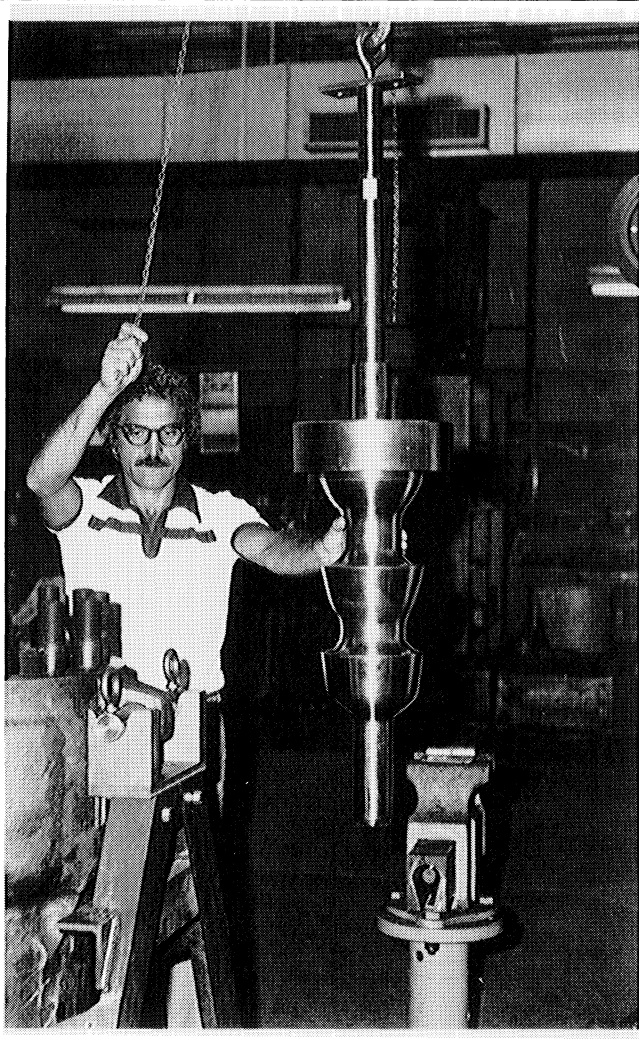
Rotary vane pump for high-viscosity materials, such as peanut butter, syrups, paints, coatings, resins, and foams. This model available in pump ratings of 1½ to 110 GPM and in various stainless steels.

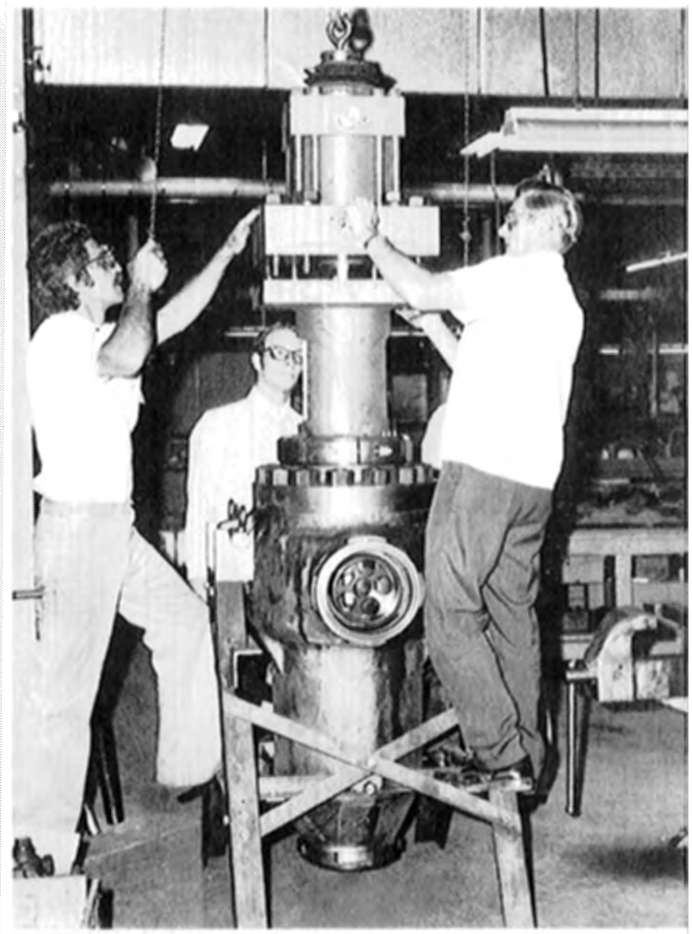
Source: Viking Pump Division, Houdaille Industries, Inc.

Three rubber-lined, 20" x 20" slurry pumps for phosphoric acid service use Type 316 for all wetted parts and mechanical seals. These pumps are capable of moving 20,000 gallons of slurry per minute under total dynamic heads of 165 feet.

Source: A-S-H Pump, Division of Envirotech Corporation

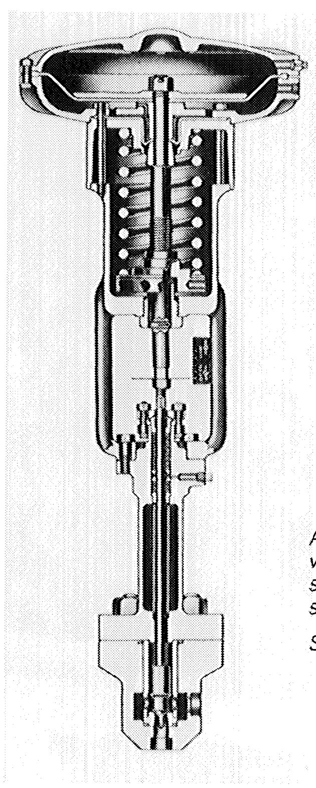






Trim (left) for 1,500 pound anticavitation control valve is stainless steel for pressure/temperature conditions as encountered in nuclear service.

Source: Leslie Co.



High-pressure (2,500 psi ASA), cage trim needle control valve features forged stainless steel body and stainless steel stem, seat rings and trim cages.

Source: Leslie Co.

of a tube. Chlorides, in particular, are conducive to the onset of pitting. This form of corrosion is sometimes observed in conjunction with concentration-cell corrosion, but it can occur on surfaces other than stagnant ones. Among the stainless steels, those containing molybdenum, such as Types 316 and 317, offer a higher degree of protection against pitting attack or crevice corrosion.

4. Stress-corrosion cracking is a localized failure caused by a combination of tensile stress, elevated temperature, and a specific medium. It is manifested by the formation of a crack or rupture in the metal. Corrosion fatigue is a variant of stress-corrosion cracking which can arise under conditions of low-cycle stresses applied to a component, such as a pump shaft in a corrosive medium.

A number of alloy systems have been known to exhibit stress-corrosion cracking in contact with certain environments—brass in ammonia, carbon steel in nitrate solutions, titanium in methanol, aluminum in sea water, and gold in acetic acid. Some 300 Series stainless steels are susceptible to stress-corrosion cracking in chloride solutions. On the other hand, the standard AISI ferritic stainless steels, such as Types 405 and 430, are resistant to stress-corrosion cracking, as well as some high-alloy 300 Series types, such as Type 329.

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 recent commercialization of new melting and refining processes has resulted in several new ferritic stainless steels with improved characteristics, which can be classified as follows; those with about 18% chromium having corrosion resistance similar to Type 304, and those with more than 18% chromium with resistance to corrosion comparable or superior to Type 316 in many media. These ferritic stainless steels are not AISI numbered grades.

Five such ferritic stainless steels commercially available are:

Alloy	ASTM	UNS
18 Cr and Titanium (Alloy 439)	XM-8	
18 Cr—2 Mo		
18 Cr—2 Mo + S	XM-34	S18200
26 Cr—1 Mo (electron beam refined).	XM-27	S44625
26 Cr—1 Mo and Titanium		S44626

5. Intergranular corrosion is a selective form of corrosion at grain boundaries of the metal. While it is primarily associated with some stainless steels, intergranular corrosion can also occur with other alloy systems.

Heating in the temperature range of 800-1650F, such as occurs in welding, makes the grain boundaries of some 300 Series stainless steels subject to intergranular attack by a corrosive (acid) environment. Intergranular corrosion can be avoided by annealing, selection of a low-carbon grade (such as Type 304L), or selection of a stabilized grade (such as Type 321 or 347.)

