PMA Design Guidelines

For Metal Stampings and Fabrications

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Precision Metalforming Association

6363 Oak Tree Blvd.

Independence, Ohio 44131

Phone: 216-901-8800

Fax: 216-901-9190

www.metalforming.com

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INTRODUCTION

This publication is for designers, specifiers and buyers of precision sheet metal components. It is intended to assist in effectively designing and specifying the products of the metalforming industry, so that the versatility, properties and economies of sheet metal may be fully realized.

It is not a guide to manufacturing. Nor is it exhaustive in covering metalforming design. Rather, it seeks to selectively provide guidelines in key areas of design and specification where general information is lacking—areas which experience has shown to be frequent sources of misunderstanding between customer and supplier.

Manufacturing processes are described only briefly to provide a basis for better understanding the advantages and limitations of metalforming. The emphasis is on design considerations and values which can lead to realistic product expectations.

The guidelines are not standards. Instead, they are suggestions and recommendations—based on extensive observations—which are believed to represent good design practices, using current technology, which can provide cost-effective products appropriate for general usage.

In many cases higher levels of precision are achievable, but almost always at additional cost. Special requirements for products with unusual properties or extraordinary precision are typically the subject of negotiations with your supplier.

In today's JIT manufacturing environment, it is possible to design a precision product starting with a nominal tooling expenditure and very short prototype lead time. Continuous development of the product, through early production into high volume product maturity, can occur smoothly with progressive changes in metalforming processes, and without altering product quality.

Careful planning is required to achieve this

scenario. The following checklist covers some of the important considerations. It is vital, not only that a designer attempt to answer these questions prior to design development, but also that the designer share as much of this information as product security will permit with prospective suppliers.

A. What is the estimated annual product quantity requirement during peak demand?
B. What is the estimated total program quantity?
C. Will tooling, gauging and fixturing be amortized or capitalized?
D. At what volume will tooling expenditures be evaluated?
E. Which are the critical dimensional tolerances?
F. Are assembly tolerances actually dimensioned from point of assembly? Assembly dimensions should always be taken from actual attachment points.
G. Does the drawing tolerance block list the greatest tolerance allowable on each dimensional parameter? Are tighter requirements individually toleranced?
H. Are cosmetic surfaces adequately identified?
I. Does the print designate viewing and test specifications for all finish requirements?
J. Are all gauging points clearly specified?
K. Does a general or specific packaging specification apply?
L. Must the product conform to specific government regulations or meet certification requirements?
M. What is the product function?

Early attention to considerations such as these, and early communication with prospective suppliers, can help clarify key parameters involving function, economics and appearance—and avoid misunderstandings, disappointments, costly redesign and retooling.

This publication represents the collective efforts of Precision Metalforming Association's Design Guidelines Project Committee over a period of several months.

It is hoped that this effort will assist designers to achieve product function and appearance economically, and avoid design induced defects, through effective design practices. The Committee welcomes comments and suggestions.

PAST CONTRIBUTORS

Mark Anderson, Mayville Metal Products
Jack Brown, Alpha Precision, Inc.
John J. Caschette, Genesee Metal Stampings, Inc.
Leonard Coraci, Jr., Dayton T. Brown, Inc.
Larry Crainich, Design Standards Corporation
Brian L. Deakins, Deakins Metal Spinning, Inc.
Walt Dieckmann, The Binkley Company
John Dosek, Keats Manufacturing Company
Tony Fisichella, MSM Industries, Inc.
Michael Grant Service Stampings Illinois, Inc.
Sherwood Griffing, U.S. Baird Corporation
Alan Hall, Gem City Metal Spinning
Daniel J. Hickle, Mayville Metal Products
Thomas Johnston, Acme Metal Spinning, Inc.
Peter K. Mercer, PackPro
William Merg, Schulze Manufacturing
Glenn Nelson, Roll Forming Corporation
David B. Peters, Corry Contract Inc.
L. Wayne Ridgley, Wayne Metal Products Co., Inc.
Herman G. Schmitz, Sausedo Metal Products, Inc.
Michael Schons, Radar Industries, Inc.
Joe Sokol, North Star Company
Tim Synk, Superior Roll Forming
Charles C. Vicary, Ervite Corporation
David Windsor, Winco Stamping, Inc.
Clarence Wrentmore, Miami Manufacturing Co.
Robert G. Zeller, Natter Manufacturing Co., Inc.

PMA DESIGN GUIDELINES COMMITTEE

Michael Grant, Chair, Service Stampings Illinois, Inc.

Karla Aaron, Hialeah Metal Spinning, Inc.
Philip Bryans, Ware Manufacturing Co., Inc.
Robert Byrne, Superior Metal Products
Larry S. Field, Elray Manufacturing Company
Norbert Markl, ITW/CIP Stampings
Kent Mishler, Thomas Engineering Company
Marko Swan, Cygnet Stamping & Fabricating, Inc.
John Wagner, Hamond Industries, Ltd.
Ken White, Eskay Metal Fabricaring

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1

PART DRAWINGS; A COMMUNICATION TOOL

How your prints influence the quality and cost of your sheet metal parts and stampings.

The ease of interpretation of the designer's drawing sets the tone of manufacturing success for the project. The drawing is the only link to your thought processes which created the product. The importance of the drawing as a communication tool cannot be over emphasized because it is an instrument, used by many people in the complicated processes of manufacturing.

Some of the most important thoughts should be applied *BEFORE* the drawing is begun. The position in which the part is portrayed will often determine the ease of interpretation. International Standard Organization (ISO) drafting standards, for instance, stipulate that the part to be shown the same way as it would be held in the machine during fabrication. This is not always possible, but lathe parts, for example, are always shown as they would be clamped in the chuck or collet. The operator therefore does not have to reverse the image in his mind, one less chance for error.

The following are intended to improve communication excellence. It is imperative to make the part features most prominent. The part must "jump out at you" from the drawing. To achieve this, use the heaviest lines for the outline and all visible lines. These should be "heavier" by a factor of three, compared to dimensional lines. Invisible edges should be shown at half the full line strength and then only, if they clarify the picture.

Cross-cut sections are one of the most informative views you can give to the interpreter of your drawing. Don't be handicapped by the "normal" projection of a cut view. If showing the view in the opposite direction from "normal" would make interpretation easier, then do so with directional arrows and an identifying letter. Cut-view lines and arrows should be slightly heavier than the outline for proper direction of the view.

Avoid "boobytrapping" your drawing. A typical example are tightly spaced dimensional lines going to different features. To eliminate

this problem, offset one line to space them apart, show one dimension on a different view or add an exploded view. Centerlines which are almost in line with each other should be terminated with a short cross-line behind the last feature to which they belong. This eliminates a very common cause for error. See Figure 1.

One more ISO drafting standard which would be prudent to adopt, is to show the

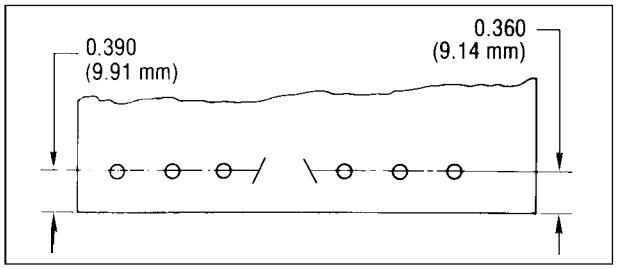


Figure 1. Illustration of good drafting practice and dimensional call-outs.

overall dimension for each view as the farthest dimension from the outline. If the total length, width or depth is given elsewhere in conjunction with other dimensions, list it as a reference dimension.

When developing a design, don't hestitate to use plain English explanatory notes to aid interpretation, make a point or further develop a detail. Avoid the use of unusual language which can be misinterpreted.

For critical features in your design, use functional dimensions and tolerances which are directly interlinked with the related feature. For instance, if a bracket is to be used to mount a part and spacing is critical to the front and top surface, dimension the bracket directly from the front and top of the part, not from some other feature.

To avoid tolerance accumulation from successive bends, always attempt to dimension features and flanges from co-planar interior datums. Indicate the critical dimensions through notes or tolerance additions and indicate the noncritical dimensions in the same manner.

Use drawing block tolerances where possible to indicate non-critical dimensions. Full-millimeter metric or single-digit decimal inch dimensions should be used with appropriate tolerances to locate operator-placed features such as spot welds, tack welds and self-piercing rivets.

Computer Aided Design (CAD) creates a whole new set of challenges. See the next chapter for further details.

The craftspeople working on your project have spent years to hone their print reading skills. They have to rely on standards to be consistently correct in their interpretation. Changing these standards is guaranteed to cause problems—something you, the designer will want to avoid.

Making your design easy to quote and manufacture requires good communication between the designer and supplier.

Even the most clearly detailed prints too often fall victim to the reduction, scanning and faxing process. Convenient and expedient as these methods are, details can get skewed in the process. Numerals, especially, get distorted, as is evident when an eight becomes a three and the fives turn into sixes, etc.

Binding documentation, for this reason, should never be faxed or scanned unless it is immediately followed up with originals sent by mail. The exception may be an original "A" size (8½ x 11 in.) print which should come through the faxing process without distortion. Binding drawings for actual production must be submitted in their original size.

Table I is a guideline and explanation for the quantity of drawing sets required depending on the number of processes involved.

The lack of binding documentation for each user on each project has resulted in countless errors, delays and expenses in the past. Always supply sufficient original document sets.

An available sample part, or even a card board mock-up, is of tremendous help in the quoting process and should be supplied whenever possible. Even the best print is not as easily interpreted as a sample part, especially a complicated one.

Giving options on design features which may be fabricated in various ways will let the metalforming supplier use the best processes for economical production. Table II is a partial listing of interchangeable processes which could be given as options.

As part of a complete drawing, an itemized list of all components is a must. Components solely identified at their locations lead to frustrating searches and double checks, with a good chance of missed items.

The designer and/or buyer should also check the availability and lead times of specified components, as they are beyond the influence of your metalforming supplier. It is not uncommon to encounter lead times of up to 12 weeks for relatively minor items essential to the project. If a drawing has undergone revisions, an Engineering Change Order (ECO) listing these changes is of great help to the estimator when requoting a project.

Table I.
Guideline for quantity of drawing sets required.

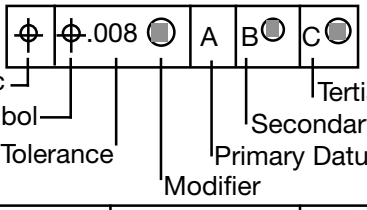
sets required	listing of processes involved
1	initial quoting only for basic fabrication
2	for quoting involving secondary outside services such as painting, silkscreening, etc.
3	for all basic production jobs 1 set for quality control (controlling documents) 1 set for programming 1 set for production routing
4	for production requiring dedicated tooling 3 sets as above 1 set for tool design and building
5 to 6	for production requiring dedicated tooling with outside tooling services 4 sets as above 1 set for outside tooling services, minimum

Table II.
A partial listing of interchangeable processes.

call-out	alternative
inserted threaded nut	- extruded and taped
inserted stand off	- formed feature
spot welded joint	- riveted joint - adhesive bonding (tape) - mechanical inter-locks (several) - formed-in-place rivet - other welding processes - combination of above
fixtured assembly	- self-aligning features
closed hem	- open hem or plastic edge protector
multiple part assembly	- one-piece construction
one-piece construction	- multiple part assembly
plastic grommet	- n/c formed and flattened hem
spot welded screen insert	- selective perforation
plastic card guides	- pierced and formed card guides

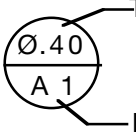
Geometric Dimensioning & Tolerance Summary Fact Data Sheet

Feature Control Frame



Datum Ident. Symbol

-A-



Datum Target Symbol

Combined Frame

▱	.0005
-A-	

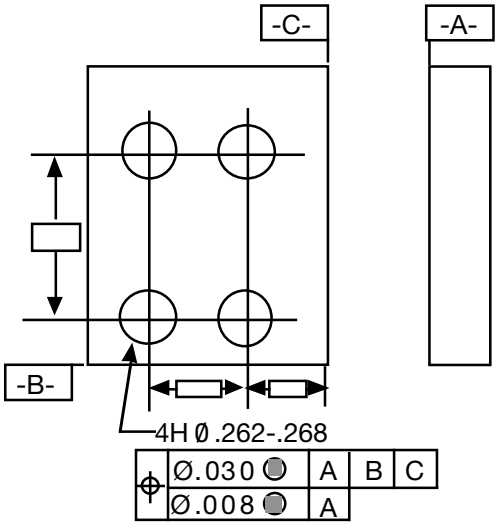
Basic

.750

Theoretically Exact

Composite Positional Tolerance

⌖	Ø.030 Ⓜ	A	B Ⓜ	C Ⓜ
	Ø.008 Ⓜ	A		



⌖	Ø.030 Ⓜ	A	B	C
	Ø.008 Ⓜ	A		

Datum Reference Frame/ 3 Plane System

Exclusions to Rule #1 Perfect Form at MCC
1. Stock Specification
2. *Flatness Note
3. *Exclusion by Note
4. Free State Variation
5. Straightness-Axis
[*1] Perfect Form at MMC not Req'd

Converting Numbered Screw to a Diameter
Max Screw O.D. = .013 x Screw No. + .060

Conversion Customary to Metric & Back
Inches x 25.4 = Millimeters (Exactly)
Millimeters x .0393700787 = Inches

Positional Tolerance Formulas
H = MMC Ø Hole Size
T= MMC Ø Positional Tolerance
F = Fastener Ø Virtual Condition

Floating Fastener System
Equal Tolerance Distribution
1. T = H - F
2. H = F + T

Floating Fastener System
Unequal Tolerance Distribution
T1 = MMC Ø Positional Tolerance part #1
T2 = MMC Ø Positional Tolerance part #2
H1 = MMC Ø Hole Size-part #1
H2 = MMC Ø Hole Size-part #2
3. T1 = (H1 + H2) - (2F + T2)
4. H1 = (T1 + T2) - (2F - H2)

Fixed Fastener System
Equal Tolerance Distribution
5. T = (H - F)/2
6. H = F + 2T

Fixed Fastener System
Unequal Tolerance Distribution
7. T1= H1 - (T2 + F)
8. H1 = T1 + T2 + F

Straightness on a Unit Basis



$$r = \frac{C}{8h} + \frac{h}{2}$$

$$h = r - \sqrt{r - \frac{C}{4}}$$

FEATURE	TOLERANCE TYPE	SYMBOL	CHARACTERISTIC	DATUM REQ'D	ALLOWABLE MODIFIERS
Individual (Single)	Form (Shape)	—	Straightness	Not Allowed -Related to a perfect counter part	Ⓜ On Axis
		▱	Flatness		Ⓜ
		○	Circularity		None
		⌭	Cylindricity		
Individual or Related	Profile (Contour)	⌒	Profile of a Line	Allow-able	Allowed Only On Datum
		⌓	Profile of a Surface		
Related	Orientation (Attitude)	∠	Angularity	Required	Ⓜ For Features or Datums of Size
		⊥	Perpendicularity		
		//	Parallelism		
	Location	⌖	Position	Preferred	Ⓜ Ⓛ Ⓡ Recored
		◎	Concentricity	Required	None
	Runout	↗	Circular Runout	Required	
		⌰	Total Runout	Required	
Modifying Symbols		Ⓜ	Maximum Material Condition		
		Ⓢ	Regardless of Feature Size		
		Ⓛ	Least Material Condition		
Additional Symbols		Ⓟ	Projected Tolerance Zone		
		Ø	Diameter (Face of Dwg.)		
		S Ø	Spherical Diameter		
		R	Radius		
		SR	Spherical Radius		
		()	Reference		
		⌒	Arc Length		

2
CAD DESIGN

Computer Aided Design, CAD, was introduced as a tool to aid designers in developing part drawings as well as decreasing the time necessary to draw the development on paper. Over time it has become a much more powerful tool enabling engineers to check form, fit, function and tolerancing of details or entire assemblies prior to actual parts being built. In the time it takes to input data, the designer can have a 3D visual model. As this process developed, Computer Aided Manufacturing, CAM, was introduced to the manufacturing environment. This allowed for data to be input into a CAM system to create machine tool programs, thus automating many of the processing steps that were traditionally done manually.

Overview

As CAD and CAM were developed, the metalforming industry welcomed them with open arms. Virtually all metalforming companies today have some sort of CAM system within their engineering departments, drastically reducing the time required to produce a part. The industry is demanding that this process be taken further by exchanging CAD files. This allows for the customer to design parts on their CAD system and exchange them with their metalforming suppliers. The goal for many companies is to create a part/assembly on a computer screen and then to have it manufactured without any paper drawings being created, reducing the overall time required from design concept to completion of parts.

Traditionally, the process from concept to the manufacturing of parts was very time consuming. When a CAD model was completed, it was turned over to a drafting department to create a typical orthographic drawing. The drawing would be given to a metalforming company who would recreate the part as a flat pattern development in their CAD system. From there it would be "downloaded" into a CAM system to create a machine tool program. This process allowed for numerous opportunities for errors. Today there are many CAM systems on the market that will actually take a CAD file and automate the unfolding for you, creating a flat

pattern development, with little opportunity for error.

