STAINLESS STEELS FOR BULK MATERIALS HANDLING

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Introduction

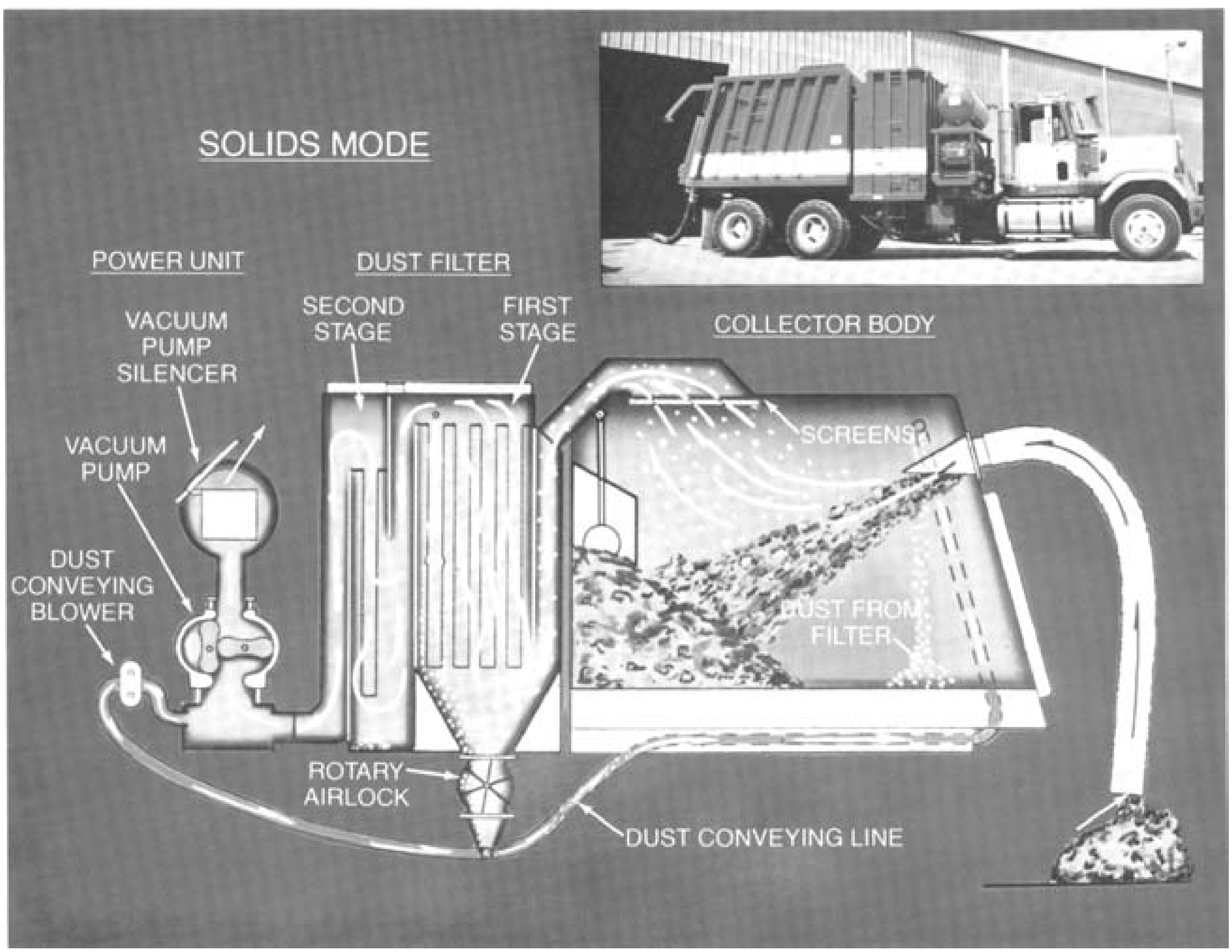
Engineers responsible for the design and selection of equipment for bulk materials handling frequently specify stainless steel to achieve optimum system performance. They recognize that stainless steel has several important characteristics which help assure long, trouble-free service in a broad range of bulk handling environments. Among the outstanding qualities of stainless steel, which makes it a material ideally suited for the handling of bulk materials, are the following:

- Resistance to corrosion
- Resistance to abrasion or erosion
- Good strength - in a broad range of temperatures
- Noncontaminating
- Sanitary acceptability
- Cleanability
- Fabricability Availability
- Cost effectiveness
- Visual appeal

Bulk material handling involves virtually all industries which require an enormous variety of equipment types; so no attempt is made to relate the information in this booklet to specific applications. Illustrated are some of the handling equipment available in stainless steel, and the text discusses factors that material handling engineers and designers should consider in selecting construction materials for this or any equipment for bulk handling. The characteristics that make stainless steel particularly useful for bulk handling systems are described, and typical engineering data are presented.

Baghouse components of the Supersucker industrial vacuum loader, such as the hopper slopes, filter bag retainers, and all fastening studs, are constructed of Type 304 stainless steel. Since the baghouse is critical to the protection of the vacuum pump, and the vacuum loader is used for either liquids, solids, or slurries many of an abrasive nature-stainless steel was selected for its resistance to abrasion, erosion and corrosion. The use of stainless steel fasteners also provides quick and easy bag replacement.

Photograph and drawing courtesy of Super Products, Milwaukee, Wisconsin.



STAINLESS STEEL BASICS

Reference is often made to stainless steel in the singular sense as if it were one material. Actually there are 57 stainless steels recognized by American Iron and Steel Institute as AISI-numbered compositions, plus there are numerous proprietary or special analysis grades. The reason for so many different types is to provide industry with specific alloy compositions that are ideally suited for requirements imposed by manufacturing and/or end use.

The AISI-numbered stainless steels are generally identified by a system of numbers in 200, 300, or 400 Series groups, such as Type 304. Industry, as a general rule, uses these numbers in referring to stainless steels, although other number designations are sometimes used. For instance, The American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers (SAE) have their own number designations. Also, stainless steels are being identified by a new Unified Numbering System (UNS) that applies to all commercial metals. For example, the UNS number for Type 304 is S30400.

Stainless steels sometimes are identified by their alloy compositions, in abbreviated form. For instance, Type 304, which contains about 18% chromium and 8% nickel, is frequently identified as "18-8" stainless.

However, for specifying or ordering, the AISI numbers, the UNS numbers, or specific steel company trade names are the preferred designations to use.

In addition to number designations, stainless steels are classified according to metallurgical structure. The classifications are austenitic, martensitic, ferritic, and precipitation *hardening.* Materials handling engineers and designers should recognize these categories because the stainless steels so classified tend to have similar characteristics with respect to corrosion resistance, hardenability, and fabricability. Table 1 puts this in better perspective.

The stainless steels frequently used in material handling equipment are Types 201, 301, 303, 304, 305, 316, 430, and 410, which are discussed in this booklet. For a more-complete discussion of all AISI-numbered stainless steels, the reader should refer to other publications available from the Committee of Stainless Steel Producers. A list of these publications can be found on page 22.

Table 1
Metallurgical Comparisons
of AISI-Numbered Stainless Steels (1)

Principal Alloying Element	**Austenitic** **Chromium + Nickel**	**Ferritic** **Chromium (17%)**	**Martensitic** **Chromium (12%)**	**Precipitation Hardening** **Chromium+ Nickel**
Hardenable by Cold Work	Yes	Moderate	No	Slight
Hardenable by Heat Treatment	No	No	Yes	Yes (Low Temperature)
Magnetic	No*	Yes	Yes	No
Corrosion Resistance	A-B	B-C**	C	A-B
Fabricability	A	B	B-C	A
General Purpose Type	304	430	410	

A=Excellent **B=Good** **C=Fair**
*Slightly magnetic in cold worked condition.
**It should be noted that many new ferritic stainless steels which do not have AISI number designations have excellent corrosion-resistant properties.

Guidelines for Selection

Stainless steels are engineering materials with good corrosion resistance, strength, and fabrication characteristics. They can readily meet a wide range of design criteria -load, service life, low maintenance, etc. normally encountered in bulk materials handling operations. However, to achieve optimum performance, i.e., the proper material for the operating conditions and at the least cost, care should be exercised in evaluating and selecting materials. Selecting the proper stainless steels essentially means weighing four elements:

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

2. Mechanical Properties - with particular emphasis on strength at room, elevated, or low temperature. Generally speaking, the combination of corrosion resistance and strength is the basis for selection.

3. Fabrication Operations - and how the product is to be made is a third-level consideration. This includes forging, machining, forming, welding, etc.

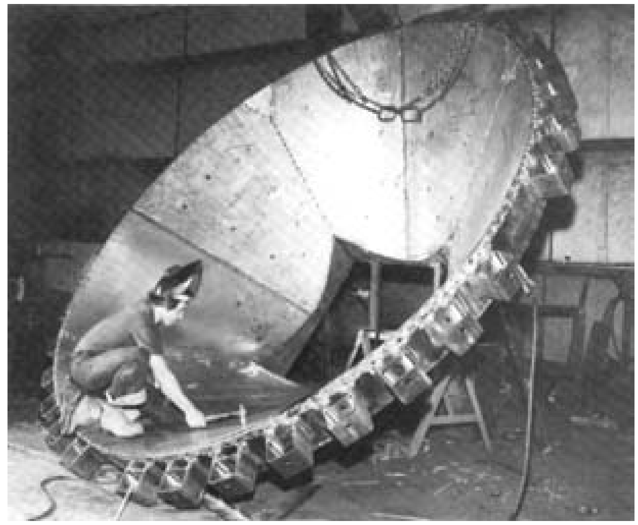
4. Total Cost - To put everything into proper perspective, a total value analysis is appropriate that will consider not only material and production costs, but the cost-saving benefits of a maintenance-free product having a long life expectance.

CORROSION RESISTANCE

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

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

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



This 12-foot diameter vibrating bin discharger is constructed of mild steel but utilizes a 1/8-inch thick Type 304 stainless steel liner, which is plug-welded to the cone. The liner is installed in sections, and seams are continuously welded with stainless steel weld rod. These dischargers are commonly used for coal refuse silos at coal preparation plants. The stainless steel provides excellent resistance to corrosion - especially with high-sulfur coal-and surface smoothness promotes free flow of refuse.

Photograph courtesy of Vibranetics, Inc., Louisville, Kentucky.