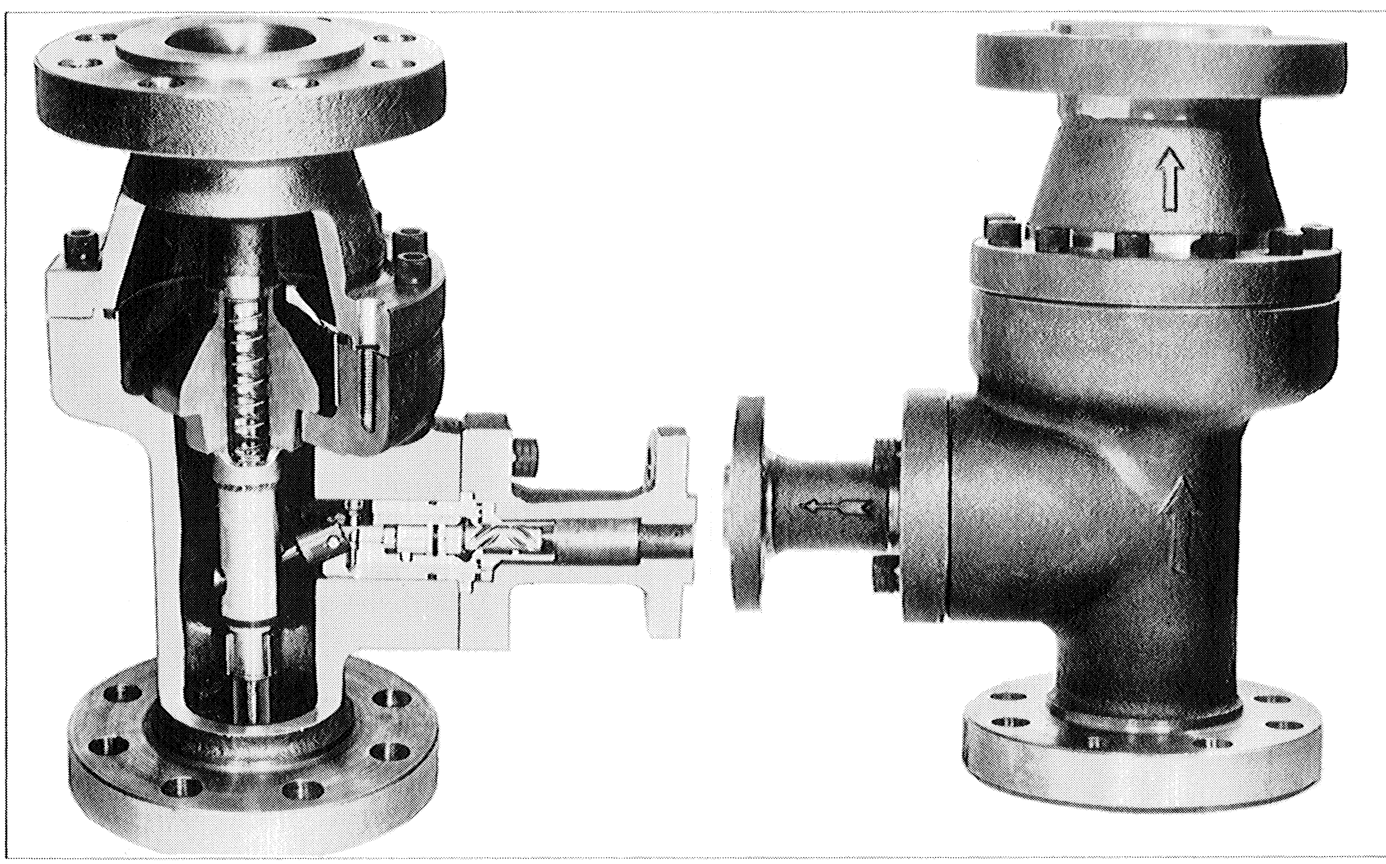
6. Galvanic corrosion may occur when dissimilar metals are in contact or otherwise electrically connected in an electrolyte.

When it is necessary to have two dissimilar metals in contact, caution should be exercised to make certain that the total surface area of the less-noble metal is greater than that of the more corrosion-resistant metal.

7. Erosion-corrosion is characterized by an accelerated attack from the combination of corrosion and mechanical wear. The erosion can be caused by solids in suspension and/or a high velocity of the fluid. It can be quite common in pumps and valves if the erosive action destroys the protective surface film of the metal. To avoid erosion-corrosion, materials in pumps and valves should possess corrosion resistance, strength, and high hardness. These properties characterize many stainless steels.

Cavitation is a special form of erosion-corrosion that results from the collapse or implosion of gas bubbles against a metal surface in high-pressure regions. The stresses are high enough to flake metal off the surface. The same material qualities mentioned above impart cavitation resistance. A change in piping or in increase in suction pressure are also beneficial.

8. Corrosion can ensue from the selective leaching of one element from a solid alloy by the corrosive medium. It is typified by dezincification and dealuminumification in some nonferrous alloys.



An automatic recirculation control valve is designed to permit passage of limited cooling water through a centrifugal feed pump during critical low-load periods. While the large components, such as the body, bonnet, and check valve are cast steel, the critical internal components are stainless steel.

Source: Yarway Corporation

Table 1
AUSTENITIC STAINLESS STEELS

AISI Type (UNS)	Chemical Analysis % (Max. unless noted otherwise) C	Mn	P	S	Si	Cr	Ni	Mo	Other	Nominal Mechanical Properties (Annealed bar unless noted otherwise) Tensile Strength ksi	Tensile Strength MPa	Yield Strength (0.2% offset) ksi	Yield Strength (0.2% offset) MPa	Elongation in 2″ (50.80 mm) %	Hardness (Rockwell)	Product Form
201 (S20100)	0.15	5.50/7.50	0.060	0.030	1.00	16.00/18.00	3.50/5.50		0.25N	95	655	45	310	40	B90	(Sheet)
202 (S20200)	0.15	7.50/10.00	0.060	0.030	1.00	17.00/19.00	4.00/6.00		0.25N	90	612	45	310	40	B90	(Sheet)
205 (S20500)	12/0.25	14.00/15.50	0.030	0.030	0.50	16.50/18.00	1.00/1.75		0.32/0.40N	120.5	831	69	476	58	B98	(Plate)
301 (S30100)	0.15	2.00	0.045	0.030	1.00	16.00/18.00	6.00/8.00			110	758	40	276	60	B85	(Sheet)
302 (S30200)	0.15	2.00	0.045	0.030	1.00	17.00/19.00	8.00/10.00			85	586	35	241	60	160**	
302B (S30215)	0.15	2.00	0.045	0.030	2.00/3.00	17.00/19.00	8.00/10.00			90	621	40	276	50	B85	
303 (S30300)	0.15	2.00	0.20	0.15	1.00	17.00/19.00	8.00/10.00	0.60*		90	621	35	241	50		
303Se (S30323)	0.15	2.00	0.20	0.060	1.00	17.00/19.00	8.00/10.00		0.15Se (Min.)	90	621	35	241	50		
304 (S30400)	0.08	2.00	0.045	0.030	1.00	18.00/20.00	8.00/10.50			85	586	34	234	60	149**	
304L (S30403)	0.030	2.00	0.045	0.030	1.00	18.00/20.00	8.00/12.00			75	517	30	207	60	149**	
S30430	0.08	2.00	0.045	0.030	1.00	17.00/19.00	8.00/10.00		3.00/4.00Cu	73	503	31	214	70	B70	(Wire)
304N (S30451)	0.08	2.00	0.045	0.030	1.00	18.00/20.00	8.00/10.50		0.10/0.16N	90	621	42	290	55	180**	
305 (S30500)	0.12	2.00	0.045	0.030	1.00	17.00/19.00	10.50/13.00			85	586	38	262	50	B80	(Sheet)
308 (S30800)	0.08	2.00	0.045	0.030	1.00	19.00/21.00	10.00/12.00			115	793	80	552	40		(Wire)
309 (S30900)	0.20	2.00	0.045	0.030	1.00	22.00/24.00	12.00/15.00			95	655	40	276	45	B83	
309S (S30908)	0.08	2.00	0.045	0.030	1.00	22.00/24.00	12.00/15.00			95	655	40	276	45	B83	
310 (S31000)	0.25	2.00	0.045	0.030	1.50	24.00/26.00	19.00/22.00			95	655	45	310	50	B89	
310S (S31008)	0.08	2.00	0.045	0.030	1.50	24.00/26.00	19.00/22.00			95	655	45	310	50	B89	
314 (S31400)	0.25	2.00	0.045	0.030	1.50/3.00	23.00/26.00	19.00/22.00			100	689	50	345	45	180**	
316 (S31600)	0.08	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00		80	552	35	241	60	B78	
316F (S31603)	0.08	2.00	0.20	0.10(Min.)	1.00	16.00/18.00	10.00/14.00	1.75/2.50		82	565	35	241	57	143**	
316L (S31620)	0.030	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00		85	586	55	379	45	190**	
316N (S31651)	0.08	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00	0.10/0.16N	90	621	42	290	55	180**	
317 (S31700)	0.08	2.00	0.045	0.030	1.00	18.00/20.00	11.00/15.00	3.00/4.00		85	586	40	276	50	160**	
317L (S31703)	0.030	2.00	0.045	0.030	1.00	18.00/20.00	11.00/15.00	3.00/4.00		86	593	38	262	55	B85	(Sheet)
321 (S32100)	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/12.00		5xC Ti (Min.)	95	655	60	414	40	185**	
329 (S32900)	0.10	2.00	0.040	0.030	1.00	25.00/30.00	3.00/6.00	1.00/2.00		105	724	80	552	25	230**	(Strip)
330 (N08330)	0.08	2.00	0.040	0.030	0.75/1.50	17.00/20.00	34.00/37.00		0.10Ta 0.20Cb	85	586	42	290	45	180**	
347 (S34700)	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/13.00		10xC Cb-Ta (Min.)	90	621	35	241	50	160**	
348 (S34800)	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/13.00		10xC Cb+Ta (Min.)	90	621	35	241	50	160**	
384 (S38400)	0.08	2.00	0.045	0.030	1.00	15.00/17.00	17.00/19.00			75	517	35	241	55	B70	(Wire)