One advantage of exchanging CAD files is the ability to get your product design into the hands of the supplier prior to the design being formally completed. Early supplier involvement in design reviews for manufacturability, tooling and manufacturing methods can be reviewed before changes are costly.

It should be noted that there are certain limitations to CAD file exchange. CAD files must be drawn to full scale. All objects within a file must be put exactly where you want them. This is imperative for the simple reason that when the CAD file is imported into your supplier's system and goes through the unfolding process it will place all of your geometry exactly as you have drawn it. If you have misplaced a hole, your final product will have that same hole misplaced. Simply put, what you CAD is what you get. As CAD file exchange becomes fully implemented within the manufacturing environment and paper documents become obsolete, the CAD file will become the master document for inspecting finished products.

Finally, CAD files must be clean. There cannot be overlapping lines or lines that do not intersect. If these types of problems are contained within the CAD file upon file exchange, then your supplier must take valuable time in cleaning up your file. Lines that don't intersect cannot cleanly go through the unfolding process.

Overlapping lines that exist within the file can create major problems in the machine tool programs. For example, if the part happens to be run on a laser cutting machine, you will get holes or edges that are double burned thus destroying the part's edge, causing a closely toleranced feature to be out of specification. These and many other problems can occur when a CAD file is not clean.

Within the metalforming community there are many different types of CAD programs that are available. Because of the variety of CAD/CAM systems in use today, there are certain guidelines that must be closely adhered to when exchanging CAD files.

Guidelines for Designing in CAD

This chapter is intended to help avoid difficulties in exchanging files. Information will include proper part geometry, what should be and what should not be contained within the file, different methods of file transfer, and minimum hardware requirements for CAD file exchange. If these guidelines are followed you will be able to exchange files, while avoiding many of the major problems that have been experienced in the past, with virtually any company with a CAD system.

In transferring the design of a sheet metal part or assembly via CAD, it is important that all necessary information be communicated to assure that the intended functionality will exist. This information includes the CAD model, critical-to-function dimensions and non-geometrical information, such as metal type, and surface finish.

CAD Model Description

A CAD model is a collection of geometric entities that describe the size and shape of a part. The entities may be 2-dimensional and show several orthographic views, or 3-dimensional and viewable from any orientation. 3-D, solid models are preferred by most manufacturers because they are more versatile for programming and for generating additional documentation.

Rules for Designing Part Features

A sheet metal part's CAD model should be composed of geometry that exactly describes the intended design of the part or assembly without unnecessary complication. See Figure 1. All geometry should be created at full-scale using nominal sizes. All edges, transitions and cross-sections that are represented in the model should be represented by geometry that is free of gaps, overlaps and duplication. See Figures 6 and 7 for illustrations of common CAD errors.

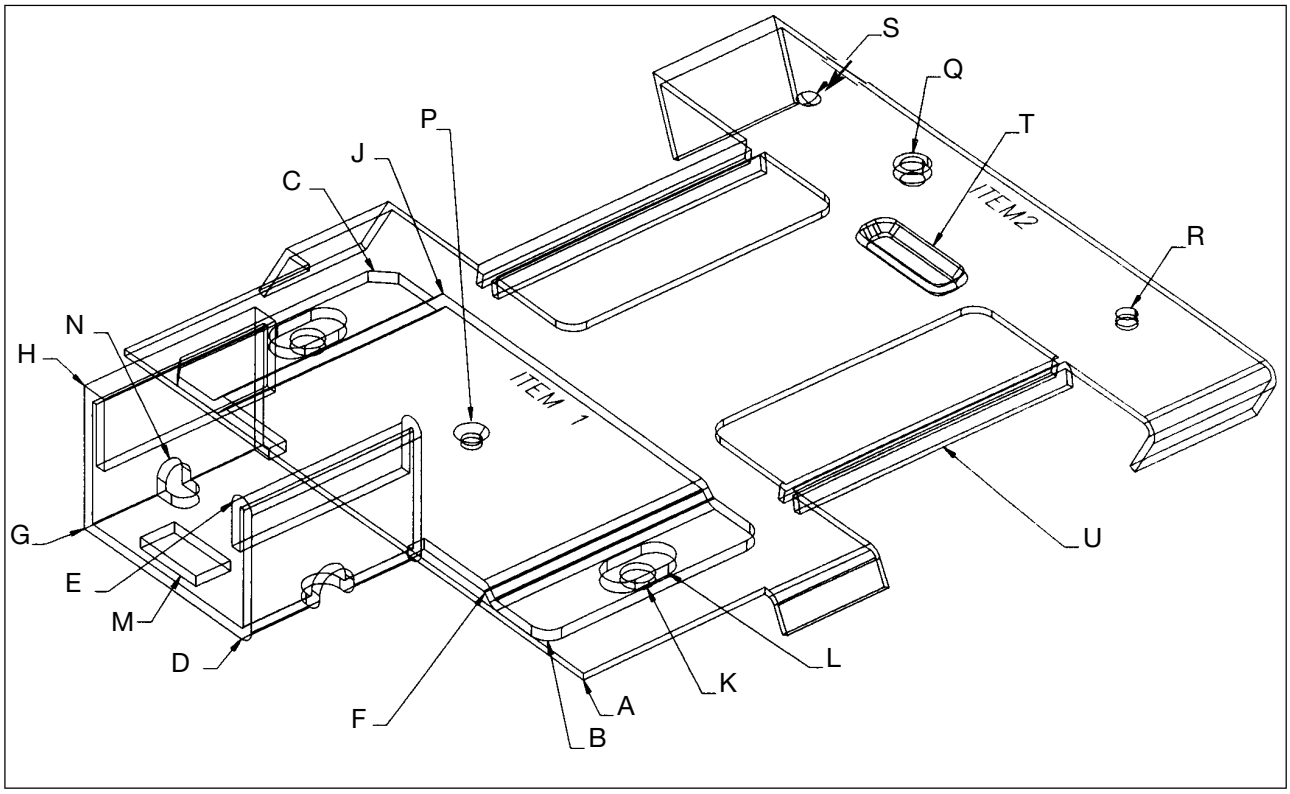


Figure 1. This model is a typical wireframe drawing showing various types of corners, bends and other commonly used sheet metal features. The preferred CAD geometry for each feature shown in the above diagram is detailed in Figures 2-5. Note: One side of diagram is drawn with bend radii and the opposite is drawn without.

Design Features

- **Edges** of the entire periphery of the sheet metal should be shown, with consistent separation equivalent to the metal's thickness. Connecting lines whose length is equal to the metal's thickness must be drawn along the periphery at every edge transition that occurs. See Figure 2.

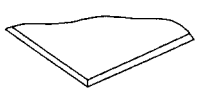
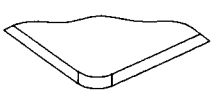
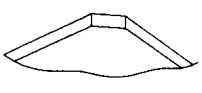
CORNERS		
SHARP	RADIUSED	CHAMFERED
		
DETAIL A	DETAIL B	DETAIL C

Figure 2. Connecting lines on periphery of corners.

- **Bends** in the material can be shown with or without bend radii. Bend radii, if shown, should be represented by pairs of concentric arcs with mold lines connecting inner and outer radii to show the extent of the bend. For simplicity, models with consistent bend radii can be represented with square corners as if the bend has no inside or outside radius. The actual radius will need to be allowed for in the design and communicated to the supplier. Bend reliefs, if required, should be shown. See Figure 3.

- **Holes** in a part should be detailed as described above for the periphery edges, including lines to connect the two surfaces. For circular holes, at least one line should be

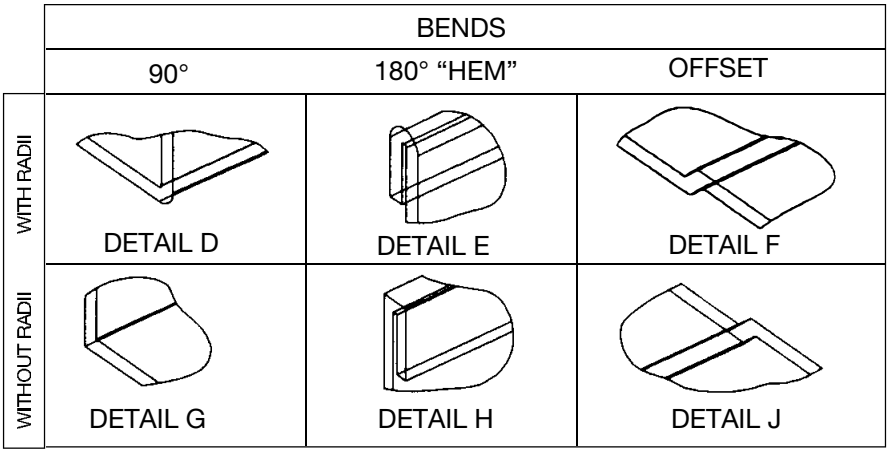


Figure 3. Preferred method for showing bends with and without radii.

used to show that the circles are related. Additional lines that would appear in orthogonal views to show the extent of the hole are generally desirable. See Figure 4.

- **Other Features.** Coined, drawn, formed, machined or rolled features as well as installed hardware should be represented by geometry that details the edges, any transitions and cross-sections of the features or hardware. See Figure 5.

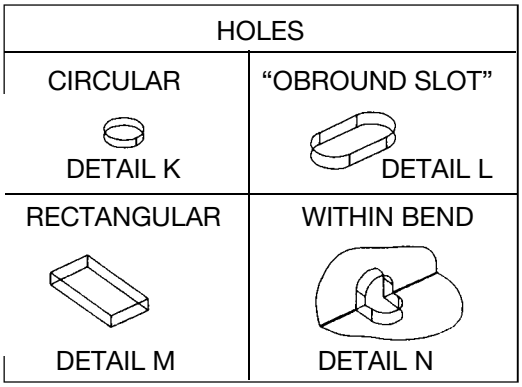


Figure 4. Preferred method of showing some more common cutouts on drawings.

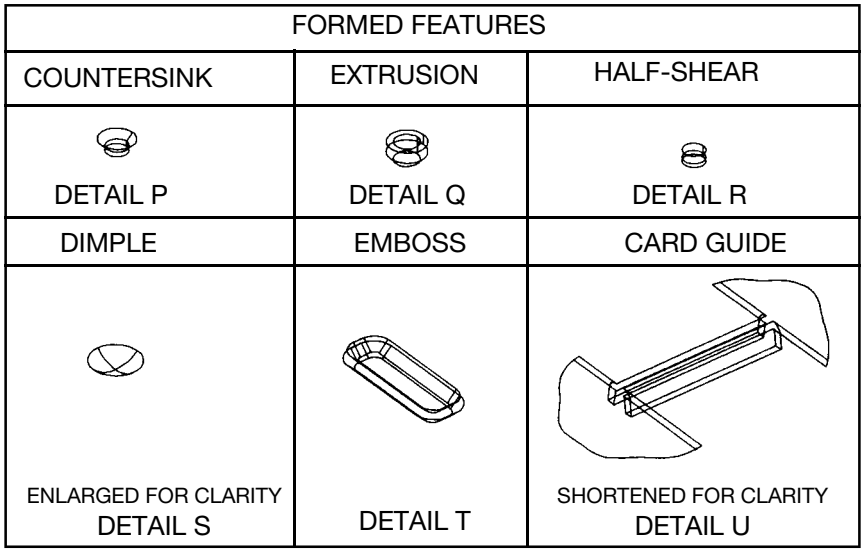


Figure 5. Preferred method of showing other common features on drawings.

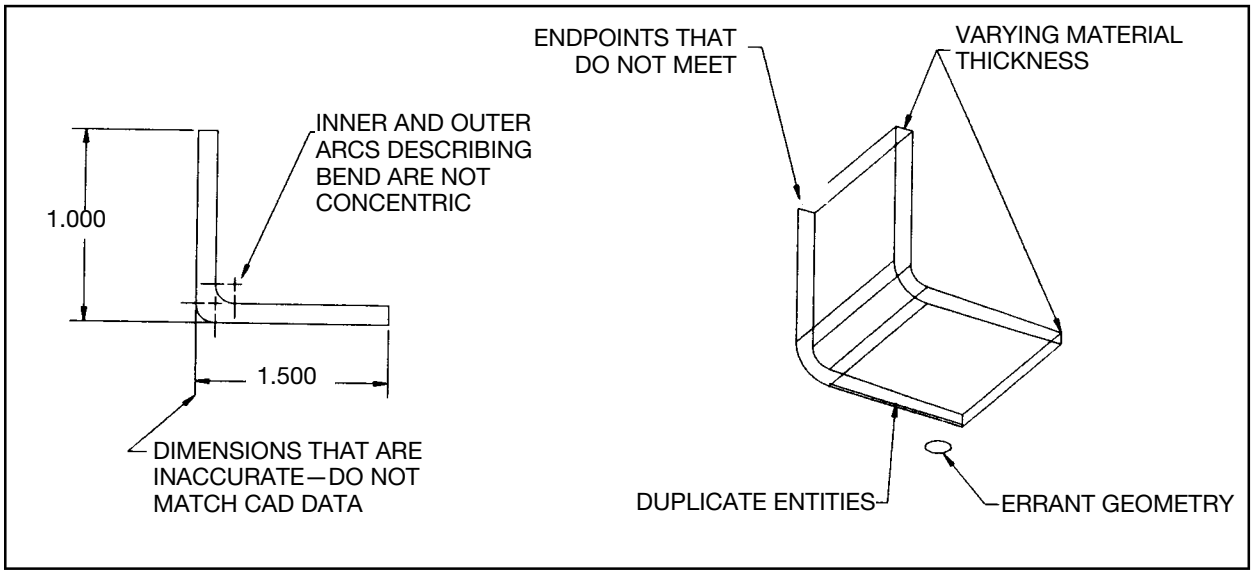


Figure 6. Some common CAD model errors illustrated in two views of a sheet metal part with a 90° bend.

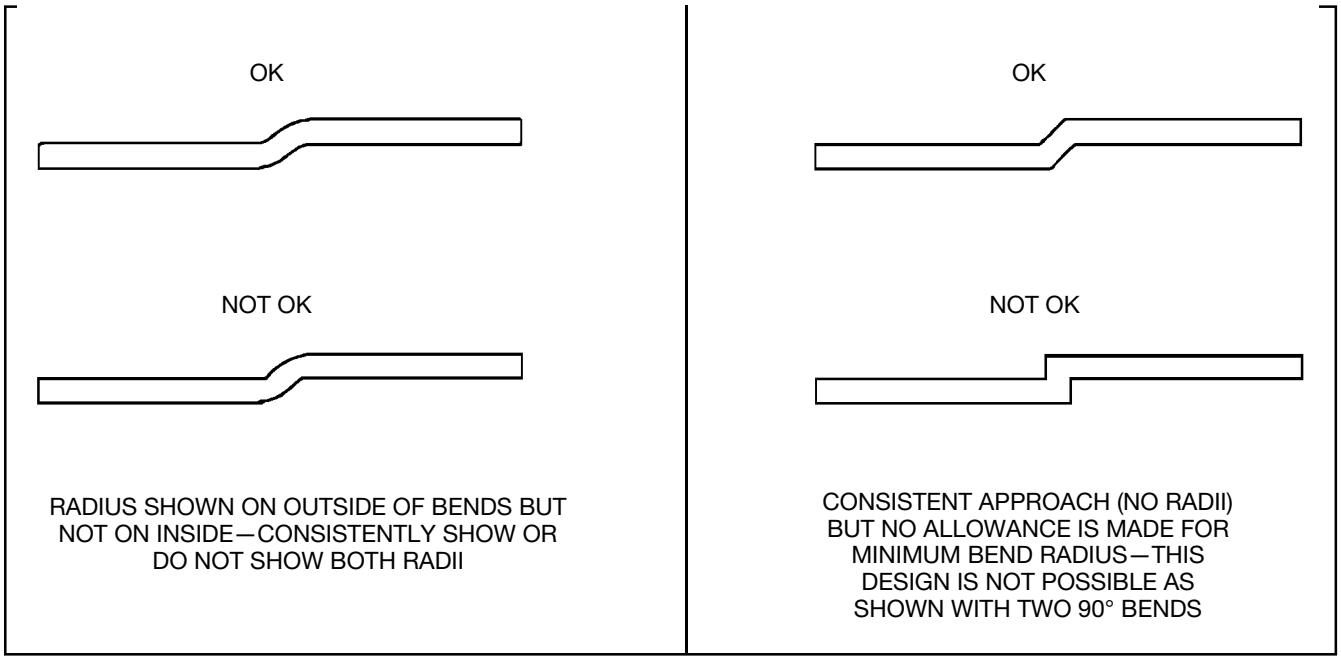


Figure 7. Two CAD model problems in sheet metal parts with offset bends shown both correctly and incorrectly.

Assemblies: Two Methods

Assemblies of sheet metal parts can be described with CAD models using one of these methods:

1) a separate file for each component. See Figure 8.
2) one file which uses a separate layer for each component.

There are distinct advantages and disadvantages to each of these methods, as detailed in Table 1.