Material Selection

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

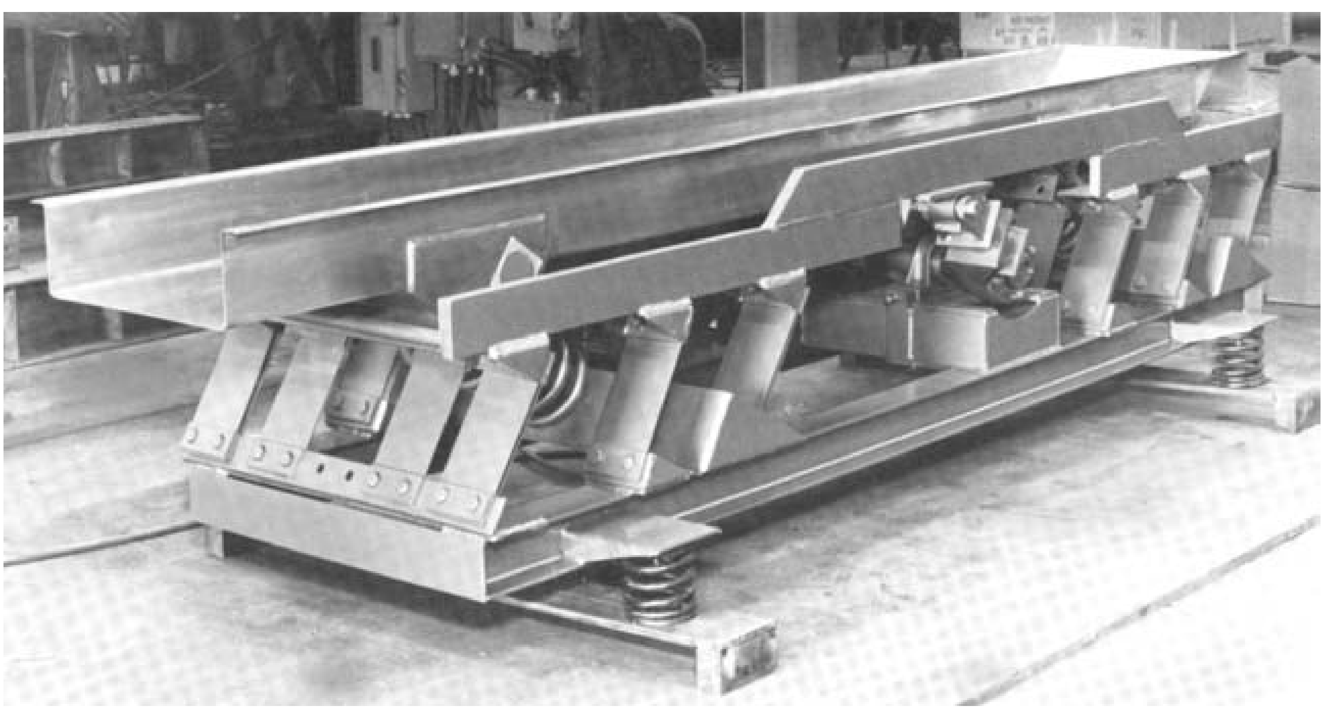
One of the three general purpose stainless steels is a good starting point in selection (Types 304, 430, or 410), because these are the most widely used types and they are readily available. Also to be considered are the more corrosion resistant Types 316 and 317.

Type 304 serves a wide range of applications. It withstands ordinary rusting in architecture, it is immune

This is a typical vibrating conveyor that is dynamically balanced to eliminate vibrations to supporting structures. The conveyor uses a solid Type 304 stainless steel trough, 18 inches wide by 12 feet long, which is polished to sanitary standards for use in food processing.

Type 304 stainless steel is approved for virtually all food processing applications.

Photograph courtesy of Vibranetics, Inc., Louisville, Kentucky.



to food-processing environments (except possibly for high-temperature conditions involving high acid and chloride contents), it resists organic chemicals, dyestuffs, and a wide variety of inorganic chemicals. Type 304 resists nitric acid well and sulfuric acids at moderate temperature and concentrations. It is used extensively for storage of liquified gases and equipment for use at elevated temperatures.

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

Type 317 contains 3-4% molybdenum and more chromium than Type 316 for even better resistance to pitting.

Type 430 has lower alloy content than Type 304 and is useful in mild environments. It is widely 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 details more specific environments in which various grades are used, such as acids, bases, organics, and pharmaceuticals.

The above comments on the suitability of stainless steels in various environments are based on a long history of successful application, but they are intended only as guidelines. Small differences in chemical content and temperature, such as might occur during processing accidents, can affect corrosion rates. Service tests are most reliable in determining optimum material, and ASTM G-4-68(1974) is a recommended practice for carrying out such tests. Tests should cover conditions both during operation and shutdown. For instance, 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 bowls of this 34-inch diameter sanitary sifter are spin-formed stainless steel. Stainless steel is used not only because it meets all sanitary standards for food or drug processing, but it also has excellent fabrication characteristics which allows a wide variety of manufacturing methods.

The sanitary sifter is used in classifying a wide range of products for the dairy, drug, chemical and food industries.

Photograph courtesy of Sprout-Waldron Metal Products Division, Muncy, Pennsylvania.

Stainless steels resist corrosion in a broad range of conditions, but they are not immune to every environment. For example, stainless steels perform poorly in reducing environments, such as hydrochloric acid at elevated temperatures. The corrosive attack experienced is a breakdown of the protective film over the entire metal surface. Consequently, cleaning formulations containing hydrochloric acid should not be used for cleaning in or around stainless steel equipment.

The types of attack which are more likely to be of concern are: pitting, crevice attack, stress-corrosion cracking, and intergranular corrosion.

Pitting occurs when the protective 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 can reduce the slideability of bin and chute liners, thus leading to a greater potential for bridging or ratholing.

Pitting is avoided in many environments by using Types 316 and 317, which contain molybdenum.

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. This practice is faithfully followed by the food processing industries, primarily to prevent accumulation of food particles in crevices. If moisture can build up in bulk product trapped in crevices, crevice corrosion should be considered as a likely possibility.

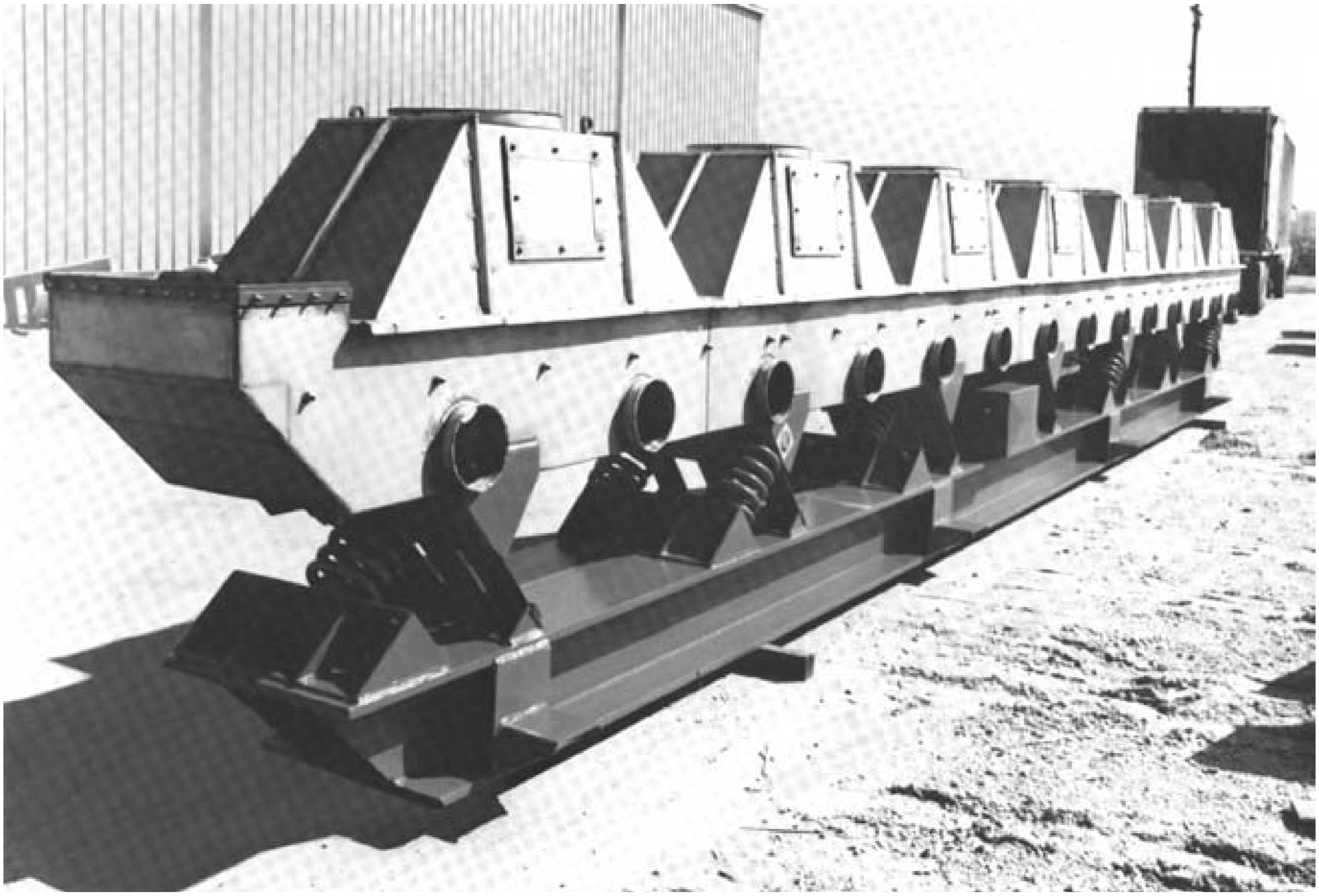
Stress Corrosion Cracking is caused by the combined effects of tensile stress and corrosion. Many alloy systems have been known to experience stress corrosion cracking - brass in ammonia, carbon steel in nitrate solutions, titanium in methanol, aluminum in sea water, and gold in acetic acid. Stainless steels are susceptible to stress corrosion cracking in chloride environments.