* May be added at manufacturer's option. ** Brinell

Source: Steel Products Manual, "Stainless and Heat Resisting Steels, December 1974," American Iron and Steel Institute.

Stainless Steels

Stainless steel is often referred to in the singular sense as though it were one material, whereas in actuality there are numerous stainless steel compositions. American Iron and Steel Institute identifies 57 stainless steels as standard AISI-numbered alloys, and there are many modifications of these alloys and many proprietary alloys.

Three general methods are used to identify the AISI-numbered stainless steels. They are:

1. Metallurgical structure.
2. The AISI numbering system, namely 200, 300, and 400 Series numbers which refer to chemical composition ranges or limits.
3. The Unified Numbering System (UNS), which was developed by the American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers (SAE). UNS numbers apply to all commercial metals and alloys.

Tables 1-4 list all AISI-numbered stainless steels according to metallurgical structure; austenitic, ferritic, martensitic, and precipitation hardening.

The *austenitic* stainless steels (Table 1) containing chromium, nickel and other alloying elements are identified as AISI 300 Series types. Alloys containing chromium, nickel, and high manganese levels are identified as AISI 200 Series types.

The 31 stainless steels in the austenitic group have different compositions and properties but many family characteristics. They can be strengthened by cold working, but not by heat treatment. They have high corrosion resistance and exceptional formability. When they are in the annealed condition, all are nonmagnetic although some become slightly magnetic by cold working. (Cast annealed austenitic stainless steels may be slightly magnetic.)

Type 304 (frequently referred to as 18-8 stainless) is the general-purpose alloy of the austenitic group.

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

Martensitic stainless steels (Table 3) are straight-chromium AISI 400 Series types that are hardenable by heat treatment. They are magnetic. They can resist corrosion in mild environments. They have fairly good ductility, and some can be heat treated to tensile strengths exceeding 200,000 psi. Type 410 is the general-purpose alloy of the martensitic group.

Precipitation hardening stainless steels (Table 4) are chromium-nickel grades which also contain copper, or aluminum. Addition of these elements makes it possible for these grades to be hardened by solution treating and aging.

With respect to the Unified Numbering System, the UNS designations are shown with each AISI type number in Tables 1-4, except for five stainless steels to which AISI has assigned UNS designations only.

Table 2
FERRITIC STAINLESS STEELS

	Chemical Analysis % (Max. unless noted otherwise)									Nominal Mechanical Properties (Annealed bar unless noted otherwise)						
AISI Type (UNS)	C	Mn	P	S	Si	Cr	Ni	Mo	Other	Tensile Strength ksi	Tensile Strength MPa	Yield Strength (0.2% offset) ksi	Yield Strength (0.2% offset) MPa	Elongation in 2″ (50.80 mm) %	Hardness (Rockwell)	Product Form
405 (S40500)	0.08	1.00	0.040	0.030	1.00	11.50/14.50			0.10/0.30 Al	70	483	40	276	30	150**	
409 (S40900)	0.08	1.00	0.045	0.045	1.00	10.50/11.75			6xC/0.75 Ti	65	448	35	241	25	B75	
429 (S42900)	0.12	1.00	0.040	0.030	1.00	14.00/16.00				71	490	45	310	30	156**	
430 (S43000)	0.12	1.00	0.040	0.030	1.00	16.00/18.00				75	517	45	310	30	155**	
430F (S43020)	0.12	1.25	0.060	0.15 (Min.)	1.00	16.00/18.00		0.60*		80	552	55	379	25	170**	
430F Se (S43023)	0.12	1.25	0.060	0.060	1.00	16.00/18.00			0.15 Se (Min.)	80	552	55	379	25	170**	
434 (S43400)	0.12	1.00	0.040	0.030	1.00	16.00/18.00		0.75/1.25		77	531	53	365	23	B83	(Wire)
436 (S43600)	0.12	1.00	0.040	0.030	1.00	16.00/18.00		0.75/1.25	5xC/0.70 Cb+Ta	77	531	53	365	23	B83	(Sheet)
442 (S44200)	0.20	1.00	0.040	0.030	1.00	18.00/23.00				80	552	45	310	20	B90	
446 (S44600)	0.20	1.50	0.040	0.030	1.00	23.00/27.00			0.25N	80	552	50	345	25	B86	

*May be added at manufacturer's option. **Brinell

Source: Steel Products Manual, "Stainless and Heating Resisting Steels, December 1974," American Iron and Steel Institute.

Corrosion Resistance

Chromium is the alloying element that gives the stainless steels their corrosion-resistance qualities by combining with oxygen from the environment to form a thin protective film on the surface. This protective film is improved by higher chromium levels and by nickel, molybdenum, and other alloying elements. Additional chromium improves film stability and resistance to general corrosion; molybdenum and chromium increase resistance to pitting and crevice corrosion; and nickel improves film resistance to strong acids. Nickel also improves fabrication qualities, such as cold forming and welding.

Material Selection

So many variables make up the severity of a corrosive environment—i.e., the type of chemicals, their concentration and purity, atmospheric conditions, temperature, time, etc.—that it is not prudent to select a material without knowledge of the exact nature of the environment. However, there are guidelines:

Type 304 serves a wide range of applications. It withstands ordinary rusting in many environments, such as those encountered in the processing of food, organic chemicals, dyestuffs, and a wide variety of inorganic