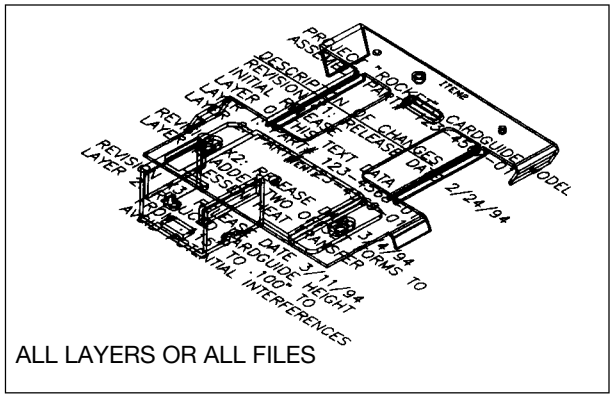


Figure 8. Views showing an assembly CAD file and separation of components by layer or by file.

Table 1. Comparison of two methods of communicating assemblies.

Parts Separated By Layer **(all parts in the assembly are in one file)**	**Parts Separated By File** **(multiple files, one part in each file)**
Pros: + requires only one file transfer + all information kept in one place, nothing lost + assembly information is defined with part models + view any combination of parts by choosing layers + file translation only needs to be done once	**Pros:** + revision level can be incorporated in file name + customer only sends files for parts being revised
Cons: – file is larger and slower to manipulate – file size may exceed CAD system limitations – large file will need to be revised and exchanged whenever a single component is revised – layer names may change during file translation	**Cons:** – file translation must be performed on each file individually – if an assembly model is desired, it must be pulled together from all of the translated files

Critical-to-Function Dimensions

In the past, part designs were typically communicated by hand-drafted drawings, showing various views of the part with dimensions for every detail and with all pertinent information included. With CAD systems, some designers have stopped generating dimensioned drawings of any kind, since dimensions can be extracted from the CAD model instead. Unfortunately, the result is an incomplete hand-off of information. The designer still needs to communicate to the manufacturer other types of information: the dimensions that are critical to the success of the design, tolerances and the other non-geometrical information that were included in the drawings.

Two-dimensional drawings are the best way to communicate critical-to-function (CTF) dimensions. Figure 9 is an example of a CTF drawing that includes critical dimensions and most of the necessary non-geometrical information. In addition, this drawing contains enough dimensions to completely form the described part. Without this information most manufacturers would have to create an additional drawing to detail the formed part to the shop and for quality assurance records. This CTF drawing is

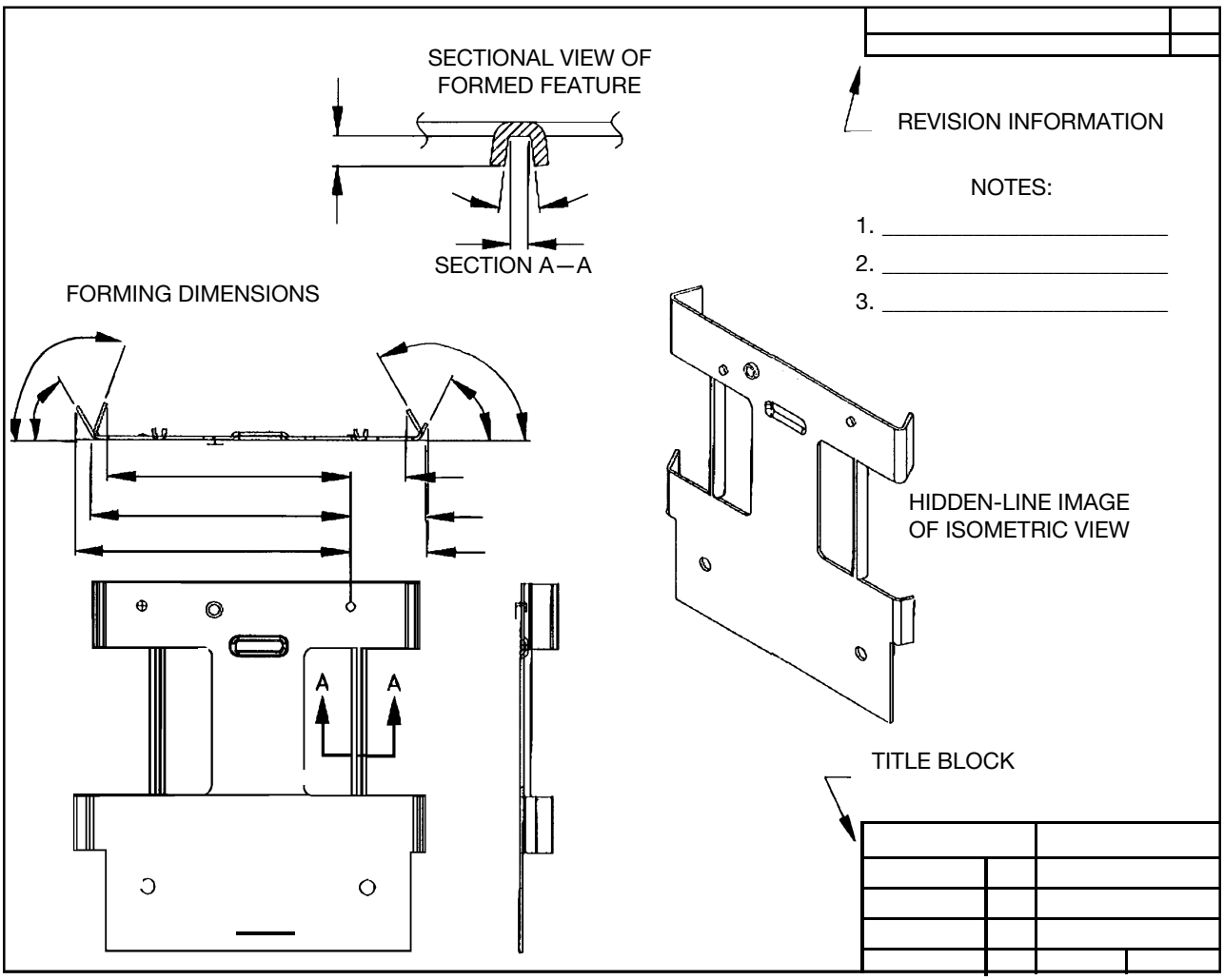


Figure 9. Features of critical-to-function drawings.

simpler to produce than a complete fabrication drawing because it has fewer dimensions.

A flat pattern view is acceptable and sometimes very helpful. The manufacturer will use these views mainly as a reference for the quoting process. If dimensions are included in any unfolded views they should be for reference only, since the manufacturer will need flexibility in order to meet the dimensions and tolerances of the formed part.

Non-geometrical information

Required information other than the wireframe geometry and CTF dimensions are known as non-geometrical information. It is textual information and most of it can be communicated in the CAD model or CTF drawing, but it can be separately enclosed in an ASCII text file or on paper. Information regarding whom to contact and the CAD media should be enclosed in a file elsewhere because that information will be needed in case there are problems or questions and to extract files from the media.

Checklist of non-geometrical information which needs to be communicated

- ❑ Design Engineer - name, phone #, e-mail address and fax #
- ❑ Manufacturing Engineer - name, phone #, e-mail address and fax #
- ❑ Buyer - name, phone #, e-mail address and fax #
- ❑ CAD media information CD/e-mail/ diskette/tape: commands required to extract the files
- ❑ File format and version number: IGES (.igs), STEP (.stp), ACIS (.sat), Parasolid (.x_t), Granite (.g)
- ❑ Part number
- ❑ Revision
- ❑ Revision description
- ❑ Part title
- ❑ Estimated number of parts required per year and part life time
- ❑ Related CAD file name(s) or layer name(s)
- ❑ Material - thickness, type, hardness (if applicable), etc.
- ❑ Punch or burr direction, material grain direction
- ❑ Deburring instructions
- ❑ Finish - plating instructions, painting instructions (i.e. mask, over spray, color), specifications, camera ready art or digital file, etc.
- ❑ Tolerances
- ❑ Part marking information
- ❑ Allowable bend radii
- ❑ Allowable bend relief
- ❑ Allowable corner radii
- ❑ Allowable tooling holes
- ❑ Hardware list - quantity, description, part number
- ❑ Assembly instructions - welding, tapping, riveting, etc.

Tolerances

CAD models define the dimensions of a part completely, but generally do not describe the tolerances that should be maintained for each dimension. Critical dimensions should be shown explicitly in the CTF drawing with tolerances, but unless this is a complete fabrication drawing, most of the remaining features are left undimensioned and untoleranced. One solution is a note or tolerance block that defines the general tolerances, not dependent on two- or three-place dimensions, but instead according to what types of features are being dimensioned.

Example: Possible Tolerance Note

As specified by the critical-to-function drawing, standard tolerances will be the following:

Single-hit hole size ±
Edge or hole to edge or hole ±
Edge or hole to form ±
Form to form ±
Form angle ±

The CAD model will contain all the nominal dimensions for a design, but tolerances need to be explicitly communicated to the supplier in a CTF drawing or other specification document. Tolerances should be called out as bilateral tolerances (i.e.: ±2mm) so that nominal falls in the middle of the tolerance band. Do not use unilateral tolerances (i.e.: +0.010"/-000"). They will cause the nominal dimension in the CAD model to be at the edge of the tolerance band.

If the CAD model is used to program a CNC operation, the computer-driven machine will target the nominal dimension and operate at the edge of limit for acceptable product. The CNC programmer can intervene and manually edit the program to target the middle of the tolerance band, but then the process is no longer being driven by customer data and errors can be made.

File Formats

• **CAD Files**. CAD software is developed by independent companies, competing to be the first to market with the best combinations of capabilities and cost. CAD systems each use their own unique way of organizing and storing the CAD data. Brand specific file formats are incompatible with each other. Part designs created by one CAD program are unreadable by others unless a neutral file format is used when transferring the CAD data.

• Neutral file formates include **IGES** (.igs, *Initial Graphics Exchange Specification*) and **STEP** (.stp, *Standard for the Exchange of Product* model data) are generally supported by all major solid modeling CAD programs. Neutral formats will strip away parmetric data that created the original geometry.

Industry standards have been developed to give CAD programs a universal file format for translating CAD information from one company's CAD format to another. Its official name is the Initial Graphics Exchange Specification — and often referred to as IGES. Files saved according to the IGES specification are identified by the DOS file extension,".IGS."

As with most standards, the capabilities of the universal IGES format follow the industry it supports. The IGES standard is updated to support the new capabilities designed into CAD systems, but there is a time delay. Today, IGES captures 3-D model information, surfaces and wireframes. It does not include 3-D solids, parametrics or certain complex curve functions.

CAD software companies take responsibility for how their CAD information is translated to and from the IGES format. Some CAD programs allow the designer to save a design directly to an .IGS file. Others require that you save the design in the CAD system's native file format, and then run a separate program to convert it to an .IGS file. In either case, it is important to use the most current revision of the IGES translator so your .IGS files can be understood by CAD systems at other companies.

A word of caution in using IGES. There are several pitfalls that can make it very difficult to use IGES effectively:

• CAD systems (and even IGES) do not support all of the geometric shapes used in the CAD design world. The root of most translation problems lies in the basic differences in the way CAD systems store design information. CAD systems may describe common geometric shapes in incompatible ways.

While one CAD system may not recognize a circle (but represent it with a 90° ellipse) another system may not recognize an ellipse (but represent one with polyline arcs). Translating a design through this combination turns circles into polyline arcs—the polyline arcs may not be understood when the design is translated back

to the CAD system used by the original designer. And that designer will not understand why the circles were "deleted" from the design without authorization. Each translation is an opportunity for creating errors.

• The IGES and STEP translator for your CAD system may be poorly written. They are often written by third party services who may not understand all the hidden incompatibilities. If your CAD system uses a shape, a color, a line width, or other feature that is not supported by IGES and STEP, the translator will determine whether or not the entity gets written to the IGES or STEP file, and what it will be translated as.

• Your IGES or STEP translator may not be a current revision. The latest IGES and STEP translator will typically convert an old design file. But an old translator will not recognize the format of a new IGES or STEP file and may discard data without telling you or create a file that is unopenable on the receiving CAD system.

Pitfalls are common in today's world and make it very difficult for a "good" supplier to interpret a "good" CAD file. To minimize problems, test the compatibility between CAD systems. Then expect to check all translated designs carefully on an ongoing basis.

Kernal specific file formats include, ACIS (.sat, *Spatial Technology*), Parasolid (.x_t, *Unigraphics Solutions*), and Granite (.g, *Parametric Technologies*). These file formats will provide a better level of compatibility and are recommended over Neutral file formats, if available. Kernal specific file formats, like neutral formats, will strip away parametric data that created the original geometry.

Product specific file formats are the native file format of the creating CAD software. This is always the best option for moving CAD data if your fabricator supports compatible software. It is recommended to check with your fabricator on software type, file format and transfer media before sending any CAD file.

Test the compatibility between CAD systems.

- Create a test file that includes each of the entities supported by your CAD system.
- Translate the file into the target CAD system.
- Compare each entity.
- Do this both ways between customer and supplier.

While IGES and STEP are the standard format for CAD geometry, there are other file formats that have become defacto standards for exchanging drawings and text. (IGES will handle drawings and text, too, however the translators available today do an unreliable job of translating them.)

• **Drawing Files**. Though drawings can be included in an .IGS file, this guideline recommends two formats for drawings, HPGL (Hewlett Packard Graphics Language) and DXF (Drawing Interchange File, a format developed for AutoCAD and commonly used by 2-D CAD systems).

• **HPGL** is a printing format that computers use for telling a plotter how to plot a drawing. To save an HPGL file, one tells the CAD software it should plot to a plotter, but captures the instructions to a disk file instead. In order to print the file later, one copies the disk file to an HPGL device—a plotter or printer. This capability is available on most CAD software packages.

The HPGL format's key strength is that all drawing information is reliably captured in the electronic file and can be printed on a wide range of plotters and printers. The file format has two drawbacks. First, the file will have the drawing's size coded into it when the file is created. Secondly, the file is a set of plotting instructions. It is no longer a CAD design and cannot be revised with most CAD software systems. HPGL files do not keep track of attribute information or drawing layers. It is essentially an electronic version of a plotted drawing.

• **.DXF** is another standard CAD design file format. It is commonly used by 2-D CAD programs, but is 3-D capable. (Your CAD manual will explain the process for saving a .DXF file.) The .DXF file can be revised and plotted. It is simpler and 2-D drawings are more reliably interpreted than drawings from an IGES file. Drawbacks are that it will be a bigger drawing file than an HPGL file.

• **Text files.** Text files are very useful for describing non-graphical information. They may be saved on the same e-mail or disk as CAD files. Text files can be in a variety of formates including Microsoft Word and WordPad.

File Contents

Until there is greater standardization in the industry, transferring design information from one CAD system to another will be unreliable.

To simplify matters, we recommend that companies use each of the file types for the particular job they do best:

- Use native CAD files, if supported, first.
- Use Kernal specific file as a second choice.
- Use .IGS or .STP as a last resort
- Use .IGS for design models.
- Use .DXF or HPGL for drawings.
- Use .DOC or .TXT files for text information.

File Preparation

We recommend that all files be compressed using a compression utility such a WinZip or Stuffit. This reduces e-mail transmission times and archives all files into a single file. If the files are coming from a Macintosh®, include the DOS 3 character extension to all files to allow for safe transfer to Windows systems.

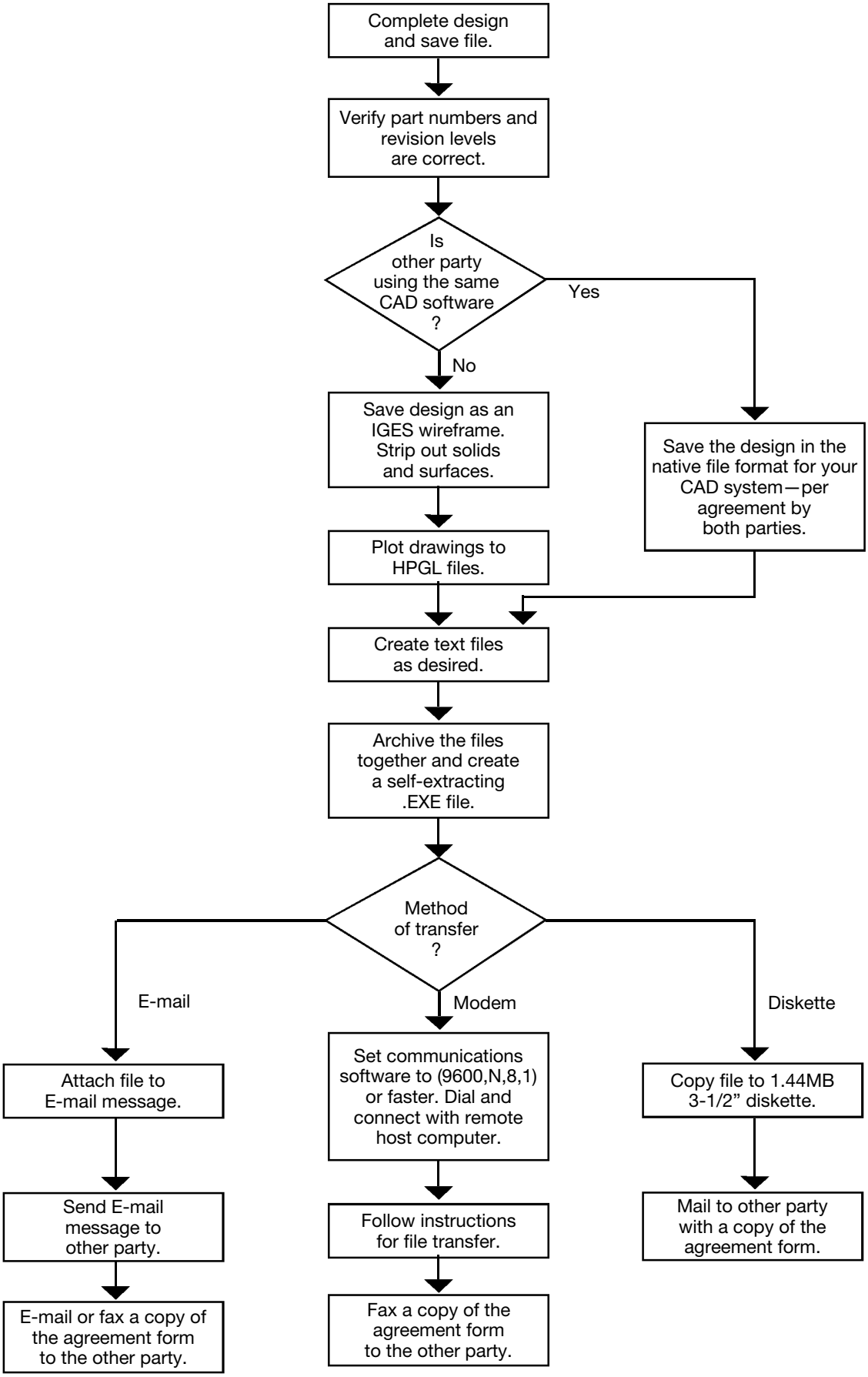
File Transfer

• E-mail attachments are the simplest way of transferring the CAD data and accompanying files. This usually has a 2 meg file size limitation. Check with your fabricator regarding mailbox size limitations.

