The Specialty Steel Industry of North America (SSINA) and the individual companies it represents have made every effort to ensure that the information presented in this handbook is technically correct. However, neither the SSINA nor its member companies warrants the accuracy of the information contained in this handbook or its suitability for any general and specific use. The SSINA assumes no liability or responsibility of any kind in connection with the use of this information. The reader is advised that the material contained herein should not be used or relied on for any specific or general applications without first securing competent advice.
GENERAL

Stainless steel is not a single alloy, but rather the name applies to a group of iron-based alloys containing a minimum of 10.5% chromium. Other elements are added and the chromium content increased to improve the corrosion resistance, improve heat resisting properties, enhance mechanical properties, and/or to improve fabricating characteristics. There are over 50 stainless steel grades that were originally recognized by the American Iron and Steel Institute (AISI) and are detailed in a designer handbook, Design Guidelines for the Selection and Use of Stainless Steel, available from the Specialty Steel Industry of North America (SSINA).

This booklet on the fabrication of stainless steel will only deal with 30 of the more common grades in three metallurgical groups: austenitic, ferritic, and martensitic.

AUSTENITIC GROUP

This group contains chromium and nickel and is identified by the Type 300 series. Grades containing chromium, nickel, and manganese are Type 200. These two types have different compositions and properties, but many common characteristics. They can be hardened by cold working, but not by heat treatment. In the annealed condition, all are essentially nonmagnetic. They have excellent corrosion resistance and unusually good formability. Type 304 (18% chromium - 8% nickel) and Type 316 (16% chromium - 10% nickel - 2% molybdenum) are the most widely used grades in this group.

FERRITIC GROUP

The ferritic stainless steels are identified by the Type 400 series. They cannot be hardened by heat treatment. They are straight chromium alloys and only moderately hardened by cold working. This group is magnetic and has good ductility and resistance to corrosion. Type 430 (16% chromium) is the general purpose stainless steel of the ferritic group.

MARTENSITIC GROUP

This group is also identified by the Type 400 series and are hardenable by heat treatment. They are magnetic and resist corrosion in mild environments. The ductility of this group is fair to good. Type 410 (11.5% chromium) is the most widely used alloy of this group.

ACKNOWLEDGMENT

The Specialty Steel Industry of North America wishes to acknowledge information obtained from the International Nickel Company, the Southern Africa Stainless Steel Development Association, the Steel Service Center Institute and the Nickel Development Institute (NiDI) as having contributed to this publication.
Exhibit 1
RELATIVE FABRICATION CHARACTERISTICS OF STAINLESS STEELS

<table>
<thead>
<tr>
<th>Group</th>
<th>Austenitic</th>
<th>Ferritic</th>
<th>Martensitic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type Number</td>
<td>201, 202, 301, 302, 304, 304L</td>
<td>309, 310S, 316, 316L, 317</td>
<td>430, 405, 442, 446</td>
</tr>
<tr>
<td></td>
<td>305, 303*</td>
<td>317LMN, 347</td>
<td>439, 410</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>410, 420</td>
</tr>
<tr>
<td>Air Hardening</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Blanking</td>
<td>F</td>
<td>F</td>
<td>E</td>
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<tr>
<td>Brazing, Silver</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>Buffing</td>
<td>G</td>
<td>G</td>
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<tr>
<td>Drawing, Deep</td>
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<tr>
<td>Forming, Hot</td>
<td>G</td>
<td>G</td>
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</tr>
<tr>
<td>Forming, Cold</td>
<td>G</td>
<td>G</td>
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<tr>
<td>Grinding, Ease of</td>
<td>F</td>
<td>G</td>
<td>F</td>
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<tr>
<td>Grinding (magnetic)</td>
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<td>No</td>
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<tr>
<td>Hardenable by Heat Treatment</td>
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<td>Yes</td>
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<tr>
<td>Punching (perforating)</td>
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<td>G</td>
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<tr>
<td>Polishing</td>
<td>G</td>
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<tr>
<td>Riveting, Hot</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>Riveting, Cold</td>
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<td>G</td>
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</tr>
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<td>Shearing, Cold</td>
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<td>F</td>
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<td>Soldering</td>
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<td>G</td>
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<tr>
<td>Brazing</td>
<td>G</td>
<td>G</td>
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<td>Spinning</td>
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<td>Welding</td>
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<td>F</td>
</tr>
<tr>
<td>Machining</td>
<td>F</td>
<td>E</td>
<td>F</td>
</tr>
</tbody>
</table>