Table 3
MARTENSITIC STAINLESS STEELS

	Chemical Analysis % (Max. unless noted otherwise)									Nominal Mechanical Properties (Annealed bar unless noted otherwise)						
										Tensile Strength		Yield Strength (0.2% offset)		Elongation in 2″ (50.80 mm)	Hardness (Rockwell)	Product Form
AISI Type (UNS)	C	Mn	P	S	Si	Cr	Ni	Mo	Other	ksi	MPa	ksi	MPa	%		
403 (S40300)	0.15	1.00	0.040	0.030	0.50	11.50/13.00				75	517	40	276	35	B82	
410 (S41000)	0.15	1.00	0.040	0.030	1.00	11.50/13.50				75	517	40	276	35	B82	
414 (S41400)	0.15	1.00	0.040	0.030	1.00	11.50/13.50	1.25/2.50			115	793	90	621	20	235**	
416 (S41600)	0.15	1.25	0.060	0.15 (Min.)	1.00	12.00/14.00		0.60***		75	517	40	276	30	B82	
416 Se (S41623)	0.15	1.25	0.060	0.060	1.00	12.00/14.00			0.15 Se (Min.)	75	517	40	276	30	B82	
420 (S42000)	0.15 (Min.)	1.00	0.040	0.030	1.00	12.00/14.00				95	655	50	345	25	B92	
420 F (S42020)	0.15 (Min.)	1.25	0.060	0.15 (Min.)	1.00	12.00/14.00		0.60***		95	655	55	379	22	220**	
422* (S42200)	0.20/0.25	1.00	0.025	0.025	0.75	11.00/13.00	0.50/1.00	0.75/1.25	0.15/0.30 V 0.75/1.25 W	145	1000	125	862	18	320**	
431 (S43100)	0.20	1.00	0.040	0.030	1.00	15.00/17.00	1.25/2.50			125	862	95	655	20	C24	
440 A (S44002)	0.60/0.75	1.00	0.040	0.030	1.00	16.00/18.00		0.75		105	724	60	414	20	B95	
440 B (S44003)	0.75/0.95	1.00	0.040	0.030	1.00	16.00/18.00		0.75		107	738	62	427	18	B96	
440 C (S44004)	0.95/1.20	1.00	0.040	0.030	1.00	16.00/18.00		0.75		110	758	65	448	14	B97	

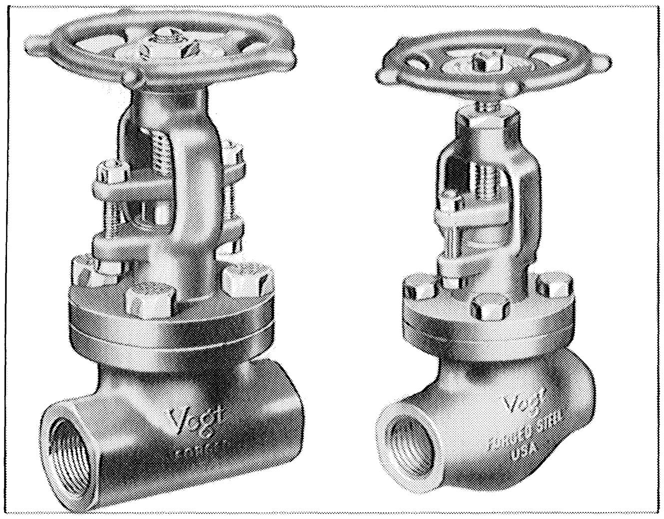
*Hardened and tempered **Brinell ***May be added at manufacturer's option.

Source: Steel Products Manual, "Stainless and Heat Resisting Steels, December 1974," American Iron and Steel Institute.

Table 4
PRECIPITATION HARDENING STAINLESS STEELS

	Chemical Analysis % (Max. unless noted otherwise)									Nominal Mechanical Properties (Solution Treated Bar)						
										Tensile Strength		Yield Strength (0.2% offset)		Elongation in 2″ (50.80 mm)	Hardness (Rockwell)	Product Form
AISI Type (UNS)	C	Mn	P	S	Si	Cr	Ni	Mo	Other	ksi	MPa	ksi	MPa	%		
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	1103	120	827	17	C33	
S15500	0.07	1.00	0.04	0.03	1.00	14.00/15.50	3.50/5.50		2.50/4.50 Cu 0.15/0.45 Cb+Ta	160	1103	145	1000	15	C35	
S17400	0.07	1.00	0.040	0.030	1.00	15.50/17.50	3.00/5.00		3.00/5.00 Cu 0.15/0.45 Cb+Ta	160	1103	145	1000	15	C35	
S17700)	0.09	1.00	0.040	0.040	0.040	16.00/18.00	6.50/7.75		0.75/1.50 Al	130	896	40	276	10	B90	

Source: Steel Products Manual, "Stainless and Heat Resisting Steels, December 1974," American Iron and Steel Institute.



Gate valve, left, and globe valve, right, both feature forged stainless steel bodies.

Source: Henry Vogt Machine Co.

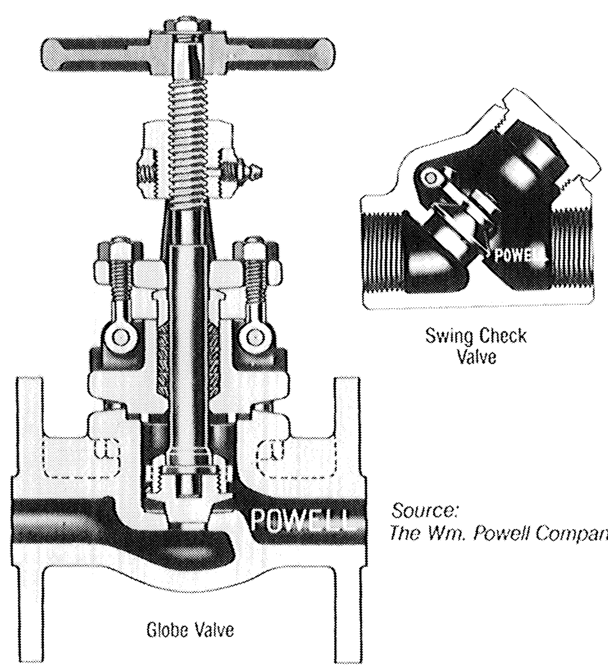
chemicals. It also retains its properties over a wide range of temperatures, down to cryogenic temperatures.

Type 316, with a slightly higher nickel content plus 2-3% molybdenum, affords better corrosion resistance than Type 304, especially in chloride environments. Type 316 finds broad application in the chemical processing industries.

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

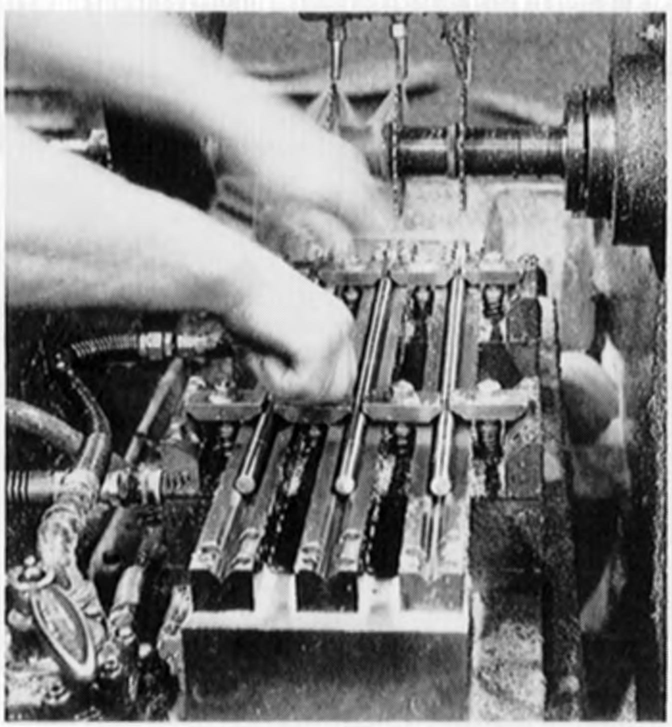
Type 410 has the lowest alloy content of the four general-purpose stainless steels and accordingly is the least corrosion resistant. It is selected for highly stressed parts needing a combination of strength and hardness.

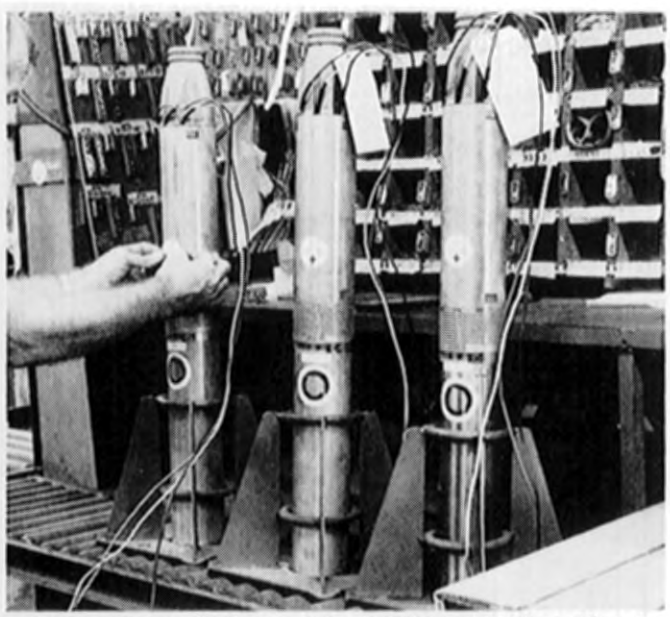
One of these four general-purpose stainless steels—Types 304, 316, 430 or 410—is a good starting point in selection because these are the most readily available.