• Your fabricator may have an FTP site which allows for peer-to-peer transfers. Usually larger files can be transmitted using this approach and the transfer is more secure.

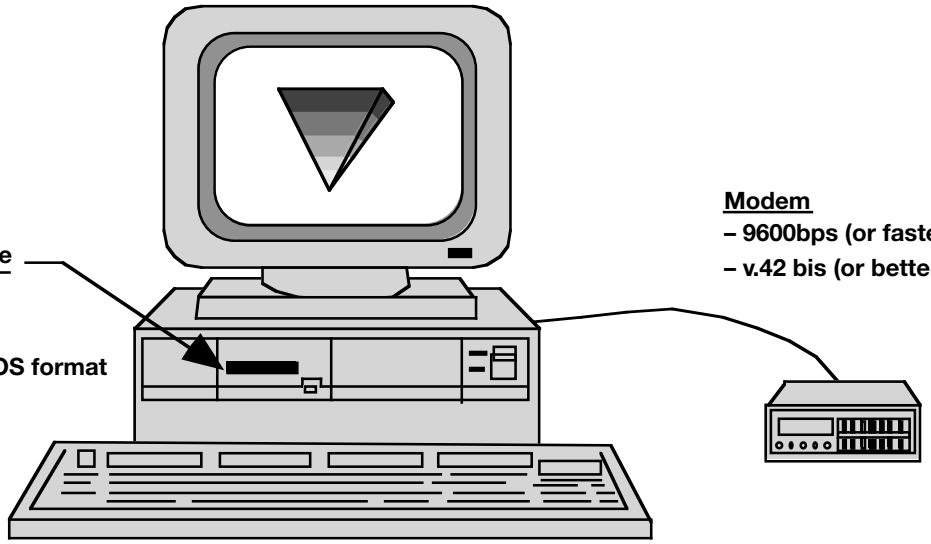
• **Disk Transfer.** Files can be saved to a CD, floppy disk or Zip disk and sent via overnight mail. Unless otherwise arranged, the disk should be a DOS format

Flowchart for Exchanging CAD Files



CAD File Transfers

Minimum Requirements
Hardware & Software



Floppy Disk Drive
– 3-1/2" diskette
– 1.44MB
– able to read DOS format

Modem
– 9600bps (or faster)
– v.42 bis (or better)

File Compatibility
– able to read:
- IGS files
- DXF files
- HPGL/HPGL2 files

Computer Software
– communications software with host capability.
– file compression software
– software for creating self-extracting .EXE files.

Preferred File Transfer Methods
– modem upload/download
– 3-1/2" DOS diskette

Optional File Transfer Methods
(only when prearranged between customer and supplier…)
– Internet e-mail
– magnetic tape
– 5-1/4" diskette

Format of Transferred File(s)
– file shall be compressed and archived in a self-extracting .EXE file.
– .EXE file may include:
.IGS 3 dimensional model
.DXF drawings
.TXT files containing text
HPGL plotter files
– CAD model shall not include solids or surfaces.
– optional file formats, solids, and surfaces may be used if prearranged between customer and supplier.

Date: _____

Sample
Customer/Supplier CAD Agreement

Company Name:_____ **Contact Name:** _____

Project Name:_____ Title: _____

Phone: _____

Part Number(s):_____ Fax: _____

Revision Level:_____ E-mail: _____

Action Requested

- ❑ Quote
- ❑ Prototype
- ❑ Production

CAD Media:

- ❑ Disk
- ❑ Modem
- ❑ E-mail
- ❑ Other

Deviations allowed:

- ❑ Material substitutions
- ❑ Hardware substitutions
- ❑ Tolerances
- ❑ Redesign for manufacturability

❑ Others

Other docs required:

- ❑ Customer standards
- ❑ Other

Controlling document is

- ❑ CAD model
- ❑ Plot files
- ❑ Hardcopy drawings
- ❑ Other_____

Types of files included:

- ❑ .IGS model
- ❑ .DXF model/plots
- ❑ HPGL/HPGL2 plots
- ❑ .TXT docs
- ❑ Material/hardware list
- ❑ Other

CAD software used? _____

Command required to extract files

All nominal dimensions for prototypes and production parts will be taken from the

CAD model

The customer agrees that the **CAD model** will be used to program computer aided manufacturing (CAM) processes.

3

MATERIAL SELECTION

Commercially produced materials suitable for stamping and fabrication cover a broad range. Included are not only all types of ferrous and non-ferrous metals but also a large array of paper, fiber, leather and plastic products. This chapter deals exclusively with ferrous and non-ferrous metals which are most commonly used in metalforming.

Typical properties of metal alloys commonly used in metalforming appear in the tables that follow.

The following is a density chart for the materials covered in this chapter.

Density Chart

Material	Density
Steels	0.28 lbs./cubic inch
Special Low Carbon Cold Rolled Steel Products	0.28 lbs./cubic inch
Spring Steels	0.28 lbs./cubic inch
Stainless Steels	0.29 lbs./cubic inch
Aluminums	0.11 lbs./cubic inch
Copper & its Alloys	0.32 lbs./cubic inch
Brass	0.31 lbs./cubic inch
Phosphor Bronze	0.32 lbs./cubic inch
Beryllium Copper	0.30 lbs./cubic inch

Steels

All steels used in metalforming start out as hot rolled. However, the use of hot rolled steel is limited because it is not available in thicknesses of less than 0.060 in. (1.5 mm). Also, the thickness variation of hot rolled stock prevents its use in high-precision applications.

• **Hot rolled steel (HRS)** can be purchased in three qualities:

1) Hot rolled, with rolling scale on its surfaces. Used for rough and heavy work, often involving basic weldments. Least expensive.

2) Pickled and oiled, referred to as HRPO steel, where the hot-rolling scale is removed by acidic etching, followed by oil coating for rust protection. Surface finish can be up to 120 root mean square (rms). Used on truck chassis and similar work.

3) Skin-passed hot-rolled steel, a HRPO steel with one "skin-pass" cold rolling added for a smoother surface, similar to cold rolled steel. All other properties remain the same as regular hot-rolled steel.

Table I. Physical and Mechanical Properties of Selected Cold & Hot Rolled Steel

Property	Generic Cold Roll	Draw Quality Cold Roll	Commercial Quality Cold Roll	1/4 Hard Cold Roll	1/2 Hard Cold Roll	Commercial Quality Hot Roll
form →	sheet or strip	sheet	sheet or strip	sheet or strip	sheet or strip	sheet
density lb/in^3 (g/cm^3)	0.28 (7.87)	0.28 (7.87)	0.28 (7.87)	0.28 (7.87)	0.28 (7.87)	0.28 (7.87)
mechanical properties						
modulus of elasticity 10^6 PSI (tension) N/mm^2	2.9 203000	2.9 203000	2.9 203000	2.9 203000	2.9 203000	2.9 203000
tensile strength 1000 PSI N/mm^2 (typical)	40.6-65.3 280-450	39.2-50.8 270-350	43.5-58.0 300-400	45.0-65.3 310-450	55.1 -75.4 380-520	45.0-52.2 310-360
yield strength 1000 PSI N/mm^2 (typical)	24.6 ~ 170	23.2 160	24.6 170	29.7 205	39.9 275	24.6 170
elongation % typical range	24-40	35-40	24-40	13-27	4-16	24-40
hardness HRB	45-75	55 max.	65 max.	60-75	70-85	45-65
forming, drawing	excellent, will meet any engineering drawing req't	excellent	very good, flat on itself in any direction	across grain: 180° at bend radius with grain: 90° at bend radius	bend radius 2T min.	bend radius 1/2T at 90°
weldability	excellent	excellent	excellent	limited	limited	excellent

• **Cold rolled steel (CRS)** is a collective name for all steel which is finish processed through a cold rolling reduction mill. This process follows the initial hot rolling and then pickling, for scale removal. The cold rolling process refines the surface finish and strain hardens the material. The name cold rolled steel does not, in itself, imply any steel quality, except for the surface finish. See Table 1.

• **Sheet and strip** CRS sheet and strip are two distinct types of steel, both mill produced in coil form. Most mills are dedicated to making either sheet or strip quality metal exclusively. Unfortunately, the terms CRS sheet and strip are very confusing and do not describe a shape or size.

Quality American mills produce CRS sheet and strip to AISI (American Iron and Steel Institute) standards having carbon content of 0.08 to 0.20%.

There are different standards for some imported steels with carbon content as low as 0.04% which is sold as "commercial grade" with a lower and sometimes undefined quality.

The four major differences between cold rolled sheet and strip:

1) Strip has a much better surface finish.

2) Strip is rolled to much tighter thickness tolerances.

3) Strip is rolled to a maximum width of 24 in. (0.6 m); sheet steel to 72 in. (1.8 m), but normally 48 in. (1.2 m).

4) Strip uses a number system for temper designations; sheet uses a descriptive system.

Strip's close thickness control and consistent

Table II. Relative Cost Comparison of Various Steel Categories.

	Hot Rolled	Cold Rolled	
type	sheet	sheet	strip
relative cost	1.0	1.5	2.0
maximum width	up to 72 in.	48 in.[1]	up to 24 in.
min./max. thickness	0.13/	0.007-0.015[2]/0.125	0.005-0.008[2]/0.187

[1] special mill orders up to 72 in. wide
[2] depending on temper

tensile strength results in much better forming characteristics, possible higher production rates, and superior surface finish.

Table II is a quick overview of the steel categories with a relative cost comparison.

Your supplier can make the proper recommendation based on the demands your design places on the material specification.

Cold rolled sheet and strip steel is readily available in all standard thicknesses and tempers from warehouses specializing in cold rolled products. Speciality cold rolled sheet and strip of exacting thickness and temper can be ordered directly from the mills, but requires a minimum order of at least five tons for sheet and one ton for strip. Delivery leadtimes are generally extended.

Another option utilizes a re-rolling mill with the ability of re-rolling an off-the-shelf product to exacting thickness, temper and finish requirements. The advantage of re-rolling mills is the ability to process smaller minimum order quantities in less time than the hot rolled mills.

Formability of Various Qualities and Tempers

Cold rolled sheet in ¼ hard and strip #3 temper can be hemmed with the grain. Drawing quality (sheet) and #5 tempers (strip) because of their excellent forming characteristics, are ideally suited for some of the most severe forms and draws.

Table III illustrates the minimum bend radius in the various tempers. Caution must be exercised when specifying minimum bend radii because of the wide range of tensile strengths and hardness ranges in each temper designation.

Other Considerations

Almost all rolled stock is produced very close to the lowest thickness limit, a condition to remember during design.

Two flatness grades are available in sheet form; commercial (roller leveled) and stretcher leveled quality. The latter has the better flatness condition. See Table IV.

Specialty Low Carbon Cold Rolled Steel Products

• **Shim steel,** hard-rolled with a bright #2 finish available in thicknesses ranging from 0.001 in. (0.02 mm) to 0.062 in. (1.57 mm). Width: 6 in. (0.2 m) to 12 in. (0.3 m) only. Coil stock or cut to length.

• **Flat wire,** half-hard #2 temper, rounded edges. Thickness starting at 0.032 in. (0.81 mm) and up to 0.187 in. (4.75 mm)

Width: from 0.250 in. (6.35 mm) to 2 in. (50.8 mm) maximum. Consult your supplier for the thickness/width combinations available. Coil stock or cut to length.

Coated CRS

Several metallic coatings are available in two coating methods: Hot dip and electrolytically deposited. Tin plated steel is available in all tempers, but the temper designation numbers are

Table III. Cold Rolled Steel Sheet & Strip Grades Formability Chart

Sheet Strip Tensile Hardness	Description of material condition & capability	Material thickness		Angle figures show the relationship between the bendline and material grain direction.					
				0°		45°		90°	
				Minimum inside form radii required.					
		in.	mm	in.	mm	in.	mm	in.	mm
Draw quality #5 temper 44,000 psi 55 RB max.	Unlimited forming and deep drawing possible.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
Soft #4 temper 48,000 psi 65 RB max.	Very ductile; can be bent 180° back on itself (hem).	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
1/4 hard #3 temper 54,000 psi 75 RB max.	Medium soft material with good to moderate forming use.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0.050 0.090 0.120	0 0 1.3 2.3 3.0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
1/2 hard #2 temper 64,000 psi 85 RB max.	Moderately stiff, somewhat limited formability.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0.060 0.120 0.160	0 0 1.5 3.0 4.1	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
Full hard #1 temper 80,000 psi 90 RB max.	Very stiff, springy, recommended for flat use only, requires large radius	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.060 0.190 0.220 0.250 0.310	1.5 4.8 5.6 6.4 7.9	0.03 0.12 0.16 0.19 0.22	0.8 3.0 4.1 4.8 5.6	0.03 0.14 0.16 0.19 0.22	0.8 3.6 4.1 4.8 5.6

The required minimum inside bend radius for 90° forms with the burr on the inside.

the opposite of CRS. All other coated steels are readily available in soft temper. See Table V.

For reasons of economy pre-coated cold rolled steel is becoming more widely used in some industries, especially for internal structural parts. In manufacturing, the following points are to be considered:

1) The cut edge is not coated.

2) Mass deburring via tumbling or vibratory methods is not an option. It is best to specify an allowable maximum burr height which can be controlled in production.

3) TIG & MIG welding require special equipment, create oxidized areas adjacent to the welds, and generate hazardous fumes.

4) Resistance welding generates some blemishes in the electrode contact area which are prone to rusting or oxidation.

5) Mechanical fasteners should be reviewed as an alternate assembly method.

Table IV. Cold Rolled Steel Flatness Tolerances

Commercial Quality **specified minimum thickness inch**	**specified width inches**	**flatness tolerances (maximum deviation from a horizontal flat surface), inch**
0.044 and thinner (1.12 mm)	12 to 36 incl. over 36 to 60 incl. over 60	3/8 (9.53 mm) 5/8 (15.88 mm) 7/8 (22.23 mm)
over 0.044 (1.12 mm)	12 to 36 incl. over 36 to 60 incl. over 60 to 72 incl. over 72	1/4 (6.35 mm) 3/8 (9.53 mm) 5/8 (15.88 mm) 7/8 (22.23 mm)
Stretcher Quality **specified minimum thickness inch**	**specified width inches** / **specified length inches**	**flatness tolerances (maximum deviation from a horizontal flat surface), inch**
over 0.015 to 0.028 incl. (0.38 to 0.71 mm)	12 to 36 incl. / to 120 incl. wider or longer	1/4 (6.35 mm) 3/8 (9.53 mm)
over 0.028 (0.71 mm)	12 to 48 incl. / to 120 incl. wider or longer	1/8 (3.18 mm) 1/4 (6.35 mm)

Table V.
Types of coated CRS and Typical Applications

Available Coatings	**Uses & Comments**
electrolytic tin bright matte finish	mostly in thin gages for grounding purposes and shielding in electronic housings
electro galvanized (zinc) plain or bonderized (for paint adhesion)	chassis, panels, housings, shelves and similar products manufactured from material up to .06 (1.5mm) thick material are edge protected by galvanic action
hot dipped galvanized CRS	primarily used for building hardware etc., with some applications in electronics
long terne plate	used in building hardware,sheeting, covers etc., easily solderable, available only in soft tempers
aluminized CRS hot dip process	heat reflective and corrosion resistant in hot environment, automotive use, electrolytic converters, mufflers etc., soft tempers only

Table VI. Tensile Strength and Hardness of Selected Spring Steels

Spring Steel		
AISI #	**tensile strength in KSI (depending on drawing temperature)**	**rockwell C hardness**
1050	112-250	22-52
1075	122-305	26-59
1095	138-320	30-62
Aircraft Quality Heat-Treatable Low Alloy		
4130	98-234	25-60

All above alloys are available in strip quality and width of 24" maximum. Check with your supplier for specific material widths in stock.