Code: E = Excellent, G = Good, F = Fair, NR = Not generally recommended (Poor)

*Chemistry designed for improved machining (as are other grades, i.e., 416, 420F, 430F, 440F)

CHARACTERISTICS OF STAINLESS STEEL

Stainless steels can be fabricated by methods similar to those used for carbon steels and other common metals. However, changes may be necessary to the extent that they differ in yield strength and rate of work hardening. All have work hardening rates higher than common carbon steels, but the austenitics are characterized by large increases in strength and hardness with cold work. With the exception of the resulfurized “free-machining” grades (Type 303 is the common type, but many others can be treated to be more easily machined), all stainless steels are suitable for crimping or flattening operations. The free machining grades will withstand mild longitudinal deformation, but may exhibit some tendency to splitting. In spite of their higher hardness, most martensitic and all of the ferritic types can be successfully fabricated. Exhibit 1 shows the relative fabrication characteristics of three groups of stainless steel.

FABRICATION PROPERTIES OF STAINLESS STEEL

Exhibit 2 lists the 30 grades and their UNS number (the Unified Numbering System was developed by the American Society for Testing Materials and the Society of Automotive Engineers for all commercial metals and alloys). Some stainless types are not suitable for certain applications and others are designed to be better adapted. Exhibit 2 shows the suitability of these 30 types in various fabrication applications.

DRILLING

All stainless steels have “work” (or strain) hardening characteristics. It is particularly notable in the 300 series. When the drill bits contact the surface of the stainless steel and as they penetrate, the material will harden and it will be more and more difficult to continue drilling with the same pressure and speed. Drilling bits are generally made from high speed steels and monolithic carbide. It is important to lubricate the drill under pressure. Soluble oils or cutting oils are often used (it is advisable to seek professional recommendations on specific oils that are available for use with stainless steel).

For long products and thick sheets and plates, the point angle should be 120 to 135 degrees. For thin sheets, in order to reduce the surface stresses, the point angle should be increased to 140 degrees and the relief angle reduced to 5 degrees*

*CUTTING

Important Note: In all cutting operations on stainless steels the following guidelines are helpful in maintaining corrosion resistance:

- No contamination by ferrous (iron or steel) material or particles should take place.
- Mechanically cut edges will naturally form the corrosion resistant passive film. The formation of such a passive film on cut edges will be enhanced by a chemical (acid) passivation treatment with nitric acid.
- Thermally cut edges may be affected in terms of chemical composition and metallurgical structure. Removal of affected surface layers by dressing is necessary so that impaired areas of mechanical and corrosion resistant properties are minimized.

Cutting operations are usually necessary to obtain the desired blank shape or size prior to forming operations and also to trim a part to final size. Mechanical cutting and thermal cutting are the two most frequently used cutting operations and the specific methods available are discussed in the individual sections below. These methods are useable with stainless steel, but because of the differences in strength, toughness and rate of work hardening, certain details in the operations may need to be modified relative to carbon steels.
MECHANICAL Shearing
The shear strength of annealed austenitic stainless steel is about 65 to 70 percent of its ultimate tensile strength. The shear strength of carbon steel is in the range of 55 to 60 percent of its ultimate strength. Generally, shears are rated on their capacity to shear mild carbon steel of 50 ksi tensile strength. The shears are supplied with rake on the upper knife in accordance with the shear manufacturer’s specification. More force and heavier equipment will be required to shear equal thicknesses of the stainless alloys. With more power required it is necessary to derate the shears against their nominal capacity, which is usually given in terms of the thickness of low carbon (mild) steel which they are capable of shearing.

Typical relative derated capacities are as follows:
- Low Carbon (mild) steel
  - 0.4 in. (10 mm) thick material
  - 0.3 in. (7.8 mm) thick material
- Ferritic Stainless Steel (F430)
  - 0.3 in. (7.8 mm) thick material
- Austenitic Material (T304)
  - 0.2 in. (5.4 mm) thick material

Note: Because thinner gauges of stainless steel are generally used, the force required to shear stainless steel for a given part is often comparable to the force needed to shear a similar part made of thicker carbon steel.

Ferritic stainless steels tend to fracture after being cut through approximately half their thickness, while austenitic stainless steels are characterized by high ductility and, hence, are more resistant to fracture. A greater degree of penetration takes place before the fracture occurs. The clearance setting of the blades is, therefore, important. For thin gauge sheet a clearance of 0.001 to 0.002 in. (0.03 to 0.05 mm) is suggested.