It is necessary for tensile stress, chlorides and elevated temperature all to be present for stress corrosion cracking to occur in stainless steel. Wet-dry or heat

Table 2
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 212 F (100 C) with Type 316 and slightly higher with Type 317. Oxidizing ions inhibit attack and other inhibitors such as arsenic may be added.
Sulfuric acid	Type 304 can be used at room temperature for concentrations over 80%. Type 316 can be used in contact with sulfuric acid up to 10% at temperatures up to 120 F (50 C) if the solutions are aerated; the attack is greater in airfree solutions. Type 317 may be used at temperatures as high as 150 F (65 C) with up to 5% concentration. The presence of other materials may markedly change the corrosion rate. As little as 500 to 2000 ppm of cupric ions make it possible to use Type 304 in hot solutions of moderate concentration. Other additives may have the opposite effect.
Sulfurous acid	Type 304 may be subject to pitting, particularly if some sulfuric acid is present. Type 316 is usable at moderate concentrations and temperatures.
Bases Ammonium hydroxide, sodium hydroxide, caustic solutions	Steels in the 300 series generally have good corrosion resistance at virtually all concentrations and temperatures in weak bases, such as ammonium hydroxide. In stronger bases, such as sodium hydroxide, there may be some attack, cracking or etching in more concentrated solutions and at higher temperatures. Commercial purity caustic solutions may contain chlorides, which will accentuate any attack and may cause pitting of Type 316 as well Type 304.
Organics Acetic acid	Acetic acid is seldom pure in chemical plants but generally includes numerous and varied minor constituents. Type 304 is used for a wide variety of equipment including stills, base heaters, holding tanks, heat exchangers, pipelines, valves and pumps for concentrations up to 99% at temperatures up to about 120 F (50 C). Type 304 is also satisfactory for contact with 100% acetic acid vapours, and if small amounts of turbidity or colour pickup can be tolerated for room temperature storage of glacial acetic acid. Types 316 and 317 have the broadest range of usefulness, especially if formic acid is also present or if solutions are unaerated. Type 316 is used for fractionating equipment, for 30 to 99% concentrations where Type 304 cannot be used, for storage vessels, pumps and process equipment handling glacial acetic acid, which would be discoloured by Type 304. Type 316 is likewise applicable for parts having temperatures above 120 F (50 C), for dilute vapours 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 vapour 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 300 F (150 C), Type 304 is resistant to fats and fatty acids, but Type 316 is needed at 300 to 500 F (150 to 260 C) and Type 317 at higher temperatures.
Paint vehicles	Type 316 may be needed if exact colour 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 off-colour 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 475 (245 C), but Type 317 will probably be required at higher temperatures.
Tar	Tar distillation equipment is almost all Type 316 because coal tar has a high chloride content; Type 304 does not have adequate resistance to pitting.
Urea	Type 316L is generally required.
Pharmaceuticals	Type 316 is usually selected for all parts in contact with the product because of its inherent corrosion resistance and greater assurance of product purity.

Source: "Stainless Steel and the Chemical Industry." Climax Molybdenum Company, 1966, Greenwich, Conn.



This large vibrating conveyor, supplied to plastic manufacturers, incorporates a solid Type 304 stainless steel trough, 24 inches wide by 40 feet long. Inside, a stainless steel screen allows the bulk material (such as plastic pellets) to be conveyed from inlet to outlet, while hot air passes up through the screen to dry the material. Stainless steel is used for corrosion-resistant and noncontaminating qualities.

Photograph courtesy of Vibranetics, Inc., Louisville, Kentucky.

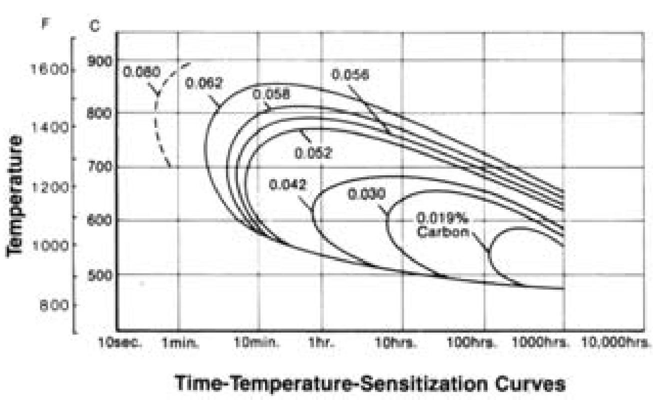
transfer conditions, which promote the concentration of chlorides, are particularly aggressive with respect to initiating stress corrosion cracking. A typical problem area is under insulation that might be applied to a container in which the bulk product is kept warm. If the insulation becomes wet, chlorides in the insulation can leach out and concentrate on the metal surface as a result of alternate wetting and drying. Any bulk product containing chlorides and exposed to elevated temperature should be viewed as having the potential for 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, Type 329 (an austenitic-ferritic stainless containing 25-30% chromium, 3-6% nickel, and 1-2% molybdenum) exhibits superior resistance to chloride stress-corrosion cracking; plus it has a general corrosion and pitting resistance similar to Type 316. Recent studies indicate that Type 317 with 3.5% (minimum) molybdenum has excellent resistance. Several proprietary austenitic stainless steels also have shown resistance to stress cracking in hot chloride environments.

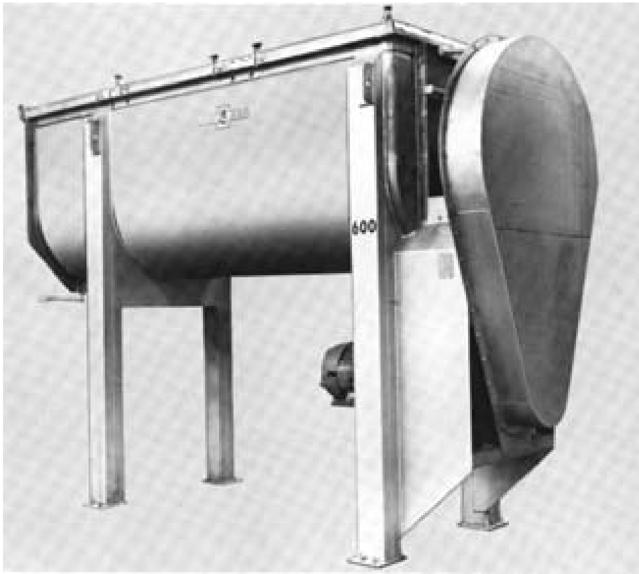
The ferritic stainless steels should also be considered when the potential exists for stress corrosion cracking.

Intergranular Corrosion. When austenitic stainless steels are heated or cooled through the temperature range of about 800-1650F, 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

Figure 1 Effect of Carbon Content on Carbide Precipitation (3)



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.



This sanitary-type, horizontal mixer is constructed of Type 304 stainless steel for all surfaces in contact with product. Stainless steel bar is used for the ribbon-type mixing flights, while the agitator arms and centre shaft are tubular products. Airjets on the agitator arms direct bursts of air through the interior to facilitate mixing and clearing. All welds are ground and polished with an 80 grit abrasive. Photograph courtesy of Sprout-Waldron Metal Products Division, Muncy, Pennsylvania.

the lowering of corrosion resistance in areas adjacent to the grain boundary. This is a time-temperature dependent phenomenon, as indicated in Figure 1.

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. For example, glacial acetic acid at room temperature or fresh clean water do not; strong nitric acids do. If the bulk handling equipment is a welded fabrication, such as shipping containers or storage bins, and the product is of a chemical nature (food products can be considered as such), then attention should be given to the possibility of intergranular attack.

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% 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 carbon precipitation to occur. However, the low-carbon grades may become sensitized at extremely long exposures to temperatures in the sensitization range.

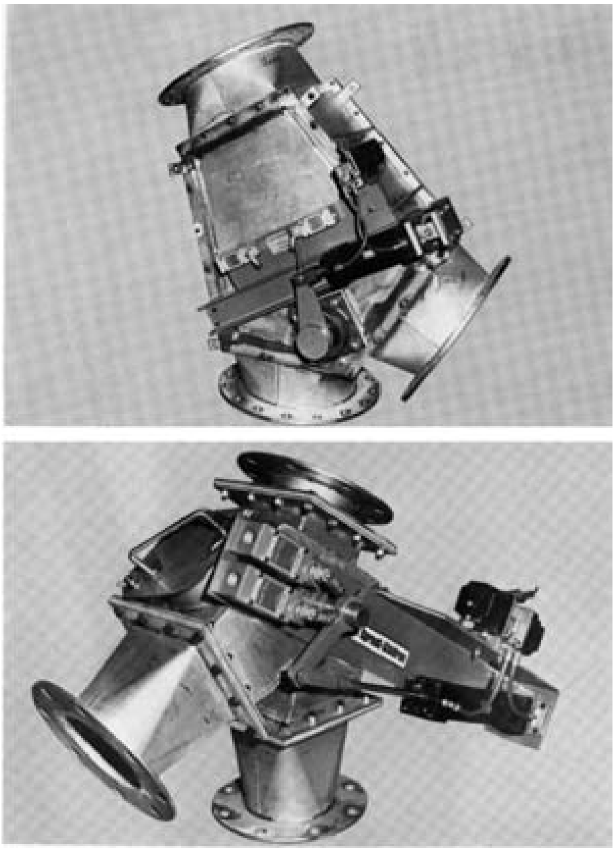
3. Selection of a stabilized grade, such as Type 321 (titanium stabilized) or Type 347 (columbium stabilized), for service in the 800-1650F range. The stabilization provided by titanium and columbium is based upon the greater affinity that they have for carbon than does chromium.

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.

A low-carbon grade is usually specified for welding fabrication, while a stabilized grade is usually specified when the component is to be used at elevated temperature.

SANITARY CHARACTERISTICS

In food processing and handling, stainless steels are preferred often specified by code or standard because they effectively resist or minimize the accumulation of surface dirt that could harbour bacterial growth, and they are easy to clean. Also, the stainless steel itself does not alter the taste of foods processed in stainless equipment. The wine, beer, and liquor industries, for example, are heavily invested with all-stainless equipment. Also, stainless steels are important to food processing, and to many other bulk handling enviroments. For instance, stainless steel is used to prevent contamination of product streams, such as in the handling of chemicals, processed pulp for fine papers, petroleum products, and pharmaceuticals. Also, the ease in which stainless steel can be cleaned permits fast turnaround for tankers, drums, bulk-handling bins, and pneumatic conveying systems -particularly when handling a multiplicity of products.