Table VII. Spring Steel, Soft Annealed Spheroidized Structure Formability Chart

Type Tensile Hardness	Description of Material Condition & Capability	Material Thickness		Angle figures show the relationship between the bendline and material grain direction.					
				0°		45°		90°	
				Minimum inside form radii required.					
		in.	mm	in.	mm	in.	mm	in.	mm
1050 64,000 psi 84 RB max.	Readily formable into complex shapes. Heat treatable to full spring temper.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.015 0.030 0.120 0.190 0.440	0.4 0.8 3.0 4.8 11.2	0.015 0.015 0.060 0.120 0.310	0.4 0.4 1.5 3.0 7.9	0 0 0.060 0.090 0.190	0 0 1.5 2.3 4.8
1075 80,000 psi 86 RB max.	Readily formable into complex shapes. Heat treatable to full spring temper.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.030 0.050 0.120 0.200 0.500	0.8 1.3 3.0 5.1 12.7	0.015 0.030 0.060 0.120 0.190	0.5 0.8 1.5 3.0 4.8	0.015 0.015 0.060 0.090 0.190	0.4 0.4 1.5 2.3 4.8
1095 90,000 psi 88 RB max.	Readily formable into complex shapes. Heat treatable to full spring temper.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.030 0.050 0.140 0.220 0.500	0.8 1.3 3.6 5.6 12.7	0.015 0.030 0.080 0.140 0.340	0.4 0.8 2.0 3.6 8.6	0.015 0.015 0.060 0.110 0.220	0.4 0.4 1.5 2.8 5.6

Shown is the required minimum inside bend radius for 90° forms with the burr on the inside. Recommended minimum bend radii for three grades of annealed spring steel, along with tensile and hardness information. Bends are oriented at 0°, 45° and 90° to grain direction.

Spring Steels

Spring steel is only available in coil or strip form, in both annealed and fully tempered spring condition. The latter often is referred to as clock-spring material. In the spring steel designation numbers, the last two digits show the carbon content in tenths and hundredths of a percent. One other alloying element present in spring steel is manganese (Mn) which improves hardenability.

Annealed spring steel is easy to stamp and form, but the heat treating to spring temper while maintaining shape is a major challenge, requiring straightening, gauging, etc.

For flat shapes or radiused and open formed parts it is most economical to use the pretempered variety of spring steel. High quantity runs of prehardened steel parts make carbide dies mandatory.

Tensile strength and hardness of commonly available spring steels, after heat treat, are given in Table VI. Highest tensile strength, alone, does not necessarily assure the best overall performance.

Production From Annealed Spring Steel

Higher carbon steels tend to present more problems. The more complex crystalline structure is prone to pitting (intercrystalline corrosion) during pickling, necessary if the product is to be plated. Cosmetic nickel plating is likely to highlight pickling pits. Plating of spring steel necessitates a two-hour bake cycle at 325°F to

Table VIII. Stainless Steel, Type 302 Formability Chart

Condition Tensile Hardness	Description of Material Condition & Capability	Material Thickness		Angle figures show the relationship between the bendline and material grain direction.					
				0°		45°		90°	
				Minimum inside form radii required.*					
		in.	mm	in.	mm	in.	mm	in.	mm
Annealed 70,000 psi 87 RB max.	Has the best combined mechanical and forming qualities of all stainless steels.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
1/4 hard 125,000 psi 29 RC max.	Semi-stiff, can be formed with moderate spring back.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.015 0.030 0.030 0.050 0.060	0.4 0.8 0.8 1.3 1.5	0.015 0.015 0.015 0.030 0.030	0.4 0.4 0.4 0.8 0.8	0.015 0.015 0.015 0.030 0.030	0.4 0.4 0.4 0.8 0.8
1/2 hard 150,000 psi 34 RC max.	Stiff, can be formed with severe spring back.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.030 0.050 0.060 0.080 0.080	0.8 1.23 1.5 2.0 2.0	0.015 0.030 0.030 0.050 0.050	0.4 0.8 0.8 1.3 1.3	0.015 0.030 0.030 0.050 0.050	0.4 0.8 0.8 1.3 1.3
3/4 hard 175,000 psi 40 RC max.	Very stiff. Spring back prevents complicated forms.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.030 0.060 0.110 0.120 0.190	0.8 1.5 2.8 3.0 4.8	0.015 0.050 0.060 0.090 0.090	0.4 1.3 1.5 2.3 2.3	0.015 0.050 0.050 0.090 0.090	0.4 1.3 1.3 2.3 2.3
Full hard 185,000 psi 46 RC max.	Extra stiff. Recommended for springs and flat parts only.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.050 0.090 0.120 0.250 0.380	1.3 2.3 3.0 6.4 9.6	0.030 0.060 0.080 0.120 0.190	0.8 1.5 2.0 3.0 4.8	0.030 0.060 0.080 0.120 0.190	0.8 1.5 2.0 3.0 4.8

Recommended minimum bend radii for five tempers of 302 stainless steel with burrs on the inside, along with tensile and hardness information. Bends are oriented at 0°, 45° and 90° to grain direction. Above minimum bend radii in comparison show the great loss of formability brought by increased tensile strength.

**Minimum bend radii for Type 304 stainless steel are similar to those Values shown above.*

eliminate hydrogen embrittlement, an inherent result of plating.

Table VII illustrates the minimum bend radius in the various grades of spring steel.

Caution must be exercised when specifying minimum bend radii because of the wide range of tensile strengths and hardness ranges.

Stainless Steels

Over 100 types of stainless steel are commercially available. Of these, approximately 25 to 30 are readily available in various thicknesses and tempers from warehouses specializing in stainless steel.

Specialty stainless steels of exacting thickness

Table IX. Relative Suitability of Stainless Steels for Various Methods of Forming

Steel	0.29% yield strength, 6.89 MPa (1 ksi)	Suitability For: Blanking	Piercing	Press-brake Forming	Deep Drawing	Spinning	Roll Forming	Coining	Embossing
Austenitic Steels									
201	55	b	c	b	a-b	c-d	b	b-c	b-c
202	55	b	b	a	a	b-c	a	b	b
301	40	b	c	b	a-b	c-d	b	b-c	b-c
302	37	b	b	a	a	b-c	a	b	b
302B	40	b	b	b	b-c	c	—	c	b-c
303, 303(Se)	35	b	b	d(a)	d	d	d	c-d	c
304	35	b	b	a	a	b	a	b	b
304L	30	b	b	a	a	b	a	b	b
305	37	b	b	a	b	a	a	a-b	a-b
308	35	b	—	b(a)	d	d	—	d	d
309, 309S	40	b	b	a(a)	b	c	b	b	b
310, 310S	40	b	b	a(a)	b	b	a	b	b
314	50	b	b	a(a)	b-c	c	b	b	b-c
316	35	b	b	a(a)	b	b	a	b	b
316L	30	b	b	a(a)	b	b	a	b	b
317	40	b	b	a(a)	b	b-c	b	b	b
321, 347, 348	35	b	b	a	b	b-c	b	b	b
Martensitic Steels									
403, 410	40	a	a-b	a	a	a	a	a	a
414	95	a	b	a(a)	b	c	c	b	c
416, 416(Se)	40	b	a-b	c(a)	d	d	d	d	c
420	50	b	b-c	c(a)	c-d	d	c-d	c-d	c
431	95	c-d	c-d	c(a)	c-d	d	c-d	c-d	c-d
440A	60	b-c	—	c(a)	c-d	d	c-d	d	c
440B	62	—	—	—	—	d	—	d	d
440C	65	—	—	—	—	d	—	d	d
Ferritic Steels									
405	40	a	a-b	a(a)	a	a	a	a	a
409	38	a	a-b	a(b)	a	a	a	a	a
430	45	a	a-b	a(a)	a-b	a	a	a	a
430F, 430F(Se)	55	b	a-b	b-c(a)	d	d	d	c-d	c
442	—	a	a-b	a(a)	b	b-c	a	b	b
446	50	a	b	a(a)	b-c	c	b	b	b

(a) severe sharp bends should be avoided. a—excellent; b—good; c—fair; d—not generally recommended

Suitability ratings are based on comparison of the steels within any one class; therefore, it should not be inferred that a ferritic steel with an (a) rating is more formable than an austenitic steel with a (c) rating for a particular method.

Table X. Properties of Various Aluminum Alloys

Property	Aluminum Alloys							
	2024-T3	6061-T6	1100-H14	3003-H14	5052-H32	5052-H34	5052-0	specular sheet
density (g/cm^3)	(2.77)	(2.70)	(2.71)	(2.73)	(2.68)	(2.68)	(2.68)	
mechanical properties								
modulus or elasticity 10^6 PSI (tension) N/mm^2	10.6 72400	9.9 68300	10.0 69000	10.2 70000	10.1 69300	10.1 69300	10.1 69300	(not available)
tensile strength 1000 PSI N/mm^2 (typical)	70.0 483	45.0 310	18.1 125	21.7 150	33.4 230	37.7 260	28.3 195	20.0 138
yield strength 1000 PSI N/mm^2 (typical)	50.0 345	39.9 275	16.7 115	21.0 145	28.3 195	31.2 215	13.0 90	18.0 124
elongation (typical) %	17	12	9	8	12	10	25	2
shear strength 1000 PSI N/mm^2	41.3 285	29.7 205	11.0 76	14.1 97	20.3 140	21.0 145	18.1 125	n/a n/a
fatigue strength 1000 PSI N/mm^2	20.3 140	14.1 97	7.0 48	9.0 62	16.7 115	18.1 125	15.9 110	n/a n/a
forming, drawing	fair	fair	good	good	fair	fair	good	fair
joining characteristics	fair	excellent	excellent	excellent	excellent	excellent	excellent	(not available)

and temper specifications can be ordered directly from mills. However, this requires orders of at least three tons, with deliveries running up to 36 weeks, depending on mill backlog.

Other sources of specialty stainless steels are re-rolling mills, which process standard off-the-shelf material to required thickness temper and finish requirements. Delivery from re-rolling mills is dependent on the mill backlog at time of order placement. Order processing can take up to 16 weeks. One of the positive aspects of using re-rolling mills is their ability to process minimum orders of 200 lbs.

Table VIII illustrates the minimum bend radius for the various tempers of 302 stainless steel. Stainless steel type 302 is one of the most ductile grades. Caution must be exercised when specifying minimum bend radii because of the wide range of tensile strengths and hardness range variations in each temper designation.

Note: Thickness of stainless steel should be specified to decimal dimensions and not gauges.

Basic Types of Stainless

• **Austenitic**—Non-hardenable chromium nickel alloys (non-magnetic in the annealed condition). This group is also known as 18-8 or "surgical" stainless steel. Types: 301-302-302B-303-304-305-308-310-314-316-317-321 and 347.

• **Martensitic**—Hardenable chromium alloys (magnetic). Types: 403-410-414-416-420-431-440A, B and C-501 and 502.

• **Ferritic**—Non-hardenable chromium alloys (magnetic) Types: 405-430-430F (F=freemachining) and 446.

See Table IX for relative suitability of stainless steel for various methods of forming.

• **Precipitation hardenable**—A specialty stainless steel alloy. Types: 15-5 PH, 17-4 PH, and 17-7 PH, (17-7 PH is most commonly available in sheet or strip).

Aluminum Alloys

Aluminum stampings are produced from wrought that has been rolled into a thin strip or sheet.

The cost of aluminum by weight is much higher than for steel, but it has the advantage of a higher strength to weight ratio. Other positive properties of aluminum are light weight, good electrical and thermal conductivity and a lasting silvery appearance, when appropriately treated. Aluminum, among its many available alloys and tempers, offers a wide variety of design application choices. See Tables X and XI.

On the negative side aluminum, unless protected, tends to scratch and dent through handling in use and also during production. Because of the special care required, aluminum is somewhat more costly to handle in production processing than ferrous metals.

Table XI. Type 1100 Aluminum Formability Chart

Temper Tensile Hardness	Description of Material Condition & Capability	Material Thickness		Angle figures show the relationship between the bendline and material grain direction.					
				0°		45°		90°	
				Minimum inside form radii required.					
		in.	mm	in.	mm	in.	mm	in.	mm
0 Soft 13,000 psi max. 26 RB max.	Exceptional ductility. Good for spinning, drawing and all types of cold working processes.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
H14 1/2 hard 18,000 psi max. 35 RB max.	Good ductility, still forms well with small inside radii.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0.030 0.050 0.060	0 0 0.8 1.2 1.5	0 0 0 0.030 0.030	0 0 0 0.8 0.8	0 0 0 0.030 0.050	0 0 0 0.8 1.2
H18 full hard 24,000 psi max. 48 RB max.	Stiff, but forms well with appropriately sized radii.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.030 0.060 0.120 0.280 0.410	0.8 1.5 3.0 7.1 10.4	0.015 0.050 0.120 0.250 0.380	0.4 1.2 3.0 6.3 9.7	0.015 0.050 0.120 0.250 0.380	0.4 1.2 3.0 6.3 9.7

Shown is the required minimum inside bend radius for 90° forms with the burr on the inside. Recommended minimum bend radii for three tempers of 1100 aluminum sheet, along with tensile and hardness information. Bends are oriented at 0°, 45° and 90° to grain direction. Aluminum, Type 1100 is known for its excellent corrosion resistance and weldability.

Table XII. Type 3003 Aluminum Formability Chart

Temper Tensile Hardness	Description of Material Condition & Capability	Material Thickness		Angle figures show the relationship between the bendline and material grain direction.					
				0°		45°		90°	
				Minimum inside form radii required.					
		in.	mm	in.	mm	in.	mm	in	mm
0 Annealed 16,000 psi max. 30 RB max.	Exceptional ductility. Can be easily formed and coined to intricate shapes.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0.015 0.015 0.030	0 0 0.4 0.4 0.8	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
H14 1/2 hard 22,000 psi max. 42 RB max.	Good ductility, still forms well with small inside radii.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.015 0.030 0.030 0.050 0.060	0.4 0.8 0.8 1.3 1.5	0 0 0 0.030 0.060	0 0 0 0.8 1.5	0 0 0 0.030 0.060	0 0 0 0.8 1.5
H18 full hard 29,000 psi max. 56 RB max.	Stiff, but forms well with properly sized radii.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.050 0.080 0.190 0.560 0.620	1.3 2.0 4.8 14.2 15.7	0.030 0.050 0.190 0.500 0.530	0.8 1.3 4.8 12.7 13.5	0.030 0.060 0.190 0.500 0.530	0.8 1.5 4.8 12.7 13.5

Shown is the required minimum inside bend radius for 90° forms with the burr on the inside. Recommended minimum bend radii for three tempers of 3003 aluminum sheet, along with tensile and hardness information. Bends are oriented at 0°, 45° and 90° to grain direction.

Aluminum Alloy Temper Designation System

The temper designation is always separated from the four-digit alloy designation by a hyphen.

- **General Terms**
  -F, as fabricated
  -O, annealed, re-crystallized
  -H, strain hardened (work hardened)
  -T, thermally treated
- **Strain-hardened Alloys (1000, 3000, 5000)**
  -H1, plus one or more digits, strain hardened only
  -H2, plus one or more digits, strain hardened and then partially annealed
  -H3, plus one or more digits, strain hardened and then stabilized (low temperature treatment to improve ductility)
- **Heat-treatable Alloys (2000, 6000, 7000)**
  -W, solution heat-treated—an unstable temper, usually designated by time increment after quench e.g.—W + 1/2 hour.
  -T3, OK
  -T4, solution heat-treated and naturally aged to an essentially stable strength level.
  -T5, OK
  -T6, OK
  -T8, OK
  -T9, OK
  -T10, OK

Table XIII. Type 5052 Aluminum Formability Chart

Temper Tensile Hardness	Description of Material Condition & Capability	Material Thickness		Angle figures show the relationship between the bendline and material grain direction.					
				0°		45°		90°	
				Minimum inside form radii required.					
		in.	mm	in.	mm	in.	mm	in.	mm
O Soft 28,000 psi max. 49 RB max.	Can be formed, drawn and coined easily; surface defects, scratches etc. must be expected.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0 0.030 0.030	0 0 0 0.8 0.8	0 0 0 0 0.03	0 0 0 0 0.8	0 0 0 0 0.030	0 0 0 0 0.8
H32 1/4 hard 33,000 psi max. 62 RB max.	Readily formed; most often specified for general use.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0.030 0.090 0.120	0 0 0.8 2.3 3.0	0 0.030 0.060 0.110 0.140	0 0.8 1.5 2.8 3.6	0 0.030 0.060 0.090 0.120	0 0.8 1.5 2.3 3.0
H34 1/2 hard 38,000 psi max. 70 RB max.	Moderately stiff; can be formed; specified when higher strength is required.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.015 0.030 0.080 0.190 0.220	0.4 0.8 2.0 4.8 5.6	0 0.030 0.060 0.190 0.190	0 0.8 1.5 4.8 4.8	0 0.030 0.060 0.190 0.190	0 0.8 1.5 4.8 4.8
H38 full hard 42,000 psi max. 80 RB max.	Very stiff, but can be formed with restrictions; used where spring action is needed; not readily available.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.050 0.080 0.200 0.500 0.560	1.3 2.0 5.1 12.7 14.2	0.030 0.060 0.190 0.500 0.500	0.8 1.5 4.8 12.7 12.7	0.030 0.060 0.190 0.500 0.500	0.8 1.5 4.8 12.7 12.7

Recommended minimum bend radii for four tempers of 5052 aluminum, along with tensile and hardness information. Bends are oriented at 0°, 45° and 90° to grain direction.