Closer clearance tends to increase blade wear, whereas larger clearances allow the material being sheared to drag over an excessive degree, resulting in excessive wear of the blades and a poor cut. As the material thickness increases the clearance should be increased accordingly and adjusted to best suit the specific piece of equipment being used, consistent with minimum roll over, burr height and distortion (camber, twist, and bow).

The clearance between the shear knives should be sufficient to avoid secondary shearing by the upper knife as it passes through the cut. Insufficient clearance exists if the cross section of the sheared edge is smeared from top to bottom. Proper clearance is present if about 40 percent of the metal thickness is burnished at the top side of the table piece and at the bottom side of the drop.

FABRICATION PROPERTIES OF STAINLESS STEEL

<table>
<thead>
<tr>
<th>Type No.</th>
<th>UNS No.</th>
<th>Austenitic</th>
<th>Martensitic</th>
<th>Ferritic</th>
</tr>
</thead>
<tbody>
<tr>
<td>S20100</td>
<td>301</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>S20200</td>
<td>302</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>S30300</td>
<td>303</td>
<td>X</td>
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<td>X</td>
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<td>304</td>
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<td>410</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>S41600</td>
<td>416</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>S42000</td>
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<td>440F</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

X = Suitable for application. XX = Better adapted for application.
The moving blade should be made with as large a possible back clearance to obtain clean cutting and acceptable knife life. The clearance usually varies from one setup to another. A good guide from which to start is a clearance equal to 3 percent of the thickness of the stock. Usually the vertical clearance is the same regardless of the thickness of the stock. The vertical clearance is usually set at 2 percent of the thickness of the stock. For very thin material, vertical clearance is less. A minimum of overlapping (vertical positive clearance) of the knives is desirable to attain burr-free edges. Knives are generally overlapped to cut all the way through the metal up to about 0.035 in. (1.3 mm) thick. For heavier gauge metal, the knives are separated (vertical negative clearance) to attain a clean cut and break action on the sheared edge.
material being cut increases in thickness.

The tooth spacing is increased as the blades are used for cutting thin material. As in power hacksawing, fine pitched tools per minute, increased for thicker material — a minimum of 30 drops per minute.

To reduce the shearing force in blanking austenitic stainless steel parts, one of the cutting tools is often provided with angular shearing edges. Figure 2. If the blanked portion is to become the part, the angular shear edges should be on the die and the punch should be flat to avoid distortion of the work piece. Conversely, if the blanked portion is the discard, the angular shear edges should be on the punch to maintain flatness in the remaining part.

To avoid jamming and breaking of the punches, blanking and punching are severe applications involving both shock and abrasion. A range of tool steels may be used, depending on the aspects of the particular job, and the production quantity required. Proper heat treatment by quenching and tempering must be employed to develop the necessary combination of properties, i.e., hardness, wear resistance and toughness.

Clearances are best determined by experience and depend on the specific piece of equipment employed, the complexity of the job, and the material. Close clearances require very careful alignment of the tools and tend to increase the wear on the tooling. Larger clearances are preferred consistent with preventing the metal being drawn into the die and minimum burr formation (particularly austenitic stainless steels). Larger clearances should be used when working temper rolled austenitic material.

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To avoid jamming and breaking of the punches, blanking and punching are severa...
Cut-off operations are normally done wet, using a soluble oil emulsion. Rub- 
ber-based discs are used.

Random straight line cutting of sheet and thin plate is normally done dry. Vih-
nered or resinoid-bonded discs are used.

Care must be exercised not to induce excessive over-heating of the cut edge.

Dedicated discs (i.e., uncontaminated by cutting of other materials) must be 
used.

Random cutting done by hand must employ safety measures, as the discs 
can jam and break in the cut groove.

THERMAL

In conventional oxy-cutting the metal is first heated by the flame, then an excess 
of oxygen is supplied. This causes exothermic (heat-generating) reactions 
which generate the heat necessary to melt the oxides formed, which are then 
removed from the cut by the velocity of the gas jet.

Stainless steel having a high level of chromium (Cr) cannot be cut by simple 
oxy-cutting methods due to the very high melting point of the chrome oxide which 
is formed. Modified or other methods, therefore, have to be employed.

Flux Cutting or Metal Powder 

Cutting

A fine wet-rich metal powder is 

sprayed into the oxy-acetylene gas 

flame. When this burns in the oxygen 

stream, a great amount of heat is gener-

ated. This is sufficient to melt the refractory 

chrome oxide, and in addition, a cladding 
effect also takes place. The molten metal 
is removed from the cut by the velocity of 
the gas stream enabling cutting to proceed.