Top photograph shows a 12-inch precision diverter valve which directs product flow from one to two lines in a positive pressure pneumatic conveying *system. Bottom photograph is a sanitary-type bucket diverter valve. Both are constructed of stainless steel, the type of stainless predicated on the nature of the environment to which they are exposed.*

Photographs courtesy of Sprout-Waldron Metal Products Division, Muncy, Pennsylvania.

RESISTANCE TO ABRASION OR EROSION

There is no question that abrasion is a problem in many material handling applications, but only in dry systems can abrasion be considered as the sole cause of failure. When fluids are involved, corrosion has to be considered as a major contributing factor. For example, consider the following:

When carbon or mild steels are exposed to air and moisture, the iron in the metal oxidizes, forming a rust on the surface. In material handling, this rust is particularly evident on equipment that has been idle overnight or over the weekend because time has allowed the rust to build up. The iron oxide that forms is, however, loose and friable, and it generally can be removed with very little effort, leaving a bright, smooth surface. When the rust is removed, the metal underneath is exposed to moisture and oxygen, and new oxides begin to form almost immediately. If the rust is continuously removed, there will be continuous loss in metal thickness.

A demonstration of this effect can be seen in coal handling equipment, where for years abrasion was

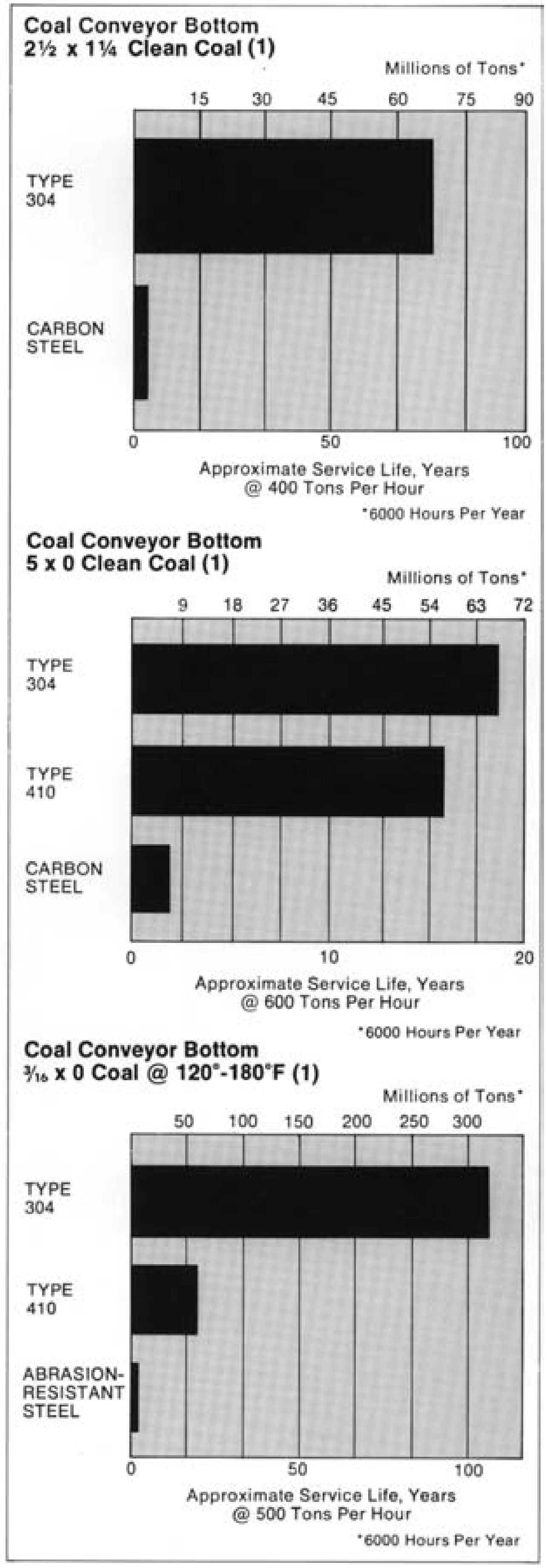
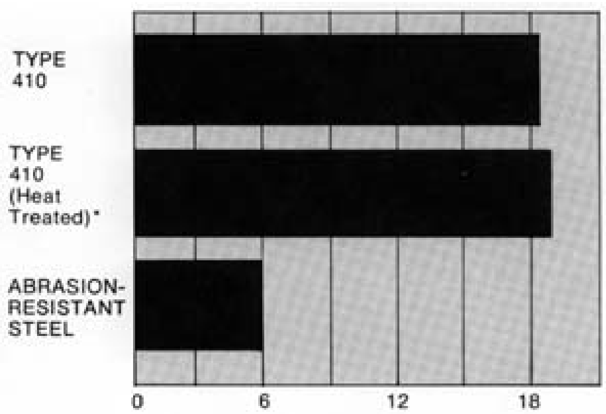


Figure 2

Centrifugal Dryer Flight Blades (1)



Approximate Service Life, Months

*½ Hour at 1850°F, Oil Quench + Temper

Figure 3

considered to be the cause of rapid metal deterioration. When stainless steel replacement liners were installed during a test, the effect was dramatic, as shown in Figure 2. The data show the superior performance of corrosion-resistant stainless steel in comparison to carbon steel and an abrasion-resistant steel. In each case, the stainless outlasted the carbon steel on the order of seven times and resulted in significantly larger tonnages of coal handling.

Even in centrifugal dryers (Figure 3), the benefit of corrosion-resistant stainless steels is in evidence. However, in this case abrasion is a more significant factor, as shown by the narrowing of service life range between abrasion-resistant steel and stainless steels. Nevertheless, the longer life of stainless resulted in significantly greater tonnages of product handled between repair or replacement of flights. The data also show that there is little difference between annealed Type 410 and heat treated Type 410.

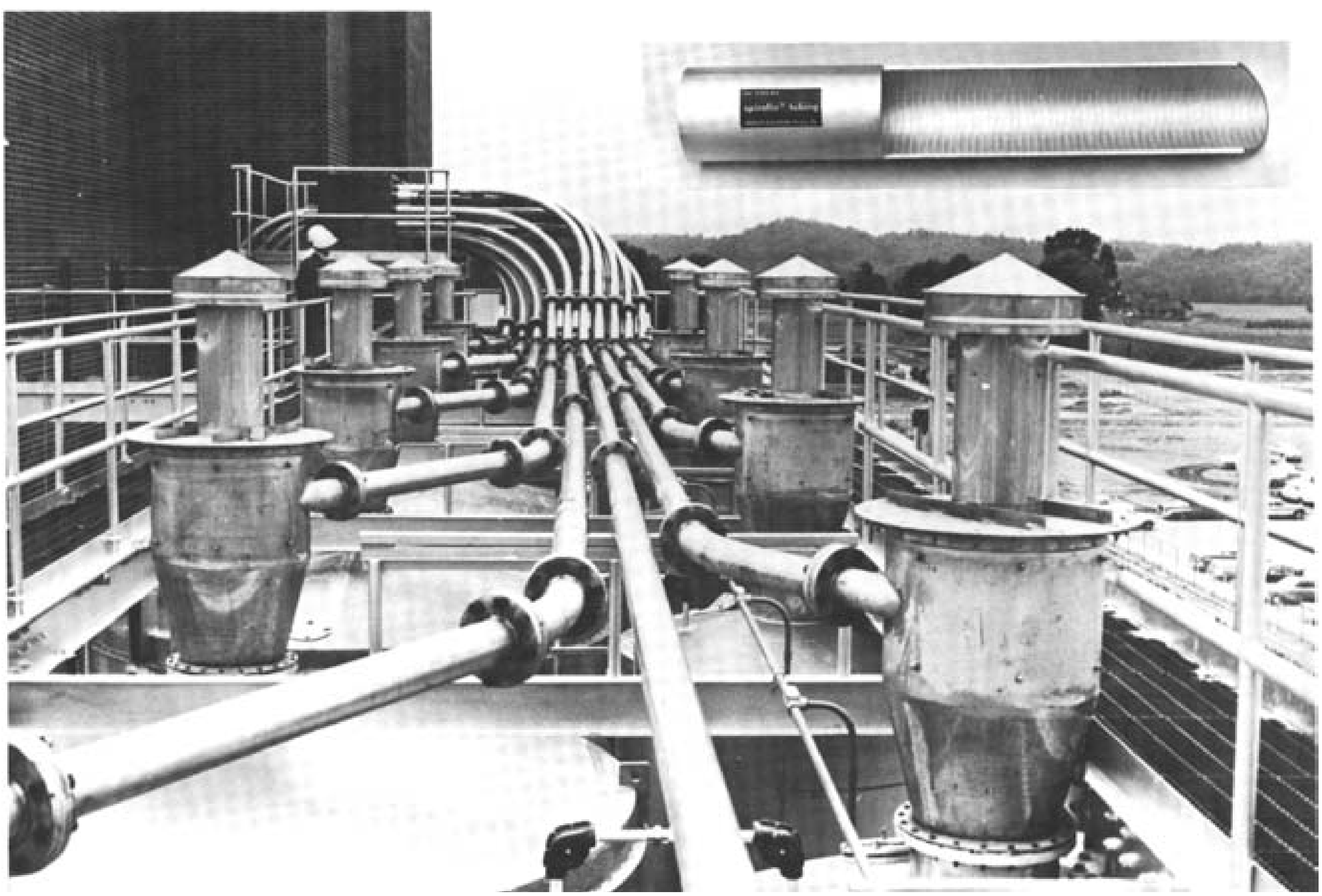
In terms of abrasion alone, it is difficult to generalize on the serviceability of stainless steels. For example, with some bulk materials, especially those with hard, rough surfaces, stainless may stand up well to abrasion

The stainless steel conveying lines in this positive-pressure, pneumatic tank filling system transfer polyester chips from process to storage. Product collectors to which pneumatic conveying lines lead are also stainless steel.

In some conveying systems, the tubular lines have uniform continuous spiral grooves, which effectively prevent the formation of ribbons and the smearing of soft plastic materials being conveyed. Stainless steel, which is available in all forms needed for bulk handling equipment like this, is selected to provide long, maintenance-free service, to prevent corrosion, to avoid product contamination, and to facilitate fabrication.

In most applications like this, thin-wall tubing can be used to minimize initial and installation cost. Economical piping systems utilize flared-on flanges and tube-bending techniques wherever practical.