-W temper becomes –T4 at room temperature after the properties stabilize.

3000 and 5000 sheet alloys are normally supplied for stamping in the –O temper.

-H tempers are more commonly seen in forgings or heavy extrusions

Formability of Aluminum Alloys

Formability is directly related to the ductility of the material. Alloys in the –O and –T4 tempers have the greatest ductility and are normally used for stamping. Stampings are typically hardened to full strength, e.g. T6, in a subsequent thermal treatment process. At higher strength levels, the aluminum alloys have lower ductility, and are thus more difficult to form without cracking.

Tables XII-XV illustrate the minimum bend radius in the various tempers of 1100, 3003, 5052 and 6061 aluminum sheet. Caution must be exercised when specifying minimum bend radii because of the wide range of tensile

Table XIV. Type 6061 Aluminum Formability Chart

Temper Tensile Hardness	Description of Material Condition & Capability	Material Thickness		Angle figures show the relationship between the bendline and material grain direction.					
				0°		45°		90°	
				Minimum inside form radii required.					
		in.	mm	in.	mm	in.	mm	in.	mm
O Soft 18,000 psi Approx. 30 RB	Soft, almost unlimited formability.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.015 0.015 0.015 0.030 0.030	0.4 0.4 0.4 0.8 0.8	0 0.015 0.015 0.015 0.015	0 0.4 0.4 0.4 0.4	0 0.015 0.015 0.015 0.015	0 0.4 0.4 0.4 0.4
T4 * (solution heat treated only) 35,000 psi Approx. 65 RB	Moderately stiff, but can be formed readily, depending on state of aging. See note*.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.015 0.030 0.090 0.250 0.380	0.4 0.8 2.3 6.4 9.7	0.015 0.030 0.090 0.250 0.380	0.4 0.8 2.3 6.4 9.7	0.015 0.030 0.090 0.250 0.380	0.4 0.8 2.3 6.4 9.7
T6 full hard 45,000 psi Approx. 75 RB	Very stiff, can be formed by strict adherence to required inside minimum radii.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.050 0.060 0.140 0.250 0.380	1.3 1.5 3.6 6.4 9.7	0.030 0.030 0.110 0.280 0.380	0.8 0.8 2.8 7.1 9.7	0.030 0.030 0.110 0.280 0.380	0.8 0.8 2.8 7.1 9.7

**T4 Temper will precipitation harden during ambient temperature storage to 80% of T6 values within 6-9 months after solution heat treatment from T0 to T4. Severe reduction in formability is the result. Bends are oriented at 0°, 45° and 90° to grain direction with the burr on the inside.*

strengths and hardness range variations in each temper designation.

Hardened alloys are not normally stamped due to low ductility.

Copper

Several types of virtually pure copper are utilized for its very high electrical and thermal conductivity, outstanding ductility for drawing purposes and its good weathering ability.

• **Common Types.** The following common types of copper are listed by their Copper Development Association identification number:

CA 110—Also called bus bar copper. Most commonly used for electrical conductor parts. Most economical to use, readily available.

CA 101 and 102—Referred to as "OFHC" copper (oxygen free high conductivity). Specified for the most demanding electronic parts, especially for use in high vacuum environments. Not susceptible to hydrogen embrittlement. More costly with limited availability.

CA 194—Primarily used for lead frames and connectors.

Table XV illustrates the minimum bend radius in the various tempers of copper. Caution must be exercised when specifying minimum bend radii because of the wide range of tensile strengths and hardness ranges in each temper designation.

Brass

Brass is an alloy of copper and zinc at approximately 60-70% Cu and 30-40% Zn content, with minor amounts of other elements such as lead, depending on the alloy. (Bronze is copper and tin). See Table XVIII. Brass is a work hardened material only, and is available in annealed through extra spring tempers. Up to 1/2-hard, brass can normally be formed with and against the grain at 0° inside radius and up to 0.040 in. (1.02 mm) thick without cracking.

Table XVII illustrates the minimum bend radius in the various tempers. Caution must be exercised when specifying minimum bend radii because of the wide range of tensile strengths and hardness ranges in each temper designation.

Phosphor Bronze

Phosphor bronze is a copper (Cu), tin (Sn) and phosphor (P) alloy, not heat-treat hardenable, but routinely used for its very good spring characteristics in its as-rolled, strain hardened

Table XV. CA-110 Copper Formability Chart

Temper Tensile Hardness	Description of Material Condition & Capability	Material Thickness		Angle figures show the relationship between the bendline and material grain direction.					
				0°		45°		90°	
				Minimum inside form radii required.*					
		in.	mm	in.	mm	in.	mm	in.	mm
Soft 22,000 psi 22 RB max.	Best cold forming and drawing qualities of all metals.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
1/4 hard 25,000 psi 28 RB max.	Excellent cold forming qualities with improved wear and stiffness.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0.015 0.015 0.015 0.015	0 0.4 0.4 0.4 0.4	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
1/2 hard 26,000 psi 42 RB max.	Good cold forming quality with moderate springiness.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.015 0.015 0.030 0.030 0.050	0.4 0.4 0.8 0.8 1.3	0 0 0.015 0.015 0.015	0 0 0.4 0.4 0.4	0 0 0.015 0.015 0.015	0 0 0.4 0.4 0.4
Full hard 28,000 psi 66 RB max.	Stiff, springy with moderately reduced formability.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.050 0.050 0.080 0.080 0.090	1.3 1.3 2.0 2.0 2.3	0.030 0.030 0.050 0.050 0.060	0.8 0.8 1.3 1.3 1.5	0.030 0.030 0.050 0.050 0.060	0.8 0.8 1.3 1.3 1.5

*Recommended minimum bend radii for four tempers of copper, along with tensile and hardness information. Bends are oriented at 0°, 45° and 90° to grain direction with the burr inside. *Minimum bend radii for other unalloyed coppers are similar to those values shown above.*

Table XVI. Common Alloys of Brass

	Common Alloys	
CA 260	70% Cu 30% Zn	Most common, also used when unspecified. called cartridge brass.
CA 230	85% Cu 15% Zn	Red brass, most often specified for contacts, etc.
CA 353	62% Cu 36% Zn +2% Pb	High leaded brass for stamping use where subsequent machining or engraving is required.
CA 360	61.5% Cu 35.5% Zn +3% Pb	Free machining brass.
CA 360 is included here since it is often used to produce hardware because of its good machinability. Unannealed it cannot be riveted or staked without cracking and splitting.		

condition. Conditions available are listed in Table XIX.

Tensile strengths given in Table XIX are specific to alloy 510, but represent a close approximation for all four alloys listed below. Because of the high 10% tolerance in tensile strength, adjacent tempers can overlap in actual material strength. For example, one lot of ½-hard material may be the same tensile strength or even slightly higher, than the next lot designated ¾-hard.

Caution is advised when specifying sharply formed parts and sample bends should be performed before specifying the material for production. Inconsistent tempers cause springback problems to occur when large radii forms are required. Experimentation is recommended to confirm manufacturability. Phosphor bronze is used instead of beryllium copper in many applications for economical reasons.

Table XIX illustrates the minimum bend radius in the various tempers for phosphor bronze. Caution must be exercised when specifying minimum bend radii because of the wide range of tensile strengths and hardness ranges in each temper designation.

Beryllium Copper

Beryllium copper (Be-Cu) is the most conductive, non-steel, spring material available. It combines its very high electric conductivity and superb elastic limits with fatigue and good heat resistance. Beryllium copper is a hazardous chemical and skin and eye contact should be prevented. Material cost of beryllium copper is the highest of the copper alloys.

Common beryllium copper alloys include:

CA 170—1.6-1.79% Be .20% min. Co + Ni, Rest Cu.

CA 172—1.8-2.0% Be .20% min. Co + Ni, Rest Cu.

CA 175—0.4-0.7% Be 2.4-2.7% Co, Rest Cu.

Material is available in both strip and coil, with stamped parts produced from coil being the bulk of production. See Table XXI. BeCu is available in seven mill hardened tempers from annealed through extra-hard spring. As with all materials, formability becomes progressively more limited with increasing hardness. Parts to be heat treated are best made from annealed stock because of unlimited formability.

Table XXI illustrates the minimum bend radius in the various tempers of beryllium copper. Caution must be exercised when specifying minimum bend radii because of the wide range

Table XVII. Tensile Properties for Several Tempers of 510 Phosphor Bronze

1/4 hard @	50 KSI* tensile average ± 10%
1/2 hard @	65 KSI tensile average ± 10%
3/4 hard @	73 KSI tensile average ± 10%
hard @	83 KSI tensile average ± 10%
xtra hard @	95 KSI tensile average ± 10%
spring @	102 KSI tensile average ± 10%
xtra spring @	107 KSI tensile average ± 10%
super spring @	110 KSI tensile average ± 10%

*(KSI = 1000 lbs per in^2)

common alloys		
CA 505	98% Cu	1.25% Sn 0.1% P
CA 510	94% Cu	5.0% Sn 0.1% P
CA 511	95.9% Cu	4.0% Sn 0.1% P
CA 521	91.9% Cu	8.0% Sn 0.1% P

Table XVIII. CA-260 Brass Formability Chart

Temper Tensile Hardness	Description of Material Condition & Capability	Material Thickness		Angle figures show the relationship between the bendline and material grain direction.					
				0°		45°		90°	
				Minimum inside form radii required.					
		in.	mm	in.	mm	in.	mm	in.	mm
Soft 48,000 psi 55 RB max.	Excellent cold forming, drawing and coining properties.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
1/4 hard 54,000 psi 66 RB max.	Very good cold forming qualities with combined limited spring quality.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.015 0.015 0.015 0.015 0.030	0.4 0.4 0.4 0.4 0.8	0 0 0 0 0.015	0 0 0 0 0.4	0 0 0 0 0.015	0 0 0 0 0.4
1/2 hard 62,000 psi 85 RB max.	Good cold forming, but limited draw qualities with very good springiness for contact use.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.015 0.015 0.030 0.030 0.050	0.4 0.4 0.8 0.8 1.3	0.015 0.015 0.015 0.015 0.030	0.4 0.4 0.4 0.4 0.8	0.015 0.015 0.015 0.015 0.030	0.4 0.4 0.4 0.4 0.8
Hard 76,000 psi 89 RB max.	Stiff, limited forming possible with excellent springiness for contacts and snap-action.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.060 0.060 0.090 0.140 0.190	1.5 1.5 2.3 3.6 4.8	0.030 0.030 0.060 0.080 0.110	0.8 0.8 1.5 2.0 2.8	0.030 0.030 0.060 0.080 0.090	0.8 0.8 1.5 2.0 2.3
Spring 94,000 psi 93 RB max.	Very stiff widely used for springs, contacts, etc.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.280 0.280 0.310 0.380 0.530	7.1 7.1 7.9 9.7 13.5	0.250 0.250 0.280 0.310 0.380	6.4 6.4 7.1 7.9 9.7	0.250 0.250 0.280 0.310 0.380	6.4 6.4 7.1 7.9 9.7

Recommended minimum bend radii for five tempers of brass, along with tensile and hardness information. Bends are oriented at 0°, 45° and 90° to grain direction. Alloy CA-260 was chosen for this chart, because it represents about 90% of all brass used in sheet and coil form.

of tensile strengths and hardness ranges in each temper designation. See Table XXII for mechanical and physical properties.

• **Heat Treating.** Be-Cu is precipitation hardenable and reaches 42 RC hardness with a two-hour heat cycle at 600°F from the annealed condition. To retain the integrity of shapes, heat treating intricately formed, thin parts is accomplished economically by encasing them in clean sand, to retard movement.

For very critical shape retention it may be necessary to make and use metal fixtures. This costly option can be avoided by prudent design practices. Shrinkage of 0.3% (0.003 in./in.) (0.07 cm/25.4 mm) occurs during heat treating and must be compensated for.

Oxidation scale from the heat cycle is best removed through vibratory finishing with the

Table XIX. Phosphor Bronze Formability Chart

Temper Tensile Hardness	Description of Material Condition & Capability	Material Thickness		Angle figures show the relationship between the bendline and material grain direction.					
				0°		45°		90°	
				Minimum inside form radii required.					
		in.	mm	in.	mm	in.	mm	in	mm
Soft 45,000 psi 56 RB max.	Excellent forming qualities; limited spring action; forms well along the grain.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0 0.015 0.015 0.015	0 0 0.4 0.4 0.4	0 0 0 0.015 0.015	0 0 0 0.4 0.4	0 0 0 0.015 0.015	0 0 0 0.4 0.4
1/2 hard 61,000 psi 86 RB max.	Good spring action, grain sensitive in forming. Note difference in radius in 0° and 90° to grain.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.060 0.120 0.220 0.310 0.380	1.5 3.0 5.6 7.9 9.5	0.050 0.080 0.090 0.160 0.220	1.3 2.0 2.3 4.1 5.6	0.050 0.080 0.090 0.160 0.220	1.2 2.0 2.3 4.1 5.6
Extra hard 78,000 psi 90 RB max.	Very good spring, forming same as above applies. Contact and spring use.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.140 0.160 0.280 0.380 0.620	3.5 4.0 7.1 9.5 15.7	0.120 0.120 0.160 0.280 0.340	3.0 3.0 4.1 7.1 8.7	0.120 0.120 0.160 0.250 0.310	3.0 3.0 4.1 6.3 7.9
Spring 87,000 psi 98 RB max.	Enduring spring material with forming limited by spring-back; contact and spring use.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.250 0.310 0.410 0.500 0.750	6.4 7.9 10.3 12.7 19.0	0.190 0.190 0.310 0.340 0.440	4.8 4.8 7.9 8.7 11.2	0.190 0.190 0.280 0.310 0.410	4.8 4.8 7.1 7.9 10.4
Extra spring 90,000 psi 52 RC max.	Extremely stiff, limited formability; contact and spring use.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.380 0.410 0.750 0.880 1.500	9.7 10.4 19.0 22.3 38.1	0.250 0.250 0.500 0.750 1.000	6.3 6.3 12.7 19.0 25.4	0.250 0.250 0.410 0.750 0.880	6.3 6.3 10.4 19.0 22.3

Recommended minimum bend radii for five tempers of phosphor bronze, along with tensile and hardness information. Bends are oriented at 0°, 45° and 90° to grain direction with the burr inside.

addition of an acidic brightener. This treatment also prepares the parts properly for plating.

• **Plating.** Special caution is indicated when specifying the thickness of nickel plating for Be-Cu parts. Best adhesion of the plating is achieved by a thickness not exceeding 0.0002 in. Preferred is from 0.0005 to 0.0001 in. (five to one tenthousandths of an inch) only, because the thinner nickel coating conforms better to the spring movements of the Be-Cu part.

High Nickel Alloys

Among the hundreds of specialty alloys used in the industry for specific purposes, the nickel based alloys are probably the most often encountered for stamping production. Table XXIV is a condensed guide to the most frequently used alloys.

The most prominent feature of nickel is its high ductility and resulting toughness. Nickel also work hardens very quickly, leading to early fail-

Table XX. Strip availability

Alloy	Thickness (in.)	Width (in.)
CA- 170 172 175	0.001 to 0.005 (0.03 to 0.13 mm) 0.005 to 0.010 (0.13 to 0.25 mm) 0.010 to 0.025 (0.25 to 0.64 mm) 0.025 to 0.040 (0.64 to 1.02 mm) 0.040 to 0.060 (1.02 to 1.53 mm) 0.060 to 0.090 (1.53 to 2.29 mm) 0.090 to 0.125 (2.29 to 3.18 mm) 0.125 to 0.188 (3.18 to 4.78 mm)	0.0625-6 (1.59 - 152.4 mm) 0.0625-8 (1.59 - 203.2 mm) 0.125-12 (3.18 - 304.8 mm) 0.187-12 (4.75 - 304.8 mm) 0.250-12 (6.35 - 304.8 mm) 0.375-12 (9.53 - 304.8 mm) 0.500-12 (12.7 - 304.8 mm) 1.0-12 (25.4 - 304.8 mm)

Widths and thicknesses available in three grades of beryllium copper strips.

Table XXI. Beryllium Copper, Alloy 172 Formability Chart

Temper Tensile Hardness	Description of Material Condition & Capability	Material Thickness		Angle figures show the relationship between the bendline and material grain direction.					
				0°		45°		90°	
				Minimum inside form radii required.					
		in.	mm	in.	mm	in.	mm	in.	mm
Soft 46,000 psi 60 RB max.	Best quality for deep drawing and complicated forms. Heat treating required for spring use.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0 0.015 0.015 0.030 0.030	0 0.4 0.4 0.8 0.8	0 0 0 0.015 0.015	0 0 0 0.4 0.4	0 0 0 0.015 0.015	0 0 0 0.4 0.4
1/4 hard 53,000 psi 79 RB max.	Some reduction in formability, gains higher strength after heat treatment.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.015 0.015 0.030 0.030 0.050	0.4 0.4 0.8 0.8 1.3	0.015 0.015 0.015 0.015 0.030	0.4 0.4 0.4 0.4 0.8	0 0.015 0.015 0.015 0.030	0 0.4 0.4 0.4 0.8
1/2 hard 60,000 psi 92 RB max.	Limited formability. Mostly used without heat treating for spring use where good conductivity is a prerequisite.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.030 0.030 0.050 0.060 0.080	0.8 0.8 1.3 1.5 2.0	0.015 0.015 0.030 0.050 0.050	0.4 0.4 0.8 1.3 1.3	0 0.015 0.030 0.050 0.050	0 0.4 0.8 1.3 1.3
Hard 72,000 psi 100 RB max.	Highest mechanical strength with very limited formability. Best for high performance flat springs.	0.015 0.030 0.060 0.090 0.120	0.4 0.8 1.5 2.3 3.0	0.090 0.190 0.310 0.380 0.500	2.3 4.8 7.9 9.7 12.7	0.030 0.080 0.250 0.340 0.400	0.8 2.0 6.3 8.6 10.2	0.030 0.060 0.220 0.310 0.380	0.8 1.5 5.6 7.9 9.7

Recommended minimum bend radii for four tempers of beryllium copper, along with tensile and hardness information. Bends are oriented at 0°, 45° and 90° to grain direction with the burr inside. The cold worked tempers gain progressively in final tensile strength when heat treated, but the forming limitations and severe cost increase must be factored into the selection.

Table XXII. Mechanical & Physical Properties of Beryllium Copper

Strip Alloy	Temper	Precipitation Hardening Treatment °F	Tensile Strength ksi	Yield Strength 0.2% offset ksi	Proportional Limit ksi	Elongation in 2 in. %	Rockwell Hardness		Electrical Conductivity LACS, % (minimum)
							B or C scale	Superficial	
CA 172	a	—	60-78	28-60	15-40	35-60	B 45-78	30T 46-69	47
	age hardenable 1/4 h	—	75-88	60-80	40-60	15-40	B 68-90	30T 82-76	16
	1/2 h	—	85-100	75-95	55-70	5-25	B 88-96	30T 75-80	15
	h	—	100-120	95-112	70-85	2-6	B 96-102	30T 80-83	15
	at	3 hr at 600	165-190	140-170	100-125	3-10	C 36-41	30N 56-61	22
	after 1/4 ht	2 hr at 600	175-200	150-180	110-135	2 1/2-6	C 38-42	30N 58-62	22
	age 1/2 ht	2 hr at 600	185-210	160-190	120-145	1-5	C 39-44	30N 59-63	22
	hardening ht	2 hr at 600	190-215	185-195	125-155	1-3	C 40-45	30N 60-64	22
	am	—	100-110	70-90	55-70	18-23	C 18-23	30N 37-44	20
	1/4 hm	—	110-120	80-100	65-80	15-20	C 21-26	30N 42-47	20
	mill 1/2 hm	—	120-135	95-115	75-95	12-18	C 25-30	30N 46-51	20
	hardened hm	—	135-150	110-135	85-105	9-15	C 30-35	30N 51-55	20
	xhm	—	160-175	135-160	100-125	6-12	C 35-39	30N 55-59	20
	xhms	—	175-190	150-170	110-130	3-9	C 37-41	30N 57-61	20
	a	—	60-78	28-60	15-40	35-60	B 45-78	30T 46-69	17
	age 1/4h	—	75-88	60-80	40-60	15-40	B 68-90	30T 62-76	16
	hardenable 1/2 h	—	85-100	75-90	55-70	5-25	B 88-96	30T 75-80	15
	h	—	100-120	95-112	70-85	2-8	B 96-102	30T 80-83	15
CA 170	at	3 hr at 600	150-180	130-160	85-115	3-12	C 33-38	30N 53-58	22
	after 1/4 ht	2 hr at 600	160-185	135-165	95-120	2 1/2-8	C 35-39	30N 55-59	22
	age 1/2 ht	2 hr at 600	170-195	145-175	105-130	1-6	C 37-40	30N 57-60	22
	hardening ht	2 hr at 600	180-200	155-185	110-140	1-5	C 39-41	30N 59-61	22
	am	—	100-110	70-90	50-70	18-23	C 18-23	30N 37-44	20
	1/4 hm	—	110-120	80-100	60-80	15-20	C 21-26	30N 42-47	20
	mill 1/2 hm	—	120-135	95-115	70-95	12-18	C 25-30	30N 46-51	20
	hardened hm	—	135-150	110-135	80-105	9-15	C 30-35	30N 51-55	20
	xhm	—	160-175	135-160	100-125	6-12	C 35-39	30N 55-59	20
CA 175	a	—	55 max.	20-30	10-20	20-35	B 20-45	30T 29-46	20
	age 1/2 h	—	60-75	50-70	30-50	5-10	B 65-76	30T 60-68	20
	hardenable h	—	70-85	60-80	40-60	2-8	B 78-88	30T 69-75	25
	at	3 hr at 900	100-120	80-100	60-80	8-15	B 92-100	30T 78-82	45
	after 1/2 ht	2 hr at 900	110-130	95-120	70-90	5-12	B 95-102	30T 79-83	45
	age ht	2 hr at 900	110-130	100-120	75-95	5-12	B 95 1-2	30T 79-83	48
	hardening htc	mill hardened	75-90	50-75	30-60	5-15	B 78-88	30T 69-75	60
	htr	mill hardened	120-150	110-140	80-110	1-5	B 97-104	30T 80-84	48

Table XXIII. Characteristics of Common Nickel Alloys

Commercial Nickel Alloys	
monel 400	a 66.5% Ni & 31.5% Cu alloy. Highly resistant to atmospheric corrosion and petroleum products. Used for heat exchangers, water meter parts, etc.
nickel 200	99% Ni. Used for food processing equipment and chemical hardware.
duranickel 301	93% Ni, 4% Al, 1% Si. Springs, clips, diaphragms for high temperature applications.
inconel & incoloy alloys	of various high Ni content. Used for jet engine, furnace, burner and nozzle parts. These alloys are known for their high heat resistance.
mu-metal	proprietory alloy. Has electronic industry uses for magnetic sensor applications and shielding. Very stress sensitive. Needs heat treating after any cold working to restore the magnetic properties.

ure of cutting tools such as countersinks or taps. For this reason, it is a good practice to design for coining and forming, rather than cutting, such features as countersinks, spotfaces, threads, etc.

Extreme ductility is also the reason that high nickel alloys develop relatively large and sharp burrs in stamping. In design, this tendency for sharp burrs must be addressed and provided for. Where mechanical burr removal is not practical, hemming may be necessary to render an edge safe to handle.

4

THE SHEARING PROCESS

The use of shears in sheet metal production has diminished through the use of cut-off tooling in CNC punching and the use of shake-out technology to separate parts from the sheet skeleton. Shears are mainly used for shearing rectangles or strips for stamping and CNC press dies.

In those cases where shearing is used to achieve final dimensions, the thickness of the material and the X-Y dimension of the part dictate the degree of precision which is feasible economically. Thicker material and greater X-Y dimensions require more generous tolerances.

In the broad range of sheet metal production, material thicknesses vary from 0.005 in. (0.13 mm) to 0.25 in. (6.35 mm) in ferrous and non ferrous materials. Shearing equipment varies, accordingly, from ¼ in. (6.0 mm) capacity x 12 ft. (3.5 m) bed length to tiny hand operated shears with a 0.030 in. (0.8 mm) capacity and a 12 in. (300 mm) blade length.

In the X-Y dimension a tolerance of ±0.060 in. (1.52 mm) is used for thicker material and ±0.010 in. (0.26 mm) for thinner material. It is advisable to consult your metalforming supplier for the capabilities of available equipment.

Nature of Cut Edges

Whenever sheet metal is cut, whether by punches and dies, shear or slitters, the characteristics of the cut edges are similar (Figure 1).

Cutting action takes place in three stages as the cutting edge moves through the material: initial plastic deformation, penetration, and

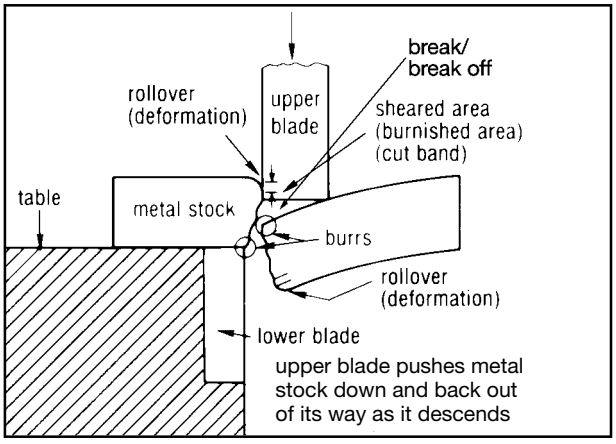


Figure 1. Characteristics of cut edges.

fracture. During initial plastic deformation, the "edge radius" or "roll over" is formed. During penetration, the "cut band" or "burnish" is created. And during fracture, the "break" or "break-off" and the burr are developed.

Shears and other metal cutting devices are normally maintained and adjusted to provide acceptable cut quality with nominal burrs and to limit wear on tooling and equipment. This produces a cut in which penetration occurs to a depth of approximately ⅓ of the material thickness and fracture occurs through the remaining material. Proper adjustment generates a burr which seldom exceeds 10% of the material thickness.

Equipment Characteristics

A wide variety of power shearing equipment is in use. Major machine elements common to most shears include the frame assembly, bed, table, ram, hold-down devices, gauges, the activating mechanism and the blades (Figure 2). Hold-down devices, arranged along the bed near the blade, engage the stock and clamp it firmly in position for shearing.

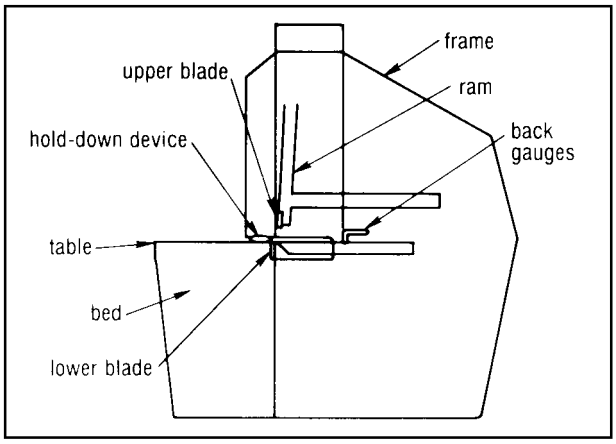


Figure 2. Machine elements common to most shears.

Back gauges serve to position the stock under the moving blade at a predetermined dimension. They may range from simple, positive, mechanical stops to a series of probes (proximity switches) which sense the stock and activate the machine when more than one are contacted simultaneously. Depending on type and sophistication, back gauges may be set manually or programmed.

Front gauges are often used to position the stock, especially when large workpieces are involved. They may be either mechanical or programmable.

Side gauges, also known as "squaring arms," are mounted perpendicular to the blade on either the left or right side of the bed, and assist in guiding and squaring the stock to the blade.

Operation

Regardless of construction, size or speed, all power shears operate similarly. A sheet of stock is advanced on the table until the back gauges are contacted and the line of cut is beneath the blade (Figure 3). When the machine is activated, the hold-down devices clamp the stock and the angled moving blade cuts progressively across the sheet in a guillotine-like action.

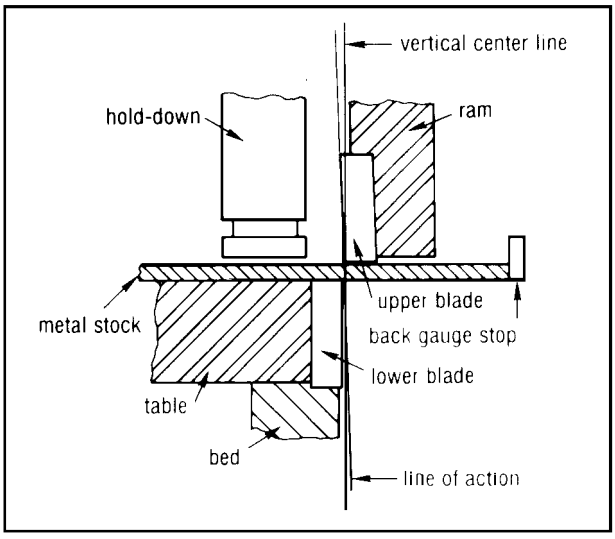


Figure 3. Shear operation

Depending on the application, power shears may be fed from the front or the back. Back feeding can reduce handling of the stock for subsequent cuts, but requires an additional operator.

Maintaining Quality

Important quality checks are performed during the shearing operation. Factors of quality control include the initial flatness of the stock, general surface and edge condition. Surface flaws and skid marks are common on coil and sheet products and are generally acceptable to the manufacturer unless such marks would cause cosmetic rejection of the finished product. Delamination, surface inclusions and other severe defects in the material may also be identified and are cause for rejection.

Design Considerations

For economical production the knowledgeable designer recognizes several aspects affecting costs and quality during shearing and in subsequent operations. Following are several such product design considerations.

• **Material Utilization.** Material suppliers generally make sheet stock available in standard sizes—widths of 30, 36, 48 and 60 inches. Significant savings can result from the effective use of these standard sizes by avoiding charges for extra slitting or mill preparation.

Early consultation with the metalformer may permit modifying the dimensions of unseen flanges on the product to achieve an overall part layout somewhat smaller than the standard sheet size. This can avoid extra costs and reduce waste.

• **Grain Direction.** Grain direction in flat rolled stock (lengthwise in the coil) is not always a significant consideration. However, in some operations such as forming and bending, grain orientation can be important.

On very large parts which have formed flanges or features, the designer should consult a qualified supplier prior to specifying the grain orientation and bend radius to determine if material size limitations will permit the formed features to be across the grain. This subject is explored in more detail in the chapters on Press Brake Forming and Stamping Production.

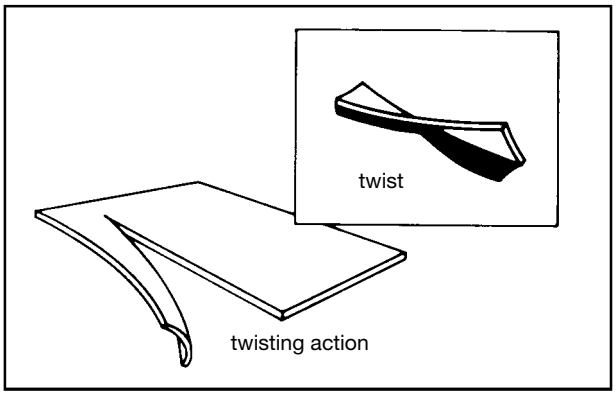


Figure 4. Twist characteristics of the shearing process.

• **Process Characteristics.** Burrs, holddown marks and twist (Figure 4) are characteristics of the shearing process.

Burrs are present after shearing (as in any metal cutting operation) and are normally controlled within acceptable limits through proper shearing practices.

Hold-down marks, appearing as slight indentations along one side of the sheared edge of the workpiece, sometimes result from the clamping action of the hold-downs. These marks are seldom a problem. They may often be accommodated as part of an unseen flange in the final product, or may be eliminated entirely during trimming in later operations.

In critical applications, coverings on the hold-downs may be used to protect the stock. Materials with removable protective coatings are sometimes used to help reduce holddown marks and scratches that are inherent in the shearing process. These alternatives will add considerable additional cost.

Twist, a spiral-like curvature of the material occurs when shearing narrow strips. It is caused by the scissors action of the shear and is influenced by the relationship of the width sheared to the thickness and temper of the strip. Twist is seldom an important consideration except when shearing narrow strips. When a job requires very narrow strips, roller slit coil material, (if order is of sufficient quantity) or bar stock can often be substituted.

5

DESIGNING FOR CNC TURRET AND LASER FABRICATION

Turret presses, also known as CNC punch presses, are particularly suited for low to medium quantity production runs. CNC presses are the work horse for "soft-tooled" manufacturing. The versatility and speed of these presses are constantly being improved, therefore increasing their viability as an economic alternative to traditional stamping practices.

Equipment Characteristics

Machines are constructed with either a C-frame or a bridge frame design. See Figure 1. CNC presses vary considerably in size and speed. The smallest, and therefore least versatile of the group are those with 20 or fewer tools in the turret, 20 tons or less of press capacity and table size of 40 in. (1 m) square or less.

Intermediate-sized units may carry up to 60 tools, have up to 30 ton press capacity, and usually use a table of up to 80 in. square. Larger machines carry as many as 72 tools, provide up to 50 tons of capacity, and feature table sizes as large as 80 in. x 80 in. and above.

Operational speeds range from 80 to about 400 hits per minute (hpm). This rating is based on the one-inch movement of workpiece material between each "hit" or workstroke.

Operation

Regardless of construction, size or speed, all turret presses operate similarly. See Figure 2. A sheet of workpiece material, gripped at the edges by workholders, is moved across the table into position between the upper and lower portions of the turret by action of two precision lead screws (one in the X axis, the other in the Y axis). Meanwhile, the turret rotates until the appropriate punch and die set is in place.