This process is adaptable from thin to 

very thick material, with cutting speeds 

only slightly less than those for equal 
thicknesses of carbon steel. Therefore, 
it is particularly suitable for the cutting of 
thick plates and slabs, and the removal 
of feeders and risers from castings.

The cut edge is both chemically and 

metallurgically affected causing alteration 
of the metal to the oxygen and possible 
precipitation of carbides (sensitization) in 
the austenitic grades. Prior to welding, 
0.10 - 0.12 in. (2.5 - 3 mm) of material 
should be removed from the cut edge to 
ensure the corrosion resistant properties 
are retained. Cut edges not welded must 
also be dressed prior to service.

The process is amendable to auto-

matic setup on profile cutting equipment. 
Stack cutting is also possible.
A variation on iron powder cutting is the injection of finely pulverized flux into the cutting oxygen stream. This flux reacts with the refractory chrome oxide to form a slag of lower melting point compounds, which is then removed from the cut by the gas stream velocity. This method is sometimes preferred because it produces a smoother cut. However, it is not as versatile as powder cutting, the edge must also be dressed to a depth of 0.08 in. (2 mm) and operators must be protected from the toxic fumes which are produced.

**Arc Cutting**

The extremely high temperatures developed in Electric-Arc processes will melt all metals, thus enabling them to be cut. Many modifications of the process exist. Different electrodes can be used, with or without gases either to promote or prevent the oxidation of the metal being cut. The two commonly-used processes are **Air Carbon-Arc Cutting** and **Oxygen Arc-Cutting**.

- **Air Carbon-Arc Cutting.** A carbon graphite electrode is used and a stream of high velocity compressed air flowing parallel to the electrode strikes the molten metal behind the arc thus removing it from the cut.

As the thickness of the material being cut increases, so does the electrode diameter and the current required. For cutting stainless steels direct current is preferred, and the power source must have sufficient capacity (e.g., 1/2 in. [12 mm] electrode needs 150-350 amps; 1 in. [25 mm] electrode needs 400-800 amps).

For thorough cutting, the electrode is held almost vertical. More than one cutting pass may be necessary for cutting material over 1/3 in. (12 mm) thick.

Edges which are to be welded must be dressed to a depth of 0.08 - 0.10 in. (2 - 2.5 mm).

**Carbon-Arc Cutting** is a modification which does not make use of the compressed air. The molten metal is removed from the cut by gravity, by the force of the arc, or both. Provided the recommended settings are followed, acceptable cuts can be produced in the thicker sheet gauges and thinner plate.

- **Oxygen-Arc Cutting.** Flux covered tubular electrodes are used with the oxygen supplied down the tube. The electric arc initiates melting and the flux covering on the electrode acts to form lower melting point oxides which are removed from the cut by the gas stream.

Direct current electrode negative gives the most rapid cut. The speed of cut varies with the thickness and composition of the metal being cut, the oxygen pressure, the amount of current and the dimensions of the electrode.

The cut surfaces are rough and uneven.

**Shielded Metal-Arc Cutting** is a modification using a heavily flux covered stick electrode. The flux performs the same function as described previously, and the molten metal is removed from the cut by gravity, the force of the arc, or both.

Standard welding equipment can be used for cutting thicker sheet gauges and thinner plate.

The cut edge must be dressed prior to welding or being placed in service.

**Plasma Arc Cutting**

Plasma forming gases are constricted and passed through an arc chamber, the arc supplied a large amount of electrical energy. This ionizes the gases and they exist as a plasma, a mixture of free electrons, positively charged ions and neutral atoms. Extremely high temperatures are attainable up to 55,000° F (30,000° C). Therefore, cutting results from the high temperature and not a chemical reaction. The constricted plasma arc heats and melts the metal in the cut and the molten products are removed by the gas jet.

**Plasma Arc Cutting with the Transferred Arc** is schematically illustrated in Figure 3. The tungsten electrode is the cathode (connected negative terminal), and the metal being cut is the anode (connected positive terminal).

**The Plasma Gases.** Many gases can be used in a plasma-arc torch, provided they do not have an adverse effect on the tungsten cathode or the metal being cut. The efficiency of the gas in terms of the thickness and the speed of cut depends on its thermal conductivity as a plasma at the high temperatures.

The traditional gases used for the cutting of stainless steels are the gases argon (Ar), nitrogen (N2), helium (He), and helium (He). Argon is easily ionized, but has a low thermal conductivity and is, therefore, added to enable the cutting of thicker material. Hydrogen has a high thermal conductivity and is, therefore, should be used for improved cutting capabilities and efficiencies on thick material over (½) in. (12 mm). Helium also has a high thermal conductivity, but is seldom used because of its high cost.