Photographs courtesy of Sprout-Waldron Metal Products Division, Muncy, Pennsylvania.

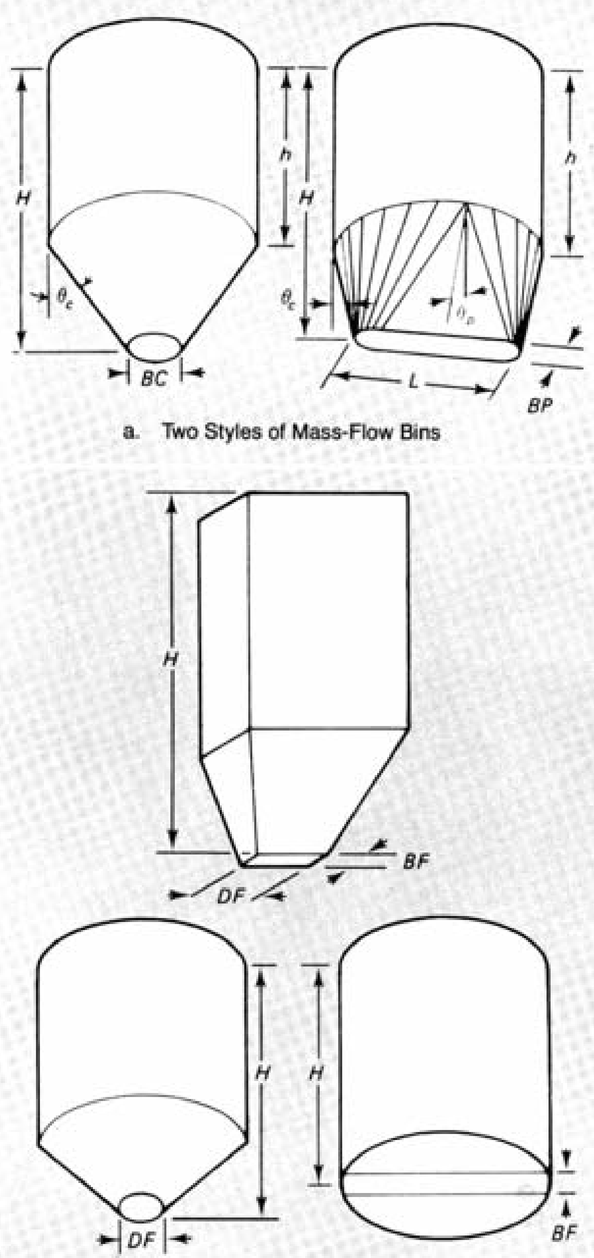


caused by the material *sliding* over the surface but may suffer rapid wear if the material is *tumbling* over or *impinging* onto the surface. Unfortunately, no suitable test has been devised that will allow one to rate the relative abrasion resistance of a material. Consequently, in-service tests under actual operating conditions are used to narrow the choice of materials.

SLIDEABILITY

Slideability describes the capability of a surface to accommodate the movement of bulk materials swiftly, smoothly, and completely without hangup, interruption, or bridging. In comparison with other construction materials, stainless steels with their hard dense surface, have superior slideability characteristics.

Figure 4 Stainless Steel Bins (4)



a. Two Styles of Mass-Flow Bins

b. Three Styles of Funnel-Flow Bins

Critical Dimensions for Mass-Flow Bins and Funnel-Flow Bins

For example, tests were conducted in which wet coal was unloaded from open hopper cars, some with standard construction steels and others lined with stainless steel plate. The stainless steel cut unloading time as much as 75%, and it eliminated the need for mechanical shakeout.

Slideability is a very important factor in virtually all bulk handling equipment because lower friction in chutes, bins and hoppers, and pneumatic piping permits longer runs, less power, gentle slopes, and more trouble-free service. Furthermore, stainless steel has, in many applications, actually improved in slideability characteristics with use.

Information is available in the literature on designing various types of bulk handling equipment with stainless steels. For example, J.R. Johanson[4] shows critical outlet dimensions needed in Type 304 bins handling a dry polymer. Some of Johanson's calculations are shown in Figure 4 and Table 3, and he states that hopper angles and slopes of chutes are directly related to the type of wall or chute material. The values given are limits. Larger outlet sizes, steeper hopper angles and slower flow rates are always acceptable.

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 exhibit yield strengths between 30 and 200 ksi, depending on composition and amount of cold work. They also exhibit good ductility and toughness even at high strengths, and this good ductility and toughness is retained to cryogenic temperatures.

Because austenitic stainless steels can be cold worked to high tensile and yield strengths, yet retaining good ductility and toughness, they meet a wide range of design criteria. For example, sheets of austenitic steels -usually Types 301 and 201- are produced in the tempers shown in Table 4.

In structural applications, the toughness and fatigue strength of these steels are important. At room temperature in the annealed condition, the austenitic steels exhibit Charpy V-notch energy absorption values in excess of 100 ft.-l b.

New Design Specification. Until recently, design engineers wanting to use austenitic stainless steels structurally had to improvise due to the lack of an appropriate design specification. The familiar American Institute for Steel Construction and AISI design specifications for carbon steel design do not apply to the design of stainless steel members because of differences in strength properties, modulus of elasticity, and the shape of the stress strain curve, Figure 5, which

Figure 5 Representative Stress-Strain Curve for Mild Steel and Half-Hard Stainless Steel (1)

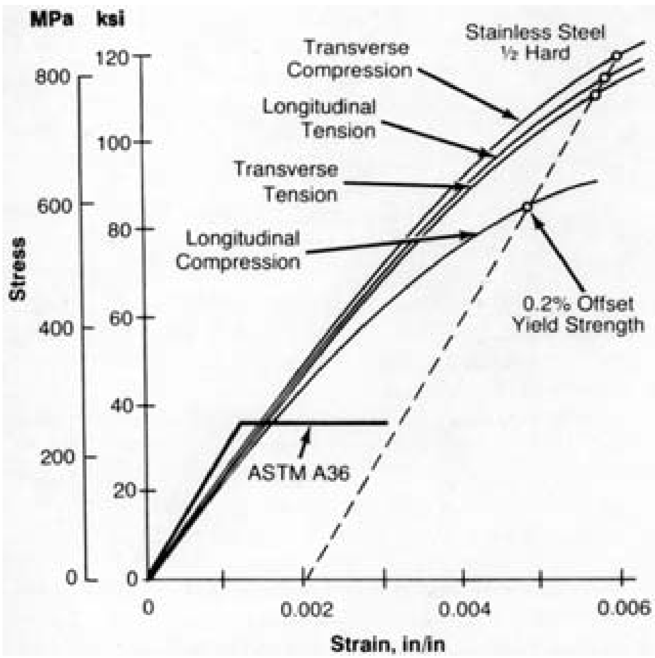


Table 4
Cold Worked Mechanical Property Designations for AISI 200 and 300 Series Stainless Steels (1)

Temper	Tensile Strength Minimum		Yield Strength Minimum	
	ksi	Mpa	ksi	Mpa
¼-Hard	125	862	75	517
½-Hard	150	1034	110	758
¾-Hard	175	1207	135	931
Full-Hard	185	1276	140	965

shows no well-defined yield point for stainless as there is for mild steel.

An extensive research project at Cornell University investigated the structural behaviour of austenitic stainless steel members. In 1974, a design specification was published, titled "Stainless Steel Cold-Formed Structural Design Manual-1974 Edition." The specification covers sheet, strip, plate, and flat bar of stainless steel Types 201, 202, 301, 302, 304 and 316 in the ¼ and ½ -hard tempers.

The physical properties of austenitic stainless steels are similar to those of the martensitic and ferritic stainless steels. The modulus of elasticity, for example, is 28 x 10^6 psi and density of 0.29 pounds per cubic inch.

Table 3 How the flow properties of a dry (0% moisture) polymer are specified (4)

Material: Sample of a polymer (0°/a moisture)

Time of storage, h	Mass-flow bins		Funnel-flow bins						
	Arching dimensions		Arching dimension	Critical rathole diameters, *DF,* ft, at various consolidating pressures, lb/ft^2					
	BC, ft	*BP, ft*	*BF ft*	150	300	600	1,200	2,400	3,180
0	0.5	0.2	0.2	0.7	0.9	1.1	1.7	2.8	3.6
72	1.1	0.6	0.6	1.5	1.6	1.8	2.2	3.0	3.5

Bulk density, γ , as a function of compacting pressure

Pressure, σ , lb/ft^2	30	150	300	600	1,200	2,400	4,800
Bulk density, γ , lb/ft^3	58.7	60.6	61.5	62.3	63.2	64.1	65.0

Maximum solids flowrate, tons/h, as a function of maximum consolidating pressure*

Cone diameter, ft	Maximum consolidating pressure, lb/ft^2			
	300	600	1,200	2,400
0.5	2.5	2.3	2.1	2.0
1	10.2	9.5	8.9	8.1
2	41	I 37	I 35	I 33

Recommended hopper angles for Type 304 mill-finish stainless steel:

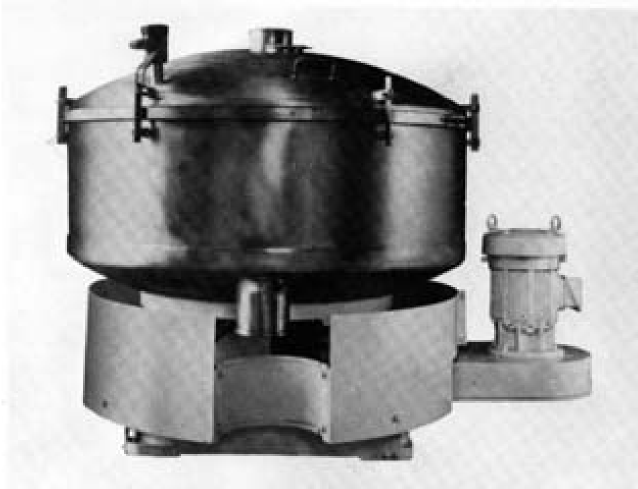
Conical angle θ_c =12.2 deg (from the vertical)

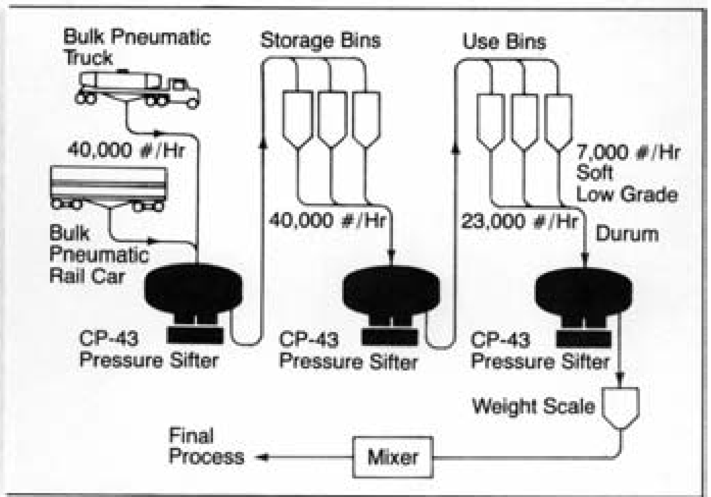
Long-slot angle θ_p = 24.3 deg (from the vertical)

Recommended minimum flat-chute angle to eliminate buildup for Type 304 stainless steel:

ϕ '= 37 deg (from the horizontal)

*From mass-flow cone without air injection.