Source:
The Wm. Powell Company

Service tests are most reliable in determining the optimum material for any application. ASTM G-4-68 (1974) describes a recommended practice for carrying out such tests. There are also several reference books that discuss corrosion and material selection, such as Uhlig's *Corrosion Handbook;* LaQue and Copson's *Corrosion Resistance of Metals and Alloys;* Fontana and Green's *Corrosion Engineering; A Guide to Corrosion Resistance* by Climax Molybdenum Company: *Corrosion Data Survey* by the National Association of Corrosion Engineers; and the American Society for Metals' *Metals Handbook.* Corrosion data, specifications, and recommended practices relating to stainless steels are also issued by ASTM.





Keyway slots are milled on two sides of 0.500" diameter Type 416 shafts for submersible pumps, shown being assembled. All critical components, including the pump casing, are stainless steel except the impellers.

Source: Tait Pump Company

Mechanical and Physical Properties

Austenitic Stainless Steels

The mechanical properties of the austenitic stainless steels can be altered by cold work. At room temperature these austenitic stainless steels exhibit yield strengths between 30,000 and 200,000 psi, depending on the exact composition and amount of cold work. They retain good ductility and toughness, even at high strengths and at cryogenic temperatures. The chemical compositions and typical mechanical properties of austenitic stainless steels are given in Table 1. The properties in Table 1 are nominal values; for specific engineering data, readers are referred to pertinent ASTM Standard Specifications.

The physical properties of austenitic stainless steels are similar to those of the martensitic and ferritic grades. Physical properties of Types 304, 430, 410 and S17400 are shown in Table 5.

Ferritic Stainless Steels

Ferritic stainless steels in general have a nominal composition at about 10.5% chromium and up. Their chemical compositions and typical mechanical properties are shown in Table 2. These alloys are not generally selected for industrial pumps, valves, or fittings.

Martensitic Stainless Steel

The martensitic grades, in the hardened condition, possess high tensile strength and hardness. To obtain an optimum combination of corrosion resistance, ductility, and toughness, the hardened steel is tempered.

Table 3 gives the chemical compositions and typical mechanical properties of these stainless steels, and Table 6 gives mechanical property values of the martensitic grades in various heat treated conditions.

Type 316 stainless steel valve body weighs 2,500 pounds and was forged on a 50,000 ton press. After initial machining, the 12" valve is 24" high and 43" wide. Valve and pump components for high-temperature service, such as in nuclear power generation or chemical processing, need the combined strength and corrosion resistance of forged stainless steel.

Source: Wyman-Gordon Company

Precipitation Hardening Stainless Steels

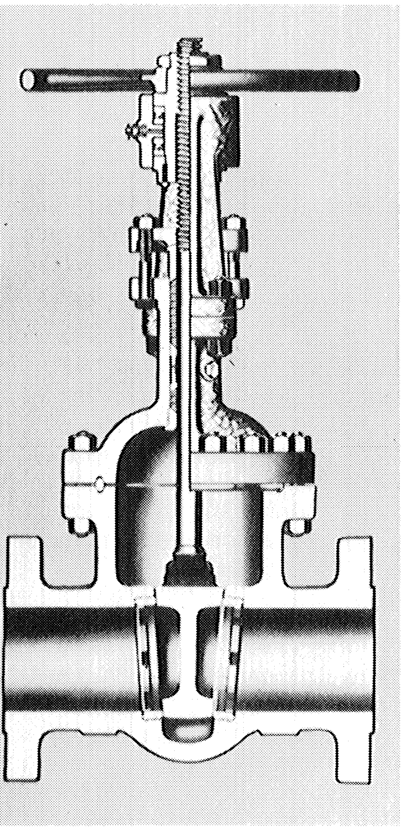
Components of pumps and valves can be fabricated of a precipitation hardening stainless steel in the annealed condition and then strengthened by heating to 900-1150F, minimizing the disadvantages of high-temperature heat treatments. Tensile strengths up to 260,000 psi can be achieved. Corrosion resistance is approximately equal to that of Type 304, while ductility is similar to that of the martensitic grades at the same strength level.

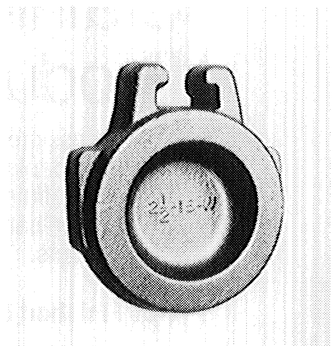
Table 4 shows the chemical composition and typical mechanical properties of the precipitation hardening stainless steels.

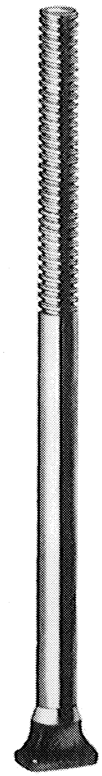
Additional information on the AISI-numbered stainless steels is discussed in the booklet *Design Guidelines For The Selection and Use of Stainless Steels.* Copies are available from the Committee of Stainless Steel Producers.

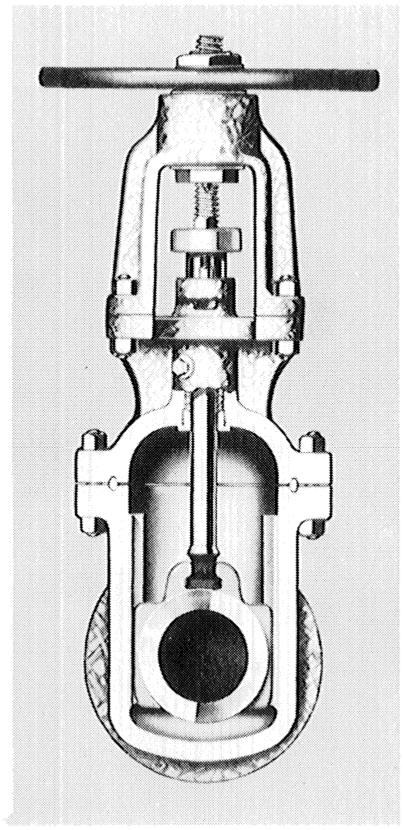
Table 5 PHYSICAL PROPERTIES OF GENERAL-PURPOSE STAINLESS STEELS (ANNEALED)

	Type 304	Type 430	Type 410	S17400
Modulus of Elasticity in Tension psi x 10^6 (GPa)	28.0 (193)	29.0 (200)	29.0 (200)	28.5 (196)
Modulus of Elasticity in Torsion psi x 10^6 (GPa)	12.5 (86.2)	— —		
Density, lbs/in^3 (kg/m^3)	0.29 (8060)	0.28 (7780)	0.28 (7780)	0.28 (7780)
Specific Heat, Btu/lb/F (J/kg•K) 32-212F (0-100C)	0.12 (503)	0.11 (460)	0.11 (460)	0.11 (460)
Thermal Conductivity, Btu/hr/ft^2/ft/F (Jkg•K) 212 F (100C)	9.4 (0.113)	15.1 (0.182)	14.4 (0.174)	10.6 (0.127)
932F (500C)	12.4 (0.149)	15.2 (0.183)	16.6 (0.201)	13.1 (0.157)
Mean Coefficient of Thermal Expansion x10^{-6}/F (x10^{-6}/C)				
32-212F (0-100C)	9.6 (17.3)	5.8 (10.4)	5.5 (9.9)	6.0 (10.8)
32-600F (0-315C)	9.9 (17.9)	6.1 (11.0)	6.3 (11.4)	6.4 (11.6)
32-1000F (0-538C)	10.2 (18.4)	6.3 (11.4)	6.4 (11.6)	
32-1200F (0-648C)	10.4 (18.8)	6.6 (11.9)	6.5 (11.7)	— —
32-1800F (0.982C)	— —	6.9 (12.4) [32-1500F]	— —	— —
Melting Point Range F	2550 to 2650	2600 to 2750	2700 to 2790	2560 to 2625
(C)	(1398 to 1454)	(1427 to 1510)	(1483 to 1532)	(1404 to 1440)









Cut-away view shows internal components of a wedge gate valve used widely in petroleum and chemical processing. At one end of the threaded stem is a tee-head, which connects to the wedge disc. The tee-head is forged integral with the stem for increased strength at the highly stressed point where the stem meets the tee. Upset forging elminates machining of these parts, which are made of Type 304 or 316. Wedge discs for gate valves are also economically forged.