The use of nitrogen under conditions employing high arc currents can lead to the formation of relatively large amounts of nitrogen dioxide (NO2), a brown gas. This is a highly poisonous gas, and all due precautions should be taken.

Active gases such as carbon dioxide (CO2) and compressed air can also be used. The use of such active gases requires torches and nozzles specifically designed for their use.

Carbon dioxide is used in conjunction with nitrogen as the plasma gas. The carbon dioxide performs the function of an arc-stabilizing gas. Compressed air is used alone as the plasma gas, and the plasma arc temperature is complemented by the

![Figure 3: Schematic Illustration of Plasma Arc Cutting with a Transferred Arc](image-url)
BENDING

When any metal is bent, the metal towards the outside of the bend is in tension with the tension gradually increasing to a maximum at the outer surface. The metal towards the inside is in compression with the maximum compressive force at the inner surface. If the applied bending force is not sufficient to cause permanent plastic flow of the metal at either the outer or inner surfaces, the metal will return elastically to its original shape when the force is removed. Therefore, the force necessary to make a permanent bend will depend on: the yield strength of the material, the increase in yield strength as the metal work hardens, the desired angle of the bend, and the thickness of the material.

SPRINGBACK

Springback as the name applies, is the tendency of a part to return to its original shape after a bending operation has been performed on it. This occurs because not all of the strain applied during bending is plastic and, hence, permanent. The elastic portion of the strain, which is recoverable, will cause the piece to straighten somewhat when the bending force is removed, as illustrated in Figure 4.

In simple bending, the springback depends upon many factors which can be subdivided into two groups:

- **The Size, Shape and Quality of the Cut.** The width of the kerf tends to be greater than that obtained by conventional oxy-gas cutting of carbon steel. The kerf width is affected by parameters which include: stand-off distance, electrode positioning within the nozzle, electrode shape, method of electrode dressing/grinding, nozzle size, cutting speed and thickness of material being cut.

  Further, a kerf angle is a typical feature. If process parameters are not carefully controlled this angle can increase to an unacceptable degree. The kerf angle should be less than 5°, and it can be reduced to 1°.

  The cut edge should be smooth, clean and have a very small heat-affected zone (HAZ) adjacent to the cut edge.

  - **Process Parameters.** Depending on the thickness of material to be cut, the following are the main variables:
    - Arc Current (amps)
    - Plasma Gas - flow rates and mixture ratios
    - Nozzles - size, shape and design which affect the cutting speed and quality of cut: optimum cutting speed giving a good quality cut is less than the maximum attainable cutting speed.
    - Width and shape of cut.

  In conjunction with the recommendations of the supplier of the equipment, these variables should be determined and set out as qualified procedures to ensure not only the quality of the cut, but also such factors as the economy and safety of the operation.

Important Note: In all cutting operations on stainless steels the following guidelines are helpful in maintaining corrosion resistance:

- No contamination by ferrous (iron or steel) material or particles should take place.
- Mechanically cut edges will naturally form the corrosion resistant passive film. The formation of such a passive film on cut edges will be enhanced by a chemical (acid) passivation treatment with nitric acid.
- Thermo-cut edges may be affected in terms of chemical composition and metallurgical structure. Removal of affected surface layers by dressing is necessary so that impaired areas of mechanical and corrosion resistant properties are minimized.
stainless steel, to assume the same form-
forming procedure for one gauge of
ferrous grades. How-
be bent to equally small bend radii,
annealed austenitic stainless steels can
strengths.
bon steel. Cold rolled tempers will need
annealed stainless steel is 50 to 60 per-
steels. The power necessary to bend
and greater springback of stainless
stainless steels is performed in the same
commercial bending operations.
Press Brakes
TYPES
Annealed Steels
For stainless and low carbon steels:
Work-Hardened Stainless Steels

Materials = Metal Thickness

<table>
<thead>
<tr>
<th>Steel Type</th>
<th>Soft</th>
<th>1/2 Hard</th>
<th>Full Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless and Low Carbon</td>
<td>1/2 to 1</td>
<td>1 to 2</td>
<td>2 to 3</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>1/2 to 1</td>
<td>1 to 2</td>
<td>2 to 3</td>
</tr>
</tbody>
</table>