Photograph shows a totally enclosed pressure sifter that operates in a pneumatic system without the need for airlocks and hoppers normally used with atmospheric screeners. All components including vessel, trays, and screens are constructed of stainless steel to meet USDA and BISSC requirements. Flow diagram shows a typical arrangement of three pressure sifters in a pneumatic system in a soup mix plant. Incoming flours and starches are unloaded through the first pressure sifter at 40,000 pounds per hour to storage. Transfers from storage to use bins are again screened, and a third unit screens starches and flours including durum and soft, low grades en route to scale.

Photograph and drawing courtesy of Gump Division, Blaw-Knox Food and Chemical Equipment, Inc., Buffalo, New York.

The mechanical and physical properties of annealed Type 304 are shown in Table 5. Cold working reduces these values slightly.

Ferritic Stainless Steels

Ferritic stainless steels contain from 11% to 25% chromium. In comparison to low-carbon steels, such as SAE 1010, the standard AISI-numbered ferritic stainless steels, (such as Type 430) exhibit somewhat higher yield and tensile strengths, and low elongations; thus they are not as formable as the low-carbon steels. Mechanical and physical properties of Type 430 are shown in Table 5.

Martensitic Stainless Steels

The martensitic grades are so named because when heated above 1600F and cooled rapidly, a metallurgical structure known as martensite is formed. In this hardened condition, the steel has very high strength and hardness, but to obtain optimum corrosion resistance, ductility, and impact strength, the steel is given a stress-relieving or tempering treatment (usually in the range 300-700F). Table 5 gives the mechanical and physical properties of Type 410 in the annealed condition.

The martensitic stainless steels are generally selected for moderate resistance to corrosion, relatively high strength, and good fatigue properties after

This 20-inch wide by 12-foot long sliderboard belt conveyor, which is water-tight, is constructed of Type 316 stainless steel for more aggressive service.

Photograph courtesy of Sprout-Waldron Metal Products Division, Muncy, Pennsylvania.

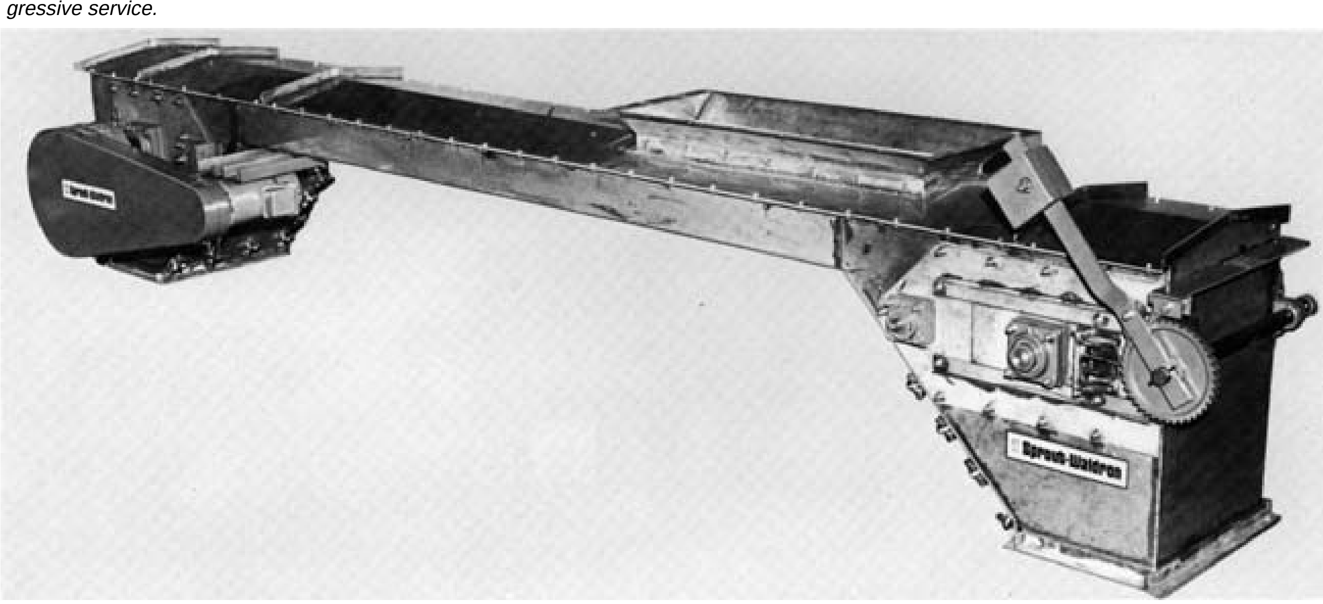
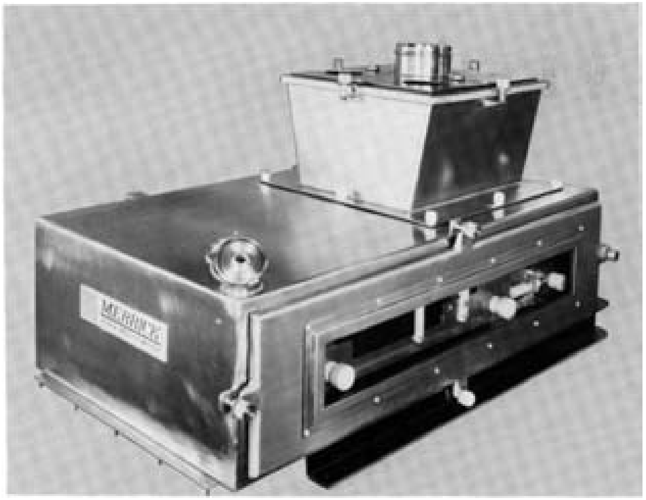


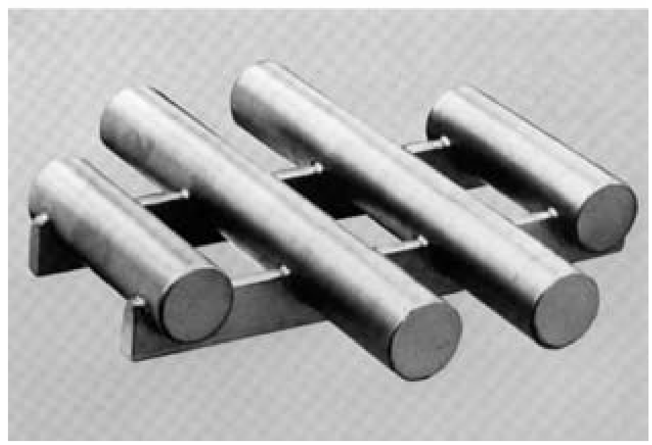
Table 5
Chemical Composition, Mechanical and Physical Properties of General Purpose Stainless Steels (1)

	Type 304	Type 430	Type 410	S17700
Chemical Analysis (Max. unless noted otherwise)				
Carbon	0.08	0.12	0.15	0.09
Manganese	2.00	1.00	1.00	1.00
Phosphorus	0.045	0.040	0.040	0.040
Sulfur	0.030	0.030	0.030	0.040
Silicon	1.00	1.00	1.00	0.040
Chromium	18.00/20.00	16.00/18.00	11.50/13.50	16.00/18.00
Nickel	8.00/10.50			6.50/7.75
Other				0.75/1.50 A1
Mechanical Properties (Annealed Sheet)				
Tensile Strength ksi (MPa)	84 (579)	75 (517)	70 (483)	130* (896*)
Yield Strength ksi (MPa) (0.2% offset)	42 (290)	50 (345)	45 (310)	40* (276*)
Elongation in 2" % (50.80 mm)	55	25	25	35*
Hardness (Rockwell)	B80	B85	B80	B85*
*Solution Treated Bar				
Physical Properties				
Modulus of Elasticity in Tension psi x 10^6 (GPa)	28.0 (193)	29.0 (200)	29.0 (200)	29.5 (204)
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				
(J/kg.K) 212F (100C)	9.4 (0.113)	15.1 (0.182)	14.4 (0.174)	9.5 (0.114)
932F (500C)	12.4 (0.149)	15.2 (0.183)	16.6 (0.201)	12.6 (0.151)
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)	6.1 (11.0)
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)	- -
32-1500F (0-982C)	- -	6.9 (12.4)	- -	-
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)



Special design, all-stainless steel weighfeeder is for bulk weighing of explosive powders. The design includes fire sensor parts, no metalto-metal contact, and special electrical grounding (to prevent static electricity sparking). Stainless steel is used for strength, corrosion resistance, and noncontaminating properties.

Photograph courtesy of Merrick Scale Mfg. Company, Passaic, New Jersey.



Magnets are used to move or remove ferrous material, and in each case, stainless steel separates the product from the magnet. The top photograph shows a magnetic conveyor in which the ferrous material is drawn along a stainless steel slider plate by magnets moving underneath. Typical applications include high-volume heat treating operations, removal of chips and cuttings in machining operations or for conveying finished parts.

The bottom photograph shows a grate magnet, which is designed for installation in hoppers, chutes or ducts - or almost anywhere in a dry granular stream. Powerful magnets packed inside stainless steel tubes create a concentrated magnetic field which traps and holds any ferrous contamination in the stream.