Source: Commercial Stamping & Forging Inc. (Stem), Crane Co. (Valve), and Endicott Forging & Mfg. Co., Inc. (Disc).

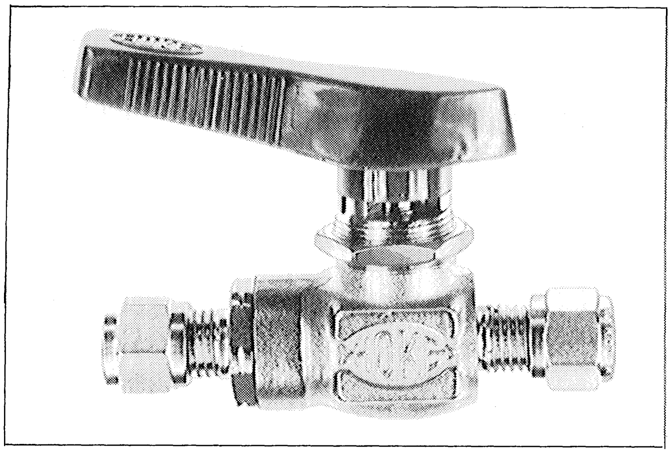
Table 6
NOMINAL MECHANICAL PROPERTIES
As Quenched Hardness and Properties After Hardening and Tempering 1 in. (25.4 mm) Diameter Bars

Type	UNS	Hardening Temp. F. (C)	As Quenched Hardness HB	As Quenched Hardness HR	Tempering Temp. F. (C)	Tensile Strength, ksi (MPa)	Yield Str. 0.2 per cent Offset ksi (MPa)	Elon. in. 2 in. (50.80 mm) per cent	Red. of Area per cent	Izod Impact V-Notch Ft. Lbs. (J)	Tempered Hardness HB	Tempered Hardness HR
403 and	S40300	1800 (981)	410	C43	400 (204)	190 (1310)	145 (1000)	15	55	35 (47)	390	C41
410	S41000				600 (315)	180 (1241)	140 (965)	15	55	35 (47)	375	C39
					800* (426)	195 (1344)	150 (1034)	17	55		390	C41
					1000* (538)	145 (1000)	115 (793)	20	65		300	C31
					1200 (648)	110 (758)	85 (586)	23	65	75 (102)	225	B97
					1400 (760)	90 (621)	60 (414)	30	70	100 (136)	180	B89
416 and	S41600	1800 (981)	410	C43	400 (204)	190 (1310)	145 (1000)	12	45	20 (27)	390	C41
416 Se	S41623				600 (315)	180 (1241)	140 (965)	13	45	20 (27)	375	C39
					1000* (538)	145 (1000)	115 (793)	15	50		300	C31
					1200 (648)	110 (758)	85 (586)	18	55	30 (41)	225	B97
					1400 (760)	90 (621)	60 (414)	25	60	60 (81)	180	B89
414	S41400	1800 (981)	425	C44	400 (204)	100 (1379)	150 (1034	15	55	45 (61)	410	C43
					600 (315)	190 (1310)	145 (1000)	15	55	45 (61)	400	C41
					800 (426)	200 (1379)	150 (1034)	16	58		415	C43
					1000* (538)	145 (1000)	120 (827)	20	60		290	C30
					1200 (760)	120 (827)	105 (724)	20	65	50 (68)	250	C22
431	S43100	1900 (1036)	440	C45	400 (204)	205 (1413)	155 (1069)	15	55	30 (41)	415	C43
					600 (315)	195 (1344)	150 (1034)	15	55	45 (61)	400	C41
					800* (426)	205 (1413)	155 (1069)	15	60		415	C43
					1000* (538)	150 (1034)	130 (896)	18	60		325	C34
					1200 (760)	125 (862)	95 (655)	20	60	50 (68)	260	C24
420	S42000	1900 (1036)	540	C54	600 (315)	230 (1586)	195 (1344)	8	25	10 (14)	500	C50
440A	S44002	1900 (1036)	570	C56	600 (315)	260 (1793)	240 (1655)	5	20	4 (5)	510	C51
440B	S44003	1900 (1036)	590	c58	600 (315)	280 (1931)	270 (1862)	3	15	3 (4)	555	C55
440C	S44004	1900 (1036)	610	C60	600 (315)	285 (1965)	75 (1896)	2	10	2 (3)	580	C57

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

Source: Steel Products Manual, "Stainless and Heat Resisting Steels, December 1974," American Iron and Steel Institute.

Stainless Steel Bar Products

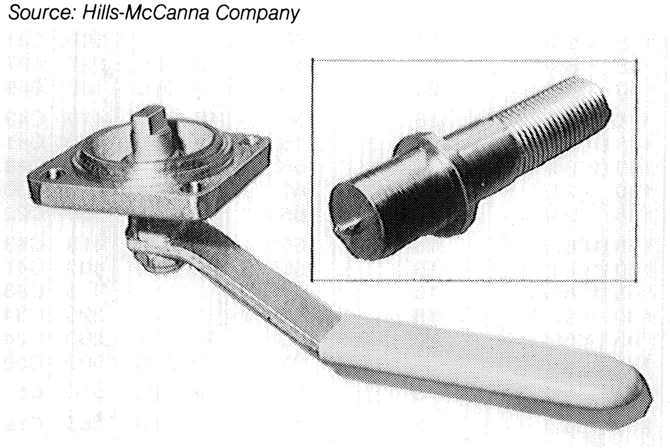


This miniature ball valve has a Type 316 forged body and machined ball. The valve has a maximum operating pressure of 6,000 psig for high-pressure instrument lines, corrosive fluid handling, gas sampling lines, or hydraulic test stands.

Source: Hoke Inc.

Stainless steel ball valves ready for final assembly. All internal components are machined from stainless steel bar.

Source: Hills-McCanna Company



Ball valve stem is machined from ¾" diameter, Type 410 bar. The 2.33" long stem is turned at 8.7 pieces per hour on a Warner & Swasey 1AB Bar Machine. The other machining operations include chamfer, face, form, thread, and cut off, followed by milling and deburring. The valve stem is shown attached to handle and bonnet.

Source: Hills-McCanna Company

Stainless steels are available in basic mill forms, namely sheet, strip, plate, bar, wire, and tubing. Since most pump, valve, and fitting applications are machined from bars or forged from bars or billets, the emphasis in this booklet is on bar products.

Hot Finished Bars

Hot finished bars are commonly produced by hot rolling or forging ingots to blooms or billets, which are then hot rolled, forged, or extruded to final dimensions.

Following hot rolling, forging or extrusion, the bars may be subjected to various operations including annealing or other heat treatment, cleaning, turning and straightening. When improved surface is required, as for bars intended for forging, bars can be machined or ground.

Cold Finished Bars

Cold finished bars are produced from hot finished bars by means of additional operations to give closer tolerance, improved surface finish or better mechanical properties.

Cold finished bars fall into three principal categories. First, there are centerless ground cold drawn bars, which represent the largest tonnage production. This type of bar is widely used in the mass production of machined components. Second, there are polished bars which have improved surface finish and dimensional accuracy. Third, there are turned, ground and polished bars with the superior surface finish, tolerance and straightness required for precision shafting.

If the application requires high strength and hardness, the cold finished bars are drawn or heat treated, depending upon composition, section, and properties desired.