The characteristics of materials, such as alloy composition and the yield strength (before and after bending). The amount of springback per degree of bend is constant regardless of the trail angle of the bend. Springback increases with increasing ratio of bend radius to part thickness. Small bending radius results in less springback than a large radius on a part of equal thickness. Increasing yield strength also increases springback. In addition, the springback depends upon the degree to which the part conforms to the contour of the tools used.

a. The geometrical factors, such as thickness, bend radius and bend angle and
b. The characteristics of materials, such as alloy composition and the yield

- Press brake bending of austenitic stainless steels is performed in the same way as bending of carbon steel with allowances made for the higher strength and greater springback of stainless steel. The power necessary to bend annealed stainless steel is 50 to 60 per cent more than that needed for carbon steel. Cold rolled tempers will need even more because of their higher strengths.

- Due to their high ductility, the annealed austenitic stainless steels can be bent to equally small bend radii. Cold rolled tempers and the ferritic grades require larger radii than annealed austenitic material.

- On bending a part, the tool stroke should be as short as possible to lessen the tendency of stainless steels to foul or score the tools. To avoid fouling, the clearance between the die and the punch should be about 10 percent more than the metal thickness. Dies should be given a high polish, and must be free from all surface blemishes, to prevent marring the finish of the stainless steel parts.

Roll Forming
Roll forming is roughly similar to drawbench forming, except that it is performed with driven rolls, rather than idling rolls, and it is a continuous process. It is a more economical method of shaping sections in long lengths and large quantities.

- Stainless steels can be roll-formed in the annealed state. Extensive roll forming has been performed successfully on harder tempers, but more passes are required.

- As with drawbench forming, generally the same bend radii recommendations as for other methods of bending should be followed, though bends approaching zero radius have been satisfactorily roll-formed.

- High carbon or alloy steels are satisfactory roll materials. Cast aluminum bronze rolls have been used where sliding motions between roll and part are great.

- Sludge solutions of water soluble oils make adequate lubricants for roll forming stainless steels. Soap solutions and extreme pressure lubricants give greater roll protection and produce a finer finish on the stainless steel. They are, however, more difficult to remove.

- Exhibit 3 shows the minimum bend radii for press brake forming of annealed and cold worked tempers of austenitic stainless steel.

- As with carbon steels, V-shaped female dies are frequently used. In this case the die opening is usually about eight times the inside radius of the formed part.

Roll Bending
The roll bending of flat stainless steel is performed in the same manner as with carbon steel. More power is required and there is more springback. The increased springback can be offset by increasing the roll pressure.

- The most common types of roll benders are of the pyramid or pinch types. Other types of benders are also used, but in the design of tools one must remember to compensate for greater springback as compared with carbon steel.

- The minimum cylinder which can be made in stainless steel on a pyramid type bender is about twice the center roll diameter as compared to about one and a half times for low carbon steel.

Example
Using a thickness (t) of 0.250 in. and a value of 410 in.

Then:

\[ \text{Die angle} = \frac{410}{t} \]

If part angle is to be 90°, the part must be bent an average of 100.8°.

If the die angle is to be 90°, the part angle will be an average of 80.3°.

If the brake forming process involves primarily a drawing operation, lubricants must be used.

| Minimum recommended bend radii vary over rather wide limits. When bend-
| ing the annealed, more ductile, austenitic grades, a minimum radius of 1/2
| the metal thickness is possible. For hard tempers of austenitic and ferritic grades
| radii up to six times the metal thickness is possible. For hard tempering pressures that are used for hot rolled carbon steel four gauges heavier. Cold
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Stretch Forming

In free bends, the material on the outside of the bend is always in tension and the metal on the inside of the bend is in compression. In stretch forming sufficient tension is applied to the material being bent, so that the compressive forces acting on the inside of the bend may be counterbalanced and leave the metal either in a neutral condition or with a small amount of tension. Of course, stretch forming increases the tension force on the outside of the bend. However, the high ductility of the annealed austenitic stainless steels makes them well suited to this method of forming. Stretch forming finds its greatest use in forming angles, channels, and hollow parts where it is effective in preventing buckling. Commonly a tension force 10 to 20 percent above the yield strength is applied to the metal before bending is started. Springback is greatly reduced by this method of forming because none of the deformed metal is under compressive force during bending. By proper selection of applied tension, it is sometimes possible to reduce springback to a negligible amount.

DESCALING

REMOVAL OF OXIDE SCALE

Pickling Solutions

When stainless steel has been heated to elevated temperatures, such as during annealing or welding, an oxide scale will form on the surface unless the material is completely surrounded by a protective atmosphere. Any such oxides should be removed to restore the stainless steel to its optimum corrosion resistant condition. Because they may vary in nature and composition, there is no single acid or process that will universally remove all types of oxides.