Photographs courtesy Eriez Magnetics, Erie, Pennsylvania.

suitable heat treatment. Type 410 is used for fasteners, machinery parts, press plates and the like. If greater hardenability or higher toughness is required, Type 414 may be used, and for better machinability, Types 416 or 416 Se are used.

Precipitation Hardening Stainless

The principle of precipitation hardening is that a supercooled solid solution (when solution treated) changes its metallurgical structure on aging. The principal advantage is that products can be fabricated in the annealed condition and then strengthened by a relatively low-temperature 900-1150F 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 - approximately equal to that of Type 304 stainless. Ductility is similar to corresponding martensitic grades at the same strength level.

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 which have satisfactory "room-temperature" characteristics do 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 cryogenic temperatures - minus 423F.

Stainless steel is featured in the contamination-free pneumatic bulk-material-handling vacuum unloader. The components fabricated of stainless steel are the receiving cyclone, centrifugal fans, fan housing, rotary airlock, mixing chamber and air tubing. In addition to the noncontaminating characteristics, stainless steel provides quick and easy cleaning for fast switching from one product to another. The smooth surface of stainless steel also helps to prevent hang-up of product within the system.

Photograph courtesy of Dunbar Kapple, Inc., Batavia, Illinois.

FABRICATION

Stainless steels are generally selected on the basis of corrosion resistance and on the basis of strength or other mechanical properties. Another consideration is fabrication. While the three general purpose stainless types predominate, namely Types 304, 430, and 410, there are variations of these types that are better suited to certain manufacturing operations. (Service requirements may preclude the use of these variations; so it is well to know that all stainless steels can be readily fabricated by conventional manufacturing methods.)

Hot Forming

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

Hot rolling is generally a steel mill operation for producing standard mill forms and special shapes. Extrusion is usually associated with softer, non-ferrous metals. In extrusion, a shaped piece is made by forcing a bar or billet through a die, the exiting cross-section conforming to the die opening. Several companies produce hot extrusions in stainless steel. Relatively small quantities are both feasible and economical.

Forging is used extensively for stainless steels of all types and in sizes from a few ounces to thousands of pounds, smaller than one inch to parts many feet long. Special operations, such as drawing, piercing, and coining further enhance forging capabilities. Designers are urged to consult forgers for design guidelines pertaining to shapes, tolerances, limitations, etc.

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

Cold Forming

The mechanical properties of stainless steels serve as an indication of their relative formability at ambient or room temperature. Annealed austenitic grades are typified as having low yield strengths, high tensile strengths, and high elongations. Some of these alloys work-harden to a high degree during cold work, which further increases their strength properties. The ferritic alloys have lower ductility than the austenitic types and are closer to carbon steel with respect to mechanical properties; and they do not work-harden significantly during cold forming. Because of their excellent mechanical properties, stainless steels have excellent cold forming characteristics.

Machining

The machining characteristics of stainless steels are substantially different from those of carbon or alloy steels and other metals. In varying degree, most stainless steels without composition modification are tough, rather gummy, and they tend to seize and gall.

While the 400 Series stainless steels are the easiest to machine, a stringy chip produced during the machining can slow productivity. The 200 and 300 Series, on the other hand, have the most difficult machining characteristics, primarily because of their propensity to work-harden at a very rapid rate.

Experienced machine shop production engineers work around these conditions and achieve good productivity with any of the stainless steels. However, wherever conditions permit, the design engineer can help minimize problems and get maximum machining productivity. Here are three suggestions; 1) specify a free-machining stainless steel, 2) suggest to the production engineer that he use a special analysis stainless steel that is "more suited for machining," or 3) specify stainless steel bar for machining that is in a slightly hardened condition.

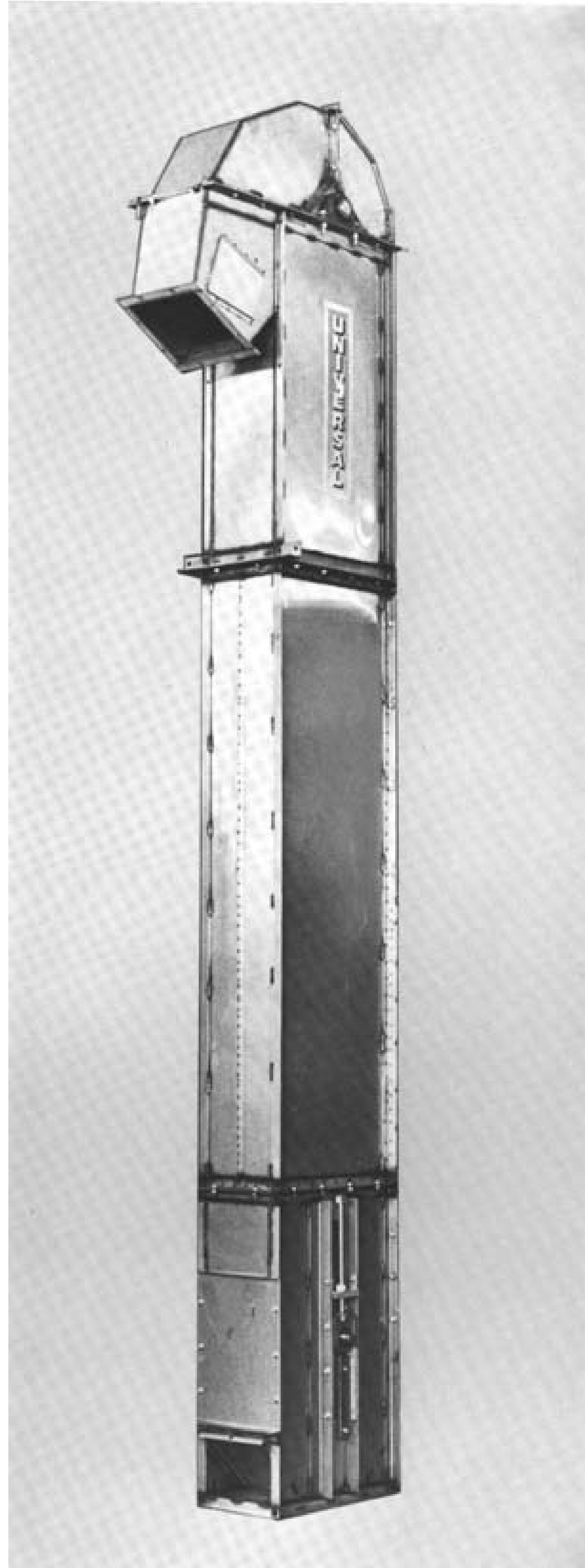
A booklet, "Free Machining Stainless Steels," which is available from the Committee of Stainless Steel Producers, discusses the subject in greater detail. Included in the booklet is a Trade Name Directory of free-machining stainless steels.

Joining

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

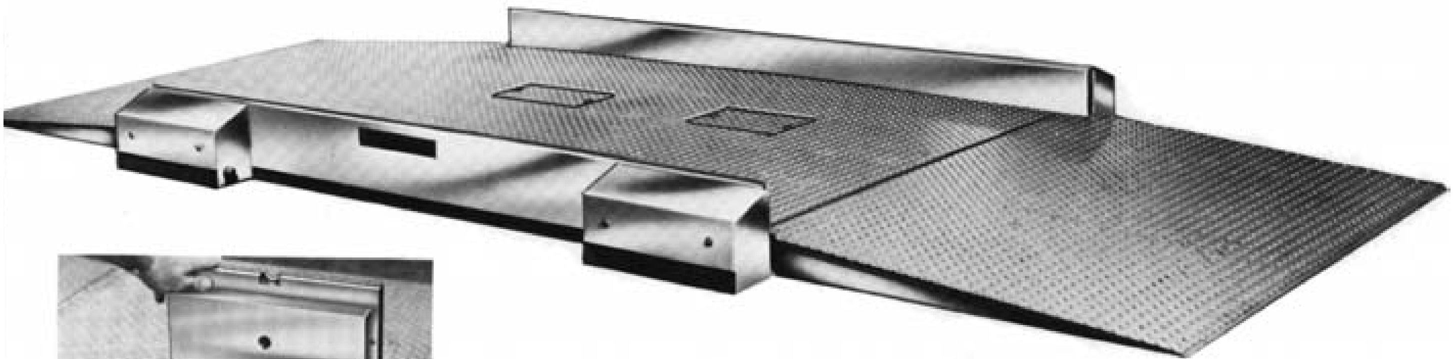
First, it is important that procedures be followed to preserve corrosion resistance in the weld and in the area immediately adjacent to the weld, referred to as the heat-affected-zone (HAZ). Second, it is desirable to maintain optimum mechanical properties in the joint, and third, certain steps are necessary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



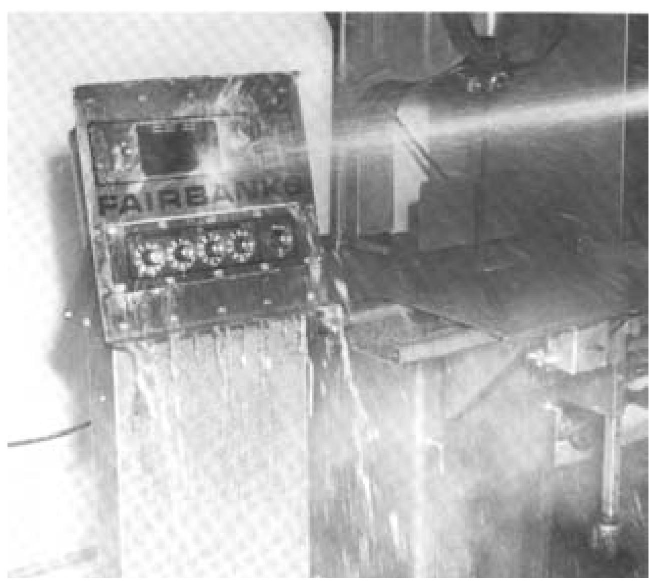
All-stainless steel bucket elevator is designed for hard-to-handle materials, such as those that are hot, abrasive, corrosive, hygroscopic, wet or lumpy, which tend to pack and build up on conveyor surfaces. Stainless steel is used for couplings, angles, fasteners, buckets and housing.

Photograph courtesy of Universal Industries, Waterloo, Iowa.