With the turret pinned in position to assure precise alignment, the program activates the ram, pushing the punch through the workpiece. After the punch is withdrawn, the machine is

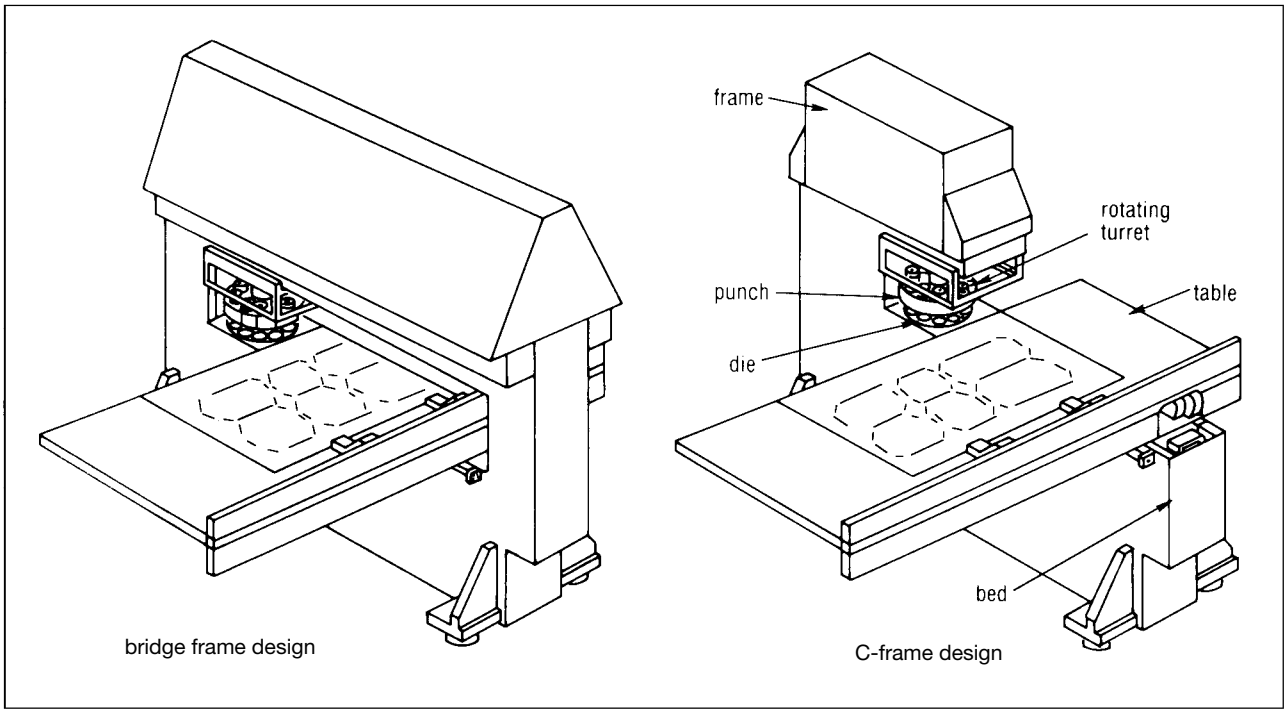


Figure 1. Typical turret press designs.

ready to prepare for the next hit.

Some turret presses are constructed so that the crankshaft is used to both depress and withdraw the tool. In this situation, urethane strippers surrounding the punch are used to hold down the workpiece during movement of the tool.

Other machines are designed to withdraw the tool by spring action rather than with the ram. This requires a separate punch holder and allows for strippers of metal rather than urethane. Metal strippers can hold the workpiece more securely, particularly during forming operations.

Advantages and Limitations

The CNC press couples the unique advantage of flexible, low production with standardized tooling.

Because of the nature of the process, it is possible to make rapid changes in part configuration, and to make them "on paper" before committing them to metal. In effect, the designer has the unique opportunity of doing design development during initial phases of production.

A related advantage is the fact that lead time from the completion of design to the production of parts can be extremely short using CNC turret press technology.

Larger production quantities are also economically run in the CNC turret press in many cases. When automatic loading and unloading equipment is employed, long periods of economical, unattended operation are possible, but sweeping generalizations regarding length of run are often misleading.

At the beginning of a project many knowledgeable designers take advantage of the quick, low-cost, flexible design opportunities inherent in the CNC turret press, then evolve into more sophisticated and costly tooling as the increasing quantities warrant.

The exact quantity level at which special tooling becomes more cost effective depends on many variables, but in most cases involves

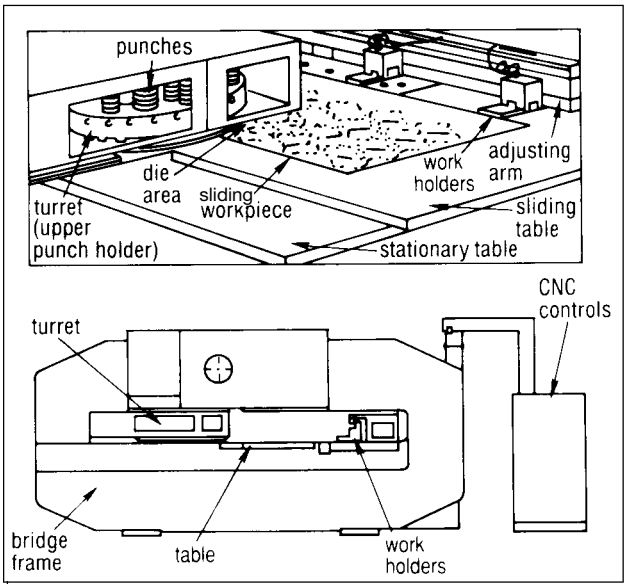


Figure 2. (Top) In this closeup a workpiece is gripped across the table into position between the upper and lower portions of the turret. The turret rotates to select and position the proper punch and die set. (Bottom) A view of the relationship of the turret table and workholders.

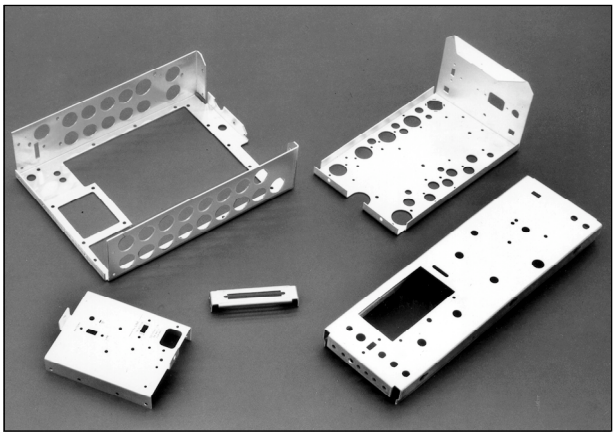


Figure 3. Sample parts produced on a turret press.

several thousands of parts. In general, parts with highly irregular outer contours or large central holes—which require long machine operating time for the turret press—reach the cross-over point for dedicated or "hard" tools at relatively lower quantities.

Certain design features make the CNC press a candidate for higher quantity production runs. For example, tightly spaced hole patterns and louvers as commonly used for ventilation purposes, could require the use of two or even three progressive stations in a hard tool die to space the openings—at considerable added cost. This added tooling cost gives the CNC press its economical quantity advantage in this example.

Another advantage of CNC press production is the extraordinary design flexibility in configuration and size of features within the part. See Figure 3 for sample parts. Machines, especially models with indexable tool stations, make the nibbling of very large and complex features practical.

Nibbling, compared to processing with a single punch or special tool, has limitations regarding precision which the designer should keep in mind. See Figures 4 and 8 for examples of nibble marks under high magnification.

Extreme flexibility of over-all part size is another advantage of CNC press production. In practical terms, the throat depth of the machine limits the over-all part dimension in the Y direction of the machine, although it is possible to reposition the part in the X direction during processing to produce a greater length. (Since each repositioning requires additional tolerance, only one repositioning per part is generally recommended.)

Standard and Special Tooling

The opportunity to improve part appearance and precision with inexpensive special tools in the turret press is sometimes overlooked. Particularly where nonstandard shapes and features are concerned the manufacturer is likely to recommend the selective use of specially shaped tools. Special tools, properly designed and used, can significantly improve dimensional control while reducing burrs and enhancing feature appearance. See example of special tooling in Figure 5.

Forming Operations

In addition to selective perforation and louvering, CNC presses are capable of forming a variety of features in an otherwise flat blank. Circuit card guide slots and recesses, embosses, coined reliefs, countersinks, lanced and formed tabs and small features, nibble-formed stiffening ribs and pierced, formed and hemmed cable path openings are all economically produced using CNC press technology. Certain guidelines must be followed when specifying these features:

• **Height.** The feature height may not exceed the clearance between the top and bottom turret—generally 0.350 in. (9 mm).

• **Sequences.** Formed features must generally be completed last. Thus pierced areas which are within or immediately adjacent to the formed feature may be deformed as a result of metal stretching during the forming operation.

• **Flatness.** Large formed areas and nibble-formed stiffening ribs may create flatness problems because, unlike dedicated tooling, there is usually not sufficient hold down pressure to keep the metal from creeping around the form.

• **Coining.** Coined areas will be limited by the tonnage of the press.

• **Burrs**. Formed features on a CNC part sometimes preclude machine deburring of the part. In addition, the formed features are produced "up" (formed toward the top of the part as it is clamped in the press) while the burr side is "down." This can be a key consideration when designing for the use of inserts and in other situations where burr direction is important.

• **Tapping**. Holes can be tapped in the turret press by roll forming the threads. This is achieved through the installation of a tapping station in the turret press. Speeds can be as high as 200 tapped holes per minute. Maximum material thickness is a function of pitch and material hardness with 12 ga as the thickest. Some materials such as high carbon, spring steel and high nickel alloys cannot be tapped due to hardness and type of machine. Materials recommended are mild steel, aluminum, brass and copper. Pitch sizes are 80 to 24 (#0 M to #.80 M)

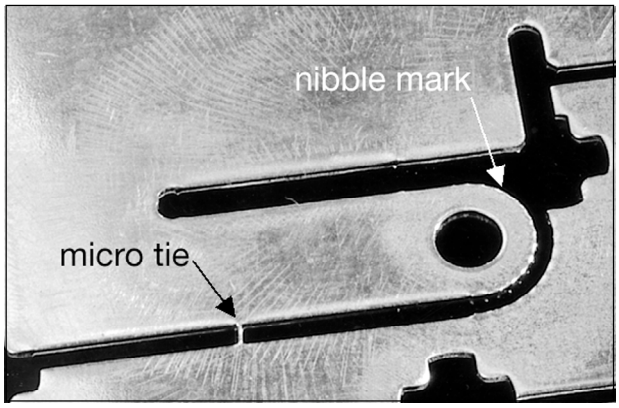


Figure 4. Close up of nibble marks and micro ties.

Design Considerations

The size, type and availability of formed features is virtually limitless. Your precision fabricator can assist you in design, tooling and specification to fully utilize this unique machine capability.

As in any manufacturing situation, there are process characteristics associated with turret press production which the experienced designer keeps in mind and takes advantage of during product design. Following are some of the potentially significant design considerations.

• **Time and Material Utilization**. To optimize processing time and material utilization, it is common for parts to be ganged or nested during turret press production. Several parts within the workpiece sheet may be held together during punching by tiny webs or bridges known as "micro ties" which are allowed to remain after punching is completed. See Figure 4.

After punching, the sheet is agitated and the individual parts break apart and are stacked,

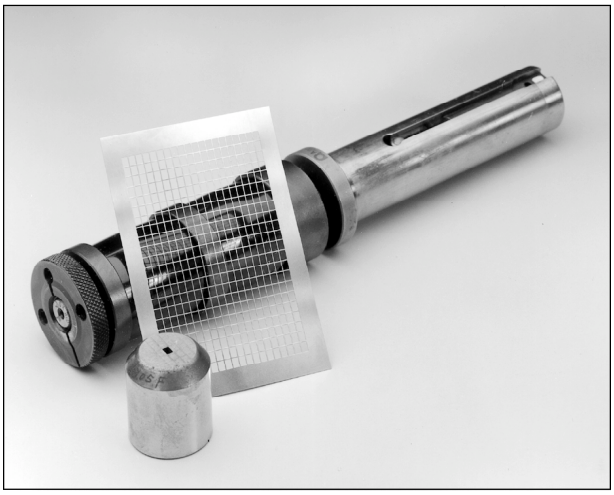


Figure 5. Example of special tooling (punch and die) for CNC turret press production.

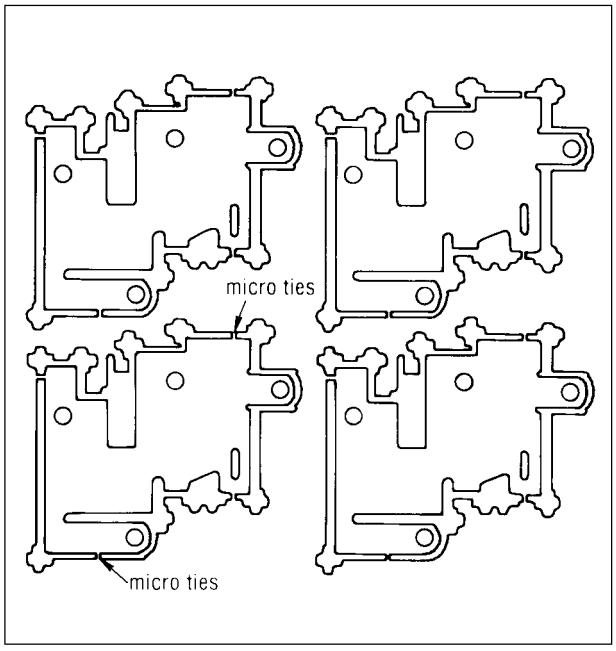


Figure 6. Example of "shaker parts" or "shake aparts."

ready for further processing, without having to be cut apart in a separate operation. The parts are therefore known as "shaker parts" or "shake aparts." See Figure 6.

The designer should be aware of the tiny burr which may remain on the perimeter of the part at the point where the micro tie is broken. Advance consultation on the location and disposition of these burrs can avoid potential subsequent problems.

• **Burr Direction.** A burr, no matter how small it may be, inevitably is formed when a punch pierces sheet metal. In pierced features the burr occurs on the side of the part opposite where the punch enters. See Figure 7.

Burr direction is important to the knowledgeable designer because it may be possible to plan the product so that the burr side of the part can be completely concealed—safely hidden from the user.

The experienced designer also takes into account the fact that clinch hardware is more reliably staked from the burr side of the part, rather than the punch side, and plans the development of the part accordingly.

• **Flatness.** The flatness of a workpiece is unavoidably affected by stresses induced and released during punching operations. Generally speaking, the more punching performed on the workpiece, the more bow or "oil canning" distortion is generated. Designs involving closely spaced hole patterns are subject to flatness distortions.

Greater flatness can be achieved, at additional expense, through subsequent leveling operations.

In many cases the designer will have a definite preference for which side of the workpiece should contain any bow distortion (positive or negative), and can specify accordingly—allowing the manufacturer to process the workpiece from the appropriate side.

• **Edge Conditions.** Certain edges of parts processed in a CNC press may exhibit characteristics of interest to the designer, particularly where nibbling is involved.

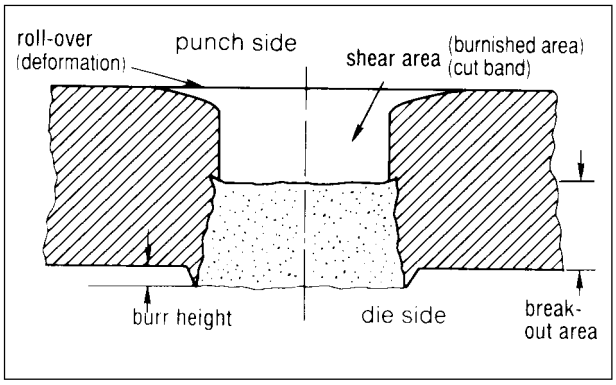


Figure 7. The normal metal deformation created by a piercing operation.

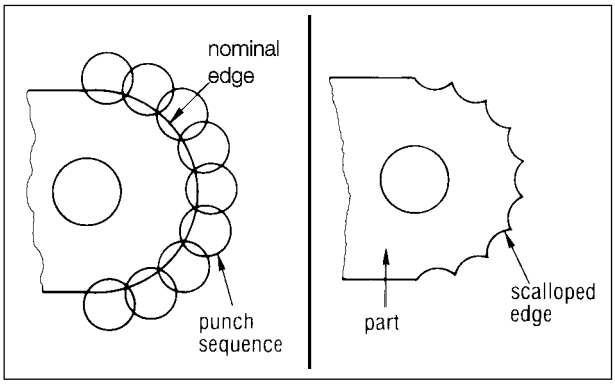


Figure 8. Example of scalloping.

The overlapping of the punch during nibbling operations inevitably leaves characteristic markings on the edge of the nibbled feature. These marks are primarily of cosmetic interest, and are often not measurable.

If the presence of nibble marks are an important cosmetic concern, the designer may wish to consider special tooling to eliminate the condition.

"Scalloping" is a condition where the nibble marks become exaggerated and protrude to the point that they are measurable. See Figure 8. Scalloping