The most common pickling solution used to remove scale produced by annealing austenitic stainless steel in air is 10 to 15 percent nitric acid plus 1 to 3 percent hydrofluoric acid. The solution is usually used at temperatures of 120 to 140°F (50 to 60°C). This acid mixture efficiently removes oxides, loosely imbedded iron and chromium depleted layers, and leaves the stainless steel surface in a clean, passivated condition. For light scale the hydrofluoric acid is usually about 1 percent and for heavier scales, the HF content may be increased to 2 to 3 percent.

Sulfuric acid 8 to 12 percent with 2 percent nitric acid (HNO₃) at 150 to 170°F (65 to 71°C) is well suited for handling ferritic or martensitic stainless steels.

When the oxide scale is heavy and tenacious the stainless steel may be treated for 5 to 10 minutes in a bath of 8 to 10 percent sulfuric acid at a temperature of 150 to 160°F (65 to 71°C). Upon removal from the bath the part should be scrubbed to remove the scale and after rinsing, pickling can be finished in a nitric-hydrofluoric acid picking solution.

When the above solutions cannot be used at the recommended temperature, they may be used at room temperature but it is usually necessary to strengthen the acid concentration. A cold solution takes longer to act and agitation of the part can be helpful.

Blasting

• Grit blasting — Grit blasting is generally unsatisfactory because grit is seldom clean, and even if it is ideally, it soon becomes contaminated with abraded material. Grit blasting leaves a rough profile that makes the stainless steel prone to create corrosion, whether or not the surface is free of iron. Thus, grit blasting should be avoided.

• Sand blasting — This method is generally unsatisfactory. However, for a severely contaminated surface, sand blasting can be used as a last resort. Now, clean sand will remove debris and heavy iron-contamination from the surface. But avoid using sand blasting, if possible.

• Glass-bead blasting — Good results have been obtained with clean, glass beads. Before applying this method, a test should be made to determine that it will remove the surface contamination. Also, periodically test to see how much reuse of the beads can be tolerated before they begin to recontaminate the surface. (Walnut shells have also performed well).

REMOVAL OF WELD DISCOLORATION

During welding, some discoloration, which is a film oxide layer, will be evident in the heated area near the weld. Mechanical removal or the heat tint should be limbed to clean glass bead blasting, paper wheels, aluminum oxide discs and wire brushing with austenitic stainless steel wire brushes. Sand and grit blasting should be prohibited. Pickling will remove the smeared surface layer left by these mechanical cleaning operations restoring much of the corrosion resistance lost during these mechanical cleaning operations. Electrocleaning with a hand held electrocleaning tool is an equally effective alternative to pickling for heat tint removal.

PASSIVATION

PASSIVATION OF STAINLESS STEEL

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

The film will form spontaneously, or repair itself if damaged, both in air due to the presence of oxygen, or when immersed in solutions, provided there is sufficient oxygen or oxidizing elements present. The basic passivation treatment for stainless steel is exposure of a clean surface to air. However, there is much practical evidence which shows that passivity, and therefore corrosion resistance, is enhanced if the passive film is formed by the action of oxidizing acid solutions.

Nitric acid is such an oxidizing acid, and it is always used for passivation treatments. Nitric acid does not corrode stainless steel, does not alter critically dimensioned parts and will not remove heat tint, embedded iron or other embedded
**FINISHING**

**GRINDING, POLISHING, AND BUFFING**

Grinding, polishing, and buffing operations are applied to stainless steel in much the same manner as to other metals. The differences which exist are related to properties of stainless steel.

1. More power is required to remove metal because of its higher strength.
2. The austenitic stainless steels have lower rates of heat conductivity than carbon steel. Thus, the surfaces may become hotter than the surface of carbon steel and heat tinting of the stainless steel surface may occur.

Two variables determine the amount of grinding and polishing required, namely, the initial surface condition and the desired finish. The rougher the starting surface, the coarser is the first grinding wheel. For the first grind on welds, it is common practice to use a wheel of grit size until the desired smoothness is reached. For more information refer to the SSINA publication "Finishes for Stainless Steel."

**CARE IN THE SHOP**

**HANDLING**

Mechanical damage (e.g., scratches and gouges) can occur easily during handling if not guarded against. Such mechanical damage will result in the passive oxide film being "punctured" leading to a possible lower resistance to the initiation of corrosion than the surrounding chemically passivated surface. In addition, corrosion in such areas can be accelerated by the galvanic corrosion effect due to the unfavorable relative area ratios which exist.