Designed specifically for the hostile environments encountered in the food and chemical processing industries, the low-profile scale shown above is constructed entirely of Type 304, with the exception of the load cells. Below right is a weigh station data printer housed in a sealed, stainless steel, NEMA IV enclosure. The photograph below that shows the advantage of using stainless steel equipment. It is easy to clean, stands up to most detergents and chemical cleaners (not hydrochloric acid-based cleaners, however), and meets or exceeds all USDA requirements.

Photographs courtesy of Colt Industries, Fairbanks Weighing Division, St. Johnsbury, Vermont.



resistance properties as nearly identical to the base metal as possible-or better. For instance, a Type 308 weld rod is specified for welding Type 304, and a 300 Series rod is often used for joining 400 Series types. The best suggestion is to follow American Welding Society (AWS) practices for weld rod selection (and weld procedures as well) or to consult weld rod manufacturers. The latter have up-to-date tables for rod selection.

Proper weld rod selection not only insures preservation of the corrosion resistant properties, but it is also important in achieving optimum mechanical properties.

Another principal difference between stainless and carbon or low-alloy steels is thermal conductivity, with stainless about half that of other steels. Hence, heat is not dissipated as rapidly.

There are four methods to accommodate this situation: lower weld current settings, skip-weld techniques to minimize heat concentration, use of back-up chill bars or other cooling techniques to dissipate heat, and proper joint design.

Soldering. Stainless steels are readily soldered with relatively few problems arising from temperature. Aggressive fluxes, however, are necessary to prepare the surface for soldering. Phosphoric acid type fluxes are preferred because they are not corrosive at room temperature.

Brazing. All stainless steels can be brazed, but because the brazing alloys are usually composed of copper, silver, and zinc, substantially high temperatures are required. This can lead to such high temperature problems as carbide precipitation and a lessening of corrosion resistance.

A complete discussion of the joining methods used for stainless steels is provided in the booklet, "Welding of Stainless Steels and Other Joining Methods," which is available from the Committee of Stainless Steel Producers.

This cryogenic grinding system is effective for reducing the size of "tough-to-handle" materials, such as plastics, dry paint powders, dyes and pigments, adhesives, pharmaceuticals, chemicals, and fibrous materials. Liquid nitrogen at a temperature of -320F causes quick and thorough embrittlement of the material, which, when ground, produces excellent size reduction with uniform size distribution. Austenitic stainless steels, such as Types 304 or 316, are generally preferred for cryogenic service because they maintain excellent strength and ductility are extremely low service temperatures.

Photograph courtesy of Pulverizing Machinery Division, MikroPul Corporation, Summit, New Jersey.

Fasteners. Although fasteners are available in many materials, stainless fasteners are a good first choice, and they are necessary if the materials being joined are stainless. Stainless fasteners are readily available in both standard and special designs.

Since corrosion resistance is an important aspect of product reliability, inherent in any attempt to prevent corrosion is the careful selection of fastener materials. A common practice in industry is to use fasteners made of metals or alloys that are equal to or more corrosion resistant than the materials they join. This practice is justified because the fasteners may have to withstand higher loads with greater unit stress than the parts being held together, and they are usually considerably smaller in surface area than the material being joined. Also, corrosion-weakened fasteners may lead to a more immediate failure with more serious consequences than the same amount of corrosive attack elsewhere in the assembly.

Additional data on stainless steel fasteners are available from the Committee of Stainless Steel Producers in the booklet, "Stainless Steel Fasteners Suggested Source List." Also available is the booklet, "Stainless Steel Fasteners, A Systematic Approach to Their Selection."

SURFACE PROTECTION AND CLEANING

Stainless steels must have clean surfaces for optimum corrosion resistance. Design engineers should take steps to see that fabricators either protect the

Inclinable screw conveyor has variable discharge heights, provided by adjustable tubular screw housing. Available capacities are from 50 to 480 cubic feet per hour; heights from 6 to 15 feet. All areas in contact with the product are of polished Type 304 to assure sanitary and noncontaminating conditions.

Photograph courtesy of S. Howes Company, Inc., Silver Creek, New York.

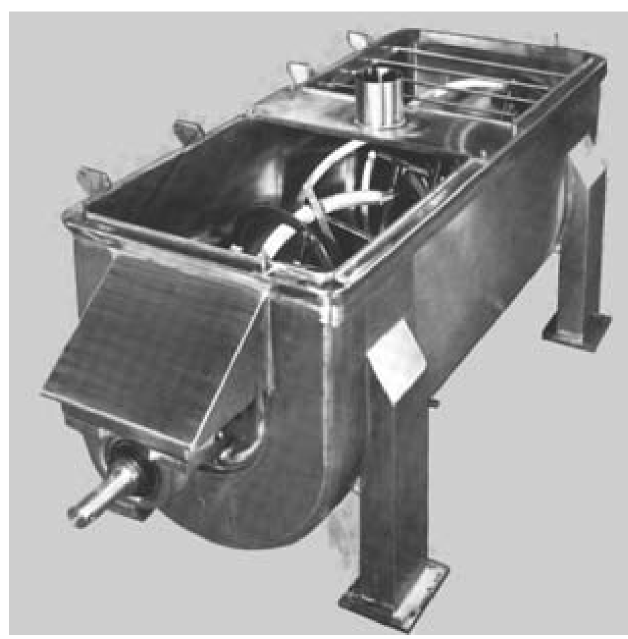
metal surface from contamination during forming and other manufacturing steps or restore the surface by mechanical or chemical cleaning.

Metal particles from steel dies can become imbedded in the surface of the stainless at pressure points. This pickup will rust and stain the surface when exposed to moisture. Chromium-plated dies or a paper or plastic protective covering on the stainless steel can prevent such problems during many fabrication steps, except for the more severe operations, such as forging, machining, heading, coining, welding, or spinning.

When stainless cannot be protected by covering, procedures should be employed to keep the material clean. Rusty water drips, dirt from overhead cranes, unclean handling equipment, even dust from open doors, can be causes of subsequent staining. The most severe problems are likely to arise in shops that work on carbon steel as well as stainless. Using grinding tools on stainless that were previously used on carbon steel can leave steel particles imbedded in the stainless surface that will later rust and stain. In such cases, the best procedure is to chemically clean the stainless after fabrication, in solutions that will dissolve the carbon steel particles, such as solutions of nitric acid and water. Such chemical cleaning is often referred to as passivation.

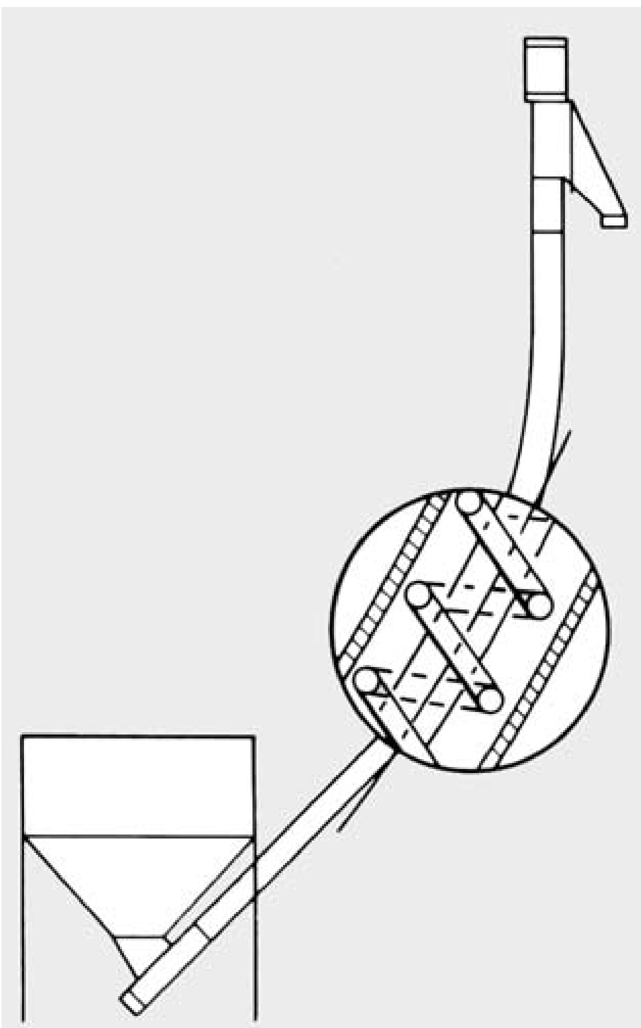
Ship loading, retractable bulk loading spout, constructed internally of Type 304, is used extensively for fertilizers (diamonium phosphate), inorganic chemicals, uranium ore (yellow cake), and various pellets and resins used in the manufacture of plastics and plastic fibres. Stainless steel is used to prevent accumulation of product on spout surfaces, to prevent product contamination, and to facilitate cleaning.

Photograph courtesy of Midwest International, Charlevoix, Michigan.



Ribbon mixer for sanitary service is constructed entirely of stainless steel for ease in achieving and maintaining a high degree of cleanliness. Fillet welds on mixer blades and large-radius corners in tank eliminate pockets or crevices where product could accumulate, and prevent proper mixing or equipment cleaning.

Photograph courtesy of S. Howes Company, Inc., Silver Creek, New York.



Flexible mechanical conveyors transport powders and granules in or out of confined areas not accessible to more conventional rigid conveyors. The outer tubing as well as the inner spiral conveyor are available in stainless steel for handling a wide variety of chemicals, plastics, pharmaceuticals and food.

Illustration courtesy Flexicon Corporation, Lodi, New Jersey.

ADDITIONAL READING

The following publications may be useful to materials handling engineers requiring more detailed information on stainless steel. Single copies of these publications are available free of charge from the Committee of Stainless Steel Producers, American Iron and Steel Institute, 1000 16th Street N.W., Washington, D.C.

"Design Guidelines for the Selection and Use of Stainless Steels"

"High-Temperature Characteristics of Stainless Steels"

"Welding of Stainless Steels and Other Joining Methods"

"Stainless Steel Fasteners, A Systematic Approach to Their Selection"

"Stainless Steel Fasteners Suggest Source List" "Review of the Wear and Galling Characteristics of Stainless Steel"

"Free-Machining Stainless Steels"
"Stainless Steel Forgings"
"Cold Forming Stainless Steel Bar and Wire" "Stainless Steel Cold Formed Structural Design Manual, 1974 Edition" ($3.00)

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