Some Advantages of Cold Finished Bars

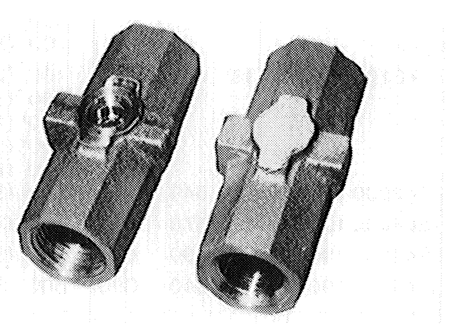
Cold finished bars have attractive characteristics:

(1) They are bright, smooth and free from scale, and therefore can often be used without further finishing.

(2) They offer superior size tolerance, concentricity and straightness.

(3) Cold work imparted by drawing, rolling, or straightening, especially when applied to the austenitic grades, can raise the yield and tensile strengths.

(4) Cold work improves machineability.



The bodies of small ball valves are frequently forged from stainless steel bar for excellent mechanical properties as required for high-pressure service.

Source: Hills-McCanna Company

Conditions and Surface Finish

Stainless steel bars are produced in the following conditions and finishes. It should be noted that each finish is not applicable to every condition.

Conditions	Surface Finishes*
1. Hot worked only (Not annealed)	(a) Scale not removed (excluding spot conditioning) (b) Rough turned or rough ground** (c) Pickled or blast cleaned
2. Annealed or otherwise heat treated	(a) Scale not removed (excluding spot conditioning) (b) Rough turned or rough ground (c) Pickled or blast cleaned (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

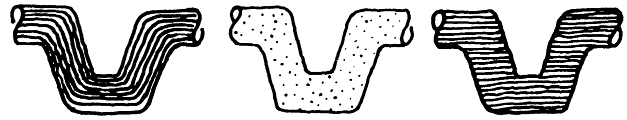
*Surface finishes (b), (e) and (f) are applicable to round bars only.

**Bars of the 400 Series which are highly hardenable, such as Types 414, 420, 420F, 431, 440A, 440B and 440C, are annealed before rough turning. Other hardenable grades, such as Types 403, 410, 416 and 416Se, may also require annealing depending on their composition and size.

***Produced in certain 300 Series Types.

Fabrication

A stainless steel is generally selected for its corrosion resistance and its strength or other mechanical properties. Another consideration is fabrication. The four most widely used grades, namely Types 304, 316, 430, and 410, are produced in variations that are better suited to certain manufacturing operations. If service requirements, however, rule out selection of one of these variations, most conventional processes are feasible to the fabrication of any stainless steel.



Forging — True grain flow; Casting — No grain flow; Bar Stock — Grain flow broken by machining

Hot Forming

Stainless steels are readily formed by hot operations such as rolling, extrusion, and forging.

Hot rolling is normally a steel mill operation to generate standard mill products. The figures below illustrate the variety of shapes in which stainless steel bars are available.

An extruded piece is made by forcing a bar or billet through a die, the exiting cross-section conforming to the die opening. Several companies produce extrusions of stainless steel.

Forging is a process used extensively to form stainless steels of all types into parts from a few ounces to thousands of pounds in weight. Designers are urged to consult forgers for design guidelines pertaining to shapes, tolerances, limitations, etc.

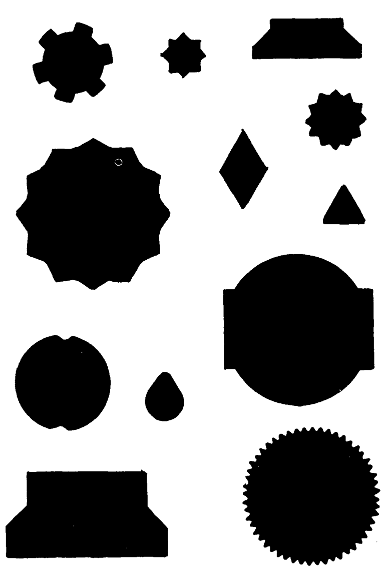
A unique feature of forgings is that the continuous grain flow follows the contour of the part, as illustrated by the left drawing above. In comparison is the random grain structure of a cast part (center) and the straight-line orientation of grain in a machined part (right). From this difference stem secondary advantages inherent in forged stainless steels as follows:

Strength where needed. Through grain refinement and flow, forging puts the strength where it's needed most.

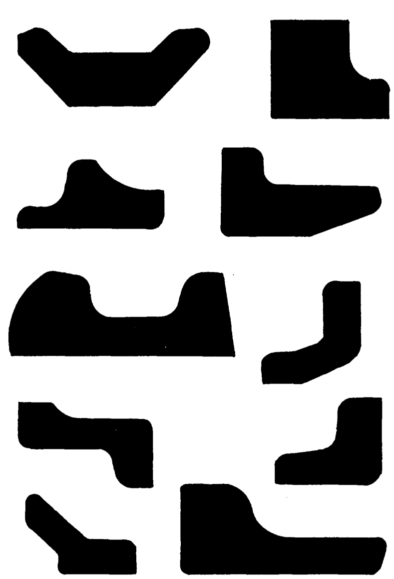
Lighter weight. Higher strength-to-weight ratio permits the use of thinner, light weight sections—without sacrificing safety.

Improves mechanical properties. Forging develops the

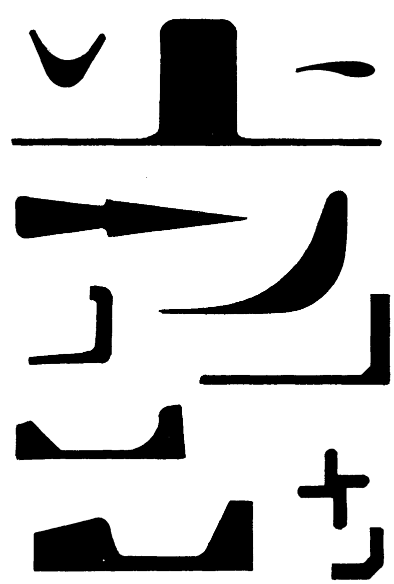
COLD-DRAWN SHAPES...
For achieving superior mechanical properties, lower machining costs, faster production and reduced scrap loss.



HOT-ROLLED SHAPES...
For applications where parts are made from straight lengths, curved pieces, or are to be formed into rings, welded and finished-machined.



COLD-ROLLED SHAPES...
For applications where parts require close tolerance, fine surface finishes, superior mechanical properties.



full impact resistance, fatigue resistance, ductility, creep-rupture life, and other mechanical properties of stainless steels.

Repeatable dimensions. Tolerances of a few thousandths are routinely maintained from part to part, simplifying final fixturing and machining requirements.

Efficient metal utilization. Forging cuts waste because it reduces metal removal.

Structural uniformity. Forgings are sound, nonporous, and uniform in metallurgical structure.

The booklet, "Stainless Steel Forgings," available from the Committee of Stainless Steel Producers, discusses in greater detail the formability of stainless steels, and it provides guidelines for designing stainless forgings.

Cold Forming

The mechanical properties of stainless steels roughly reflect their relative formability. Annealed austenitic grades display the low yield strength, high tensile strength, and high ductility values that permit severe cold deformation. These alloys harden during cold forming, thereby increasing the strength levels. The ferritic grades exhibit lower ductility than the austenitic types and more closely approximate the mechanical properties of carbon steel. They do not work harden significantly during cold forming.

Machining

The machining characteristics of stainless steels are substantially different from those of carbon and alloy steels or of other metals. In varying degree, most stainless steels without modifications to their composition to favor machinability are tough and rather gummy, qualities which, along with a tendency to seize and gall, exert high unit pressure on the cutting tool.

The 400 Series stainless steels are the easiest to machine, but stringy chips can slow productivity. The 200 and 300 Series are the most difficult to machine primarily because they work harden rapidly at the point of tool contact.

An experienced machine shop engineer can usually work around these conditions and realize good productivity in machining any of the stainless steels. The design engineer can also help gain maximum machining rates by specifying a free-machining stainless steel in a slightly hardened condition.

Free-Machining Stainless Steel

Some stainless steel compositions contain sulfur, manganese, selenium, lead, copper, aluminum, or phosphorus to improve machining characteristics. These alloying additions in proper concentrations reduce the friction between the workpiece and the tool. Sulfur and selenium also cause the chip to break off more readily.

Suppose, for example, that Type 304 is being considered on grounds of corrosion resistance and strength, but fabrication entails extensive machining. Type 303, which is the free-machining variation of Type 304, could be specified provided its properties satisfy end-use requirements.

Type 303 Se is another free-machining stainless steel similar to Type 303 except that it contains selenium as the ingredient to enhance the machining characteristics. It is used for better surface finishes or when cold working may be involved, such as staking, swaging, spinning, or severe thread rolling, in addition to machining.

If end-use conditions call for Type 430 stainless, the designer can specify free-machining Types 430F or 430F Se, which have similar properties. Type 430F contains more sulfur, while 430F Se contains selenium instead of having a high sulfur content.

The free-machining choices in lieu of Type 410 are Types 416 (higher sulfur) or 416 Se (selenium). And for Type 420, the shop might consider Type 420F.

The use of sulfur or selenium to improve the machining characteristics of stainless steels can affect corrosion resistance, transverse ductility, and other qualities, such as weldability. These free-machining grades should be used only after a review of all the requirements of the application.

When elaborate machining operations are to be performed on stainless steel forgings, the bar producer can slightly modify the composition of the free-machining grade to strike a balance between optimum forging and machining characteristics. Bars produced solely for forgeability will not show optimum machineability. Further, forging bars are produced to hot rolled size tolerances, which are usually too broad for many automatic machine tools.

Special Analysis Stainless Steels

In melting of stainless steels, minor modifications are made in the composition to enhance certain characteristics of the metal, such as machineability.

If, for example, end-use conditions are too restrictive to permit the use of Type 303 instead of Type 304, designers might suggest using Type 304 in a special analysis that has somewhat better machining qualities but with very little difference in corrosion resistance.

Hardened Stainless Steel Bar

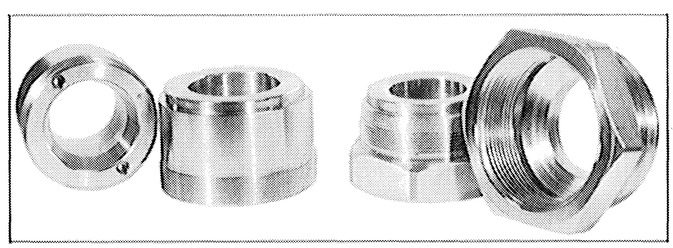
When conditions require maximum resistance to corrosion in the alloy selected, and there is no room for compromise in the composition, the machine shop can order bar stock in a slightly hardened condition that may result in a small improvement in machinability.

Under any circumstances, and especially when corrosive environments are involved, it is always good practice to consult with a stainless steel producer.

Screw Machining Operations

Automatic screw machining is a fast and efficient method for cutting that benefits greatly from the use of the free-machining stainless steels. Many screw machine operations can turn out parts at rates as high as 300 to 400 per hour. With appropriate design and good shop tooling practices, even the nonfree-machining stainless steels can be handled at relatively high production rates.

A booklet, "Free Machining Stainless Steels," which is available from the Committee of Stainless Steel Producers, discusses this subject in greater detail. Included in the booklet is a Trade Name Directory of free-machining stainless steels.



These ball valve components were machined from Type 316 hollow bar at a rate of 30 pieces per hour, which is about 25% faster than machining from solid bar. In addition to increased production, there was less downtime to remove chips and less scrap. The sulfur content of Type 316 was increased slightly to enhance machineability. The hexes are end caps for a ball valve, and the rounds are inserts.

Source: Jamesbury Corporation

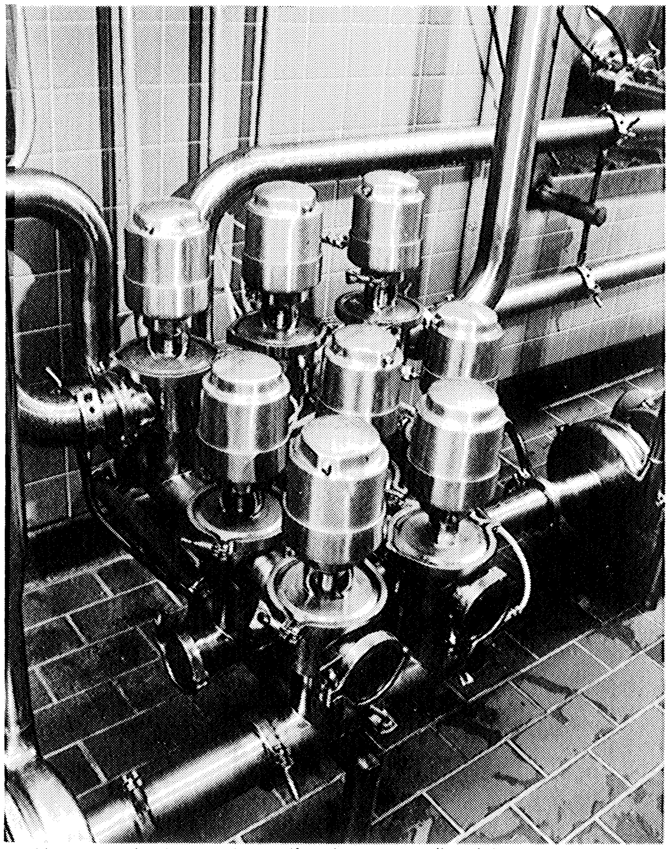
Joining

Welding

Nearly all of the stainless steels can be welded by most methods employed by industry today. Because of differences between these alloys vs. carbon or low-alloy steels, however, there are variations in welding techniques.

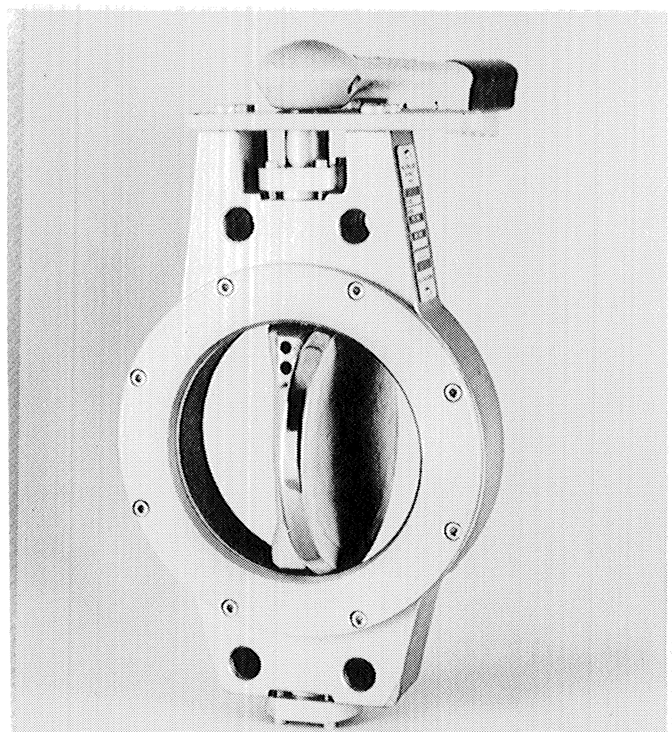
First, it is important that procedures be followed to preserve corrosion resistance in the weld and in the area immediately adjacent to the weld, referred to as the heat-affected zone (HAZ). Second, it is desirable to maintain optimum mechanical properties in the joint, and third, certain steps are necessary to minimize heat distortion.

The principal difference between stainless and other steel types is alloy content, which provides corrosion resistance. In welding, it is necessary to select a weld rod that provides weld filler metal having corrosion resistant properties as nearly identical to the base metal as possible—or better. The best suggestion is to follow American Welding Society (AWS) practices for weld rod selection (and weld procedures) or to consult weld rod manufacturers who have up-to-date tables for rod selection.



Air-actuated valves and centrifugal pumps—all stainless steel construction—installed in a milk processing plant.

Source: Ladish Co., Tri-Clover Division



This butterfly valve is designed to handle a broad range of conditions and media encountered in chemical processing. Although the body and disc are available in either carbon steel or stainless steel, the critical internal components are stainless. For example, the following components are made of Type 316; taper pin, disc spacer, bearing assembly, and gland ring. Stainless steel Types S17400, 302, and 304 are also used in various components. Some components are Tufftride hardened to minimize wear and galling.

Source: Hills-McCanna Company

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