- Plates and sheets should be stored vertically in racks and not be dropped out of the racks or onto one another. Racks should be protected to prevent iron contamination.
- Heavy plates should be carefully separated and checked with wooden blocks, in order for the forks of a fork-lift to be inserted between plates without mechanically damaging the surface. If the forks are haphazardly forced in between plates, some degree of contamination of the scratches and gouges could also occur, thus aggravating the damage so induced.
- Plates and sheets laid out for use should be divided by wooden planks to prevent surface damage and facilitate subsequent handling.
- Plate clamps, if used, must be used with care as the serrated faces usually dig in, indent and gouge the surface.
- If chain slings are used, these inevitably tend to slip, again causing mechanical damage to the surface. Slings of heavy-duty synthetic material are preferable.
- Thin gauge cold rolled material often has a superior finish (e.g., polished or bright annealed). Clean linen gloves should be worn when handling such material to avoid finger markings. Such marks can be removed by the use of a mild organic solvent followed by cleaning with a warm detergent solution. Sometimes a warm detergent will suffice. Thorough clean water rinsing and drying completes the removal procedure.

Note: ASTM A890 describes a number of ways fabricating shops can reduce surface contamination during fabrication.
CONTAMINATION
Contamination arises mainly from the surfaces of equipment which have previously been in contact with carbon steel. The carbon steel and oxide scale may be smeared on and transferred to the stainless steel surface. While it is not always possible to have handling equipment dedicated for use with stainless steel, this should be done if possible (e.g., synthetic material slings).

All other handling equipment should be cleaned prior to use with stainless steel. It is, therefore, advisable to plan and schedule the handling of stainless steel, because if handling equipment is used on a random basis, this cleaning is often neglected and contamination results.

CLEANING
RUST CONTAMINATION
Sometimes the appearance of rust streaks on stainless steel leads to the belief that the stainless steel is rusting. Look for the source of the rust in some iron or steel not actually a part of the stainless steel itself. Steel (ferrous) contamination is prevented by the use of stainless steel wire brushes, and grinding with abrasives that have not been used on carbon steel.

The primary method of cleaning surfaces contaminated with embedded iron is nitric-HF pickling in 10% nitric 2% HF either warm or at ambient temperature. Pickling paste is a good alternative to immersion.

CAUTION: Do not use paint, lacquer or varnish on stainless steel for maintenance. It is much safer and easier to clean the metal periodically than to rely on any sort of protective covering.

CLEANING METHODS
Soap or detergent and water will remove ordinary deposits of grease, dirt and similar contaminations. Washing should be followed with a water rinse and thorough drying.

Tightly adhering deposits of food, oil, grease, mildew, atmospheric stain, and other light discolorations may be removed with the appropriate commercial cleaners shown in Exhibit 4.

For high luster finishes soft clothes or pads must be used without contamination from foreign dirt or grit (even from water employed to dampen) in order to avoid scratching highly reflective surfaces.

For additional information refer to the NiDI publication No. 9001 “Cleaning and Descaling Stainless Steels,” or the SSINA Designer Handbook “The Care and Cleaning of Stainless Steel.”

<table>
<thead>
<tr>
<th>Job</th>
<th>Cleaning Agents*</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine Cleaning</td>
<td>Warm Water, Soap, Ammonia, Detergent</td>
<td>Apply with sponge or cloth. Can be used on all finishes.</td>
</tr>
<tr>
<td>Fingerprints and Smears</td>
<td>3M Stainless Steel Cleaner and Polish, Argir 29, Lac-O-Nu, Arcal 20, Stainless Shine</td>
<td>Provides barrier film to minimize fingerprints. Can be used on all finishes.</td>
</tr>
<tr>
<td>Stain and Discoloration</td>
<td>3M Stainless Steel Cleaner and Polish, Allchem Rub lightly, using dry or damp cloth, in the direction of polish lines on the stainless steel.</td>
<td></td>
</tr>
<tr>
<td>Grease and Blood</td>
<td>Scotch-Brite Power Pad 2001, Easy-Off, De-Greasant</td>
<td>Excellent removal on acids, all finishes. Particularly useful where stabbing is not practicable.</td>
</tr>
</tbody>
</table>

*NOTE: Use of proprietary names is intended only to indicate a type of cleaner and does not constitute an endorsement. Omission of any proprietary cleanser does not imply its inadequacy. All products should be used in strict accordance with instructions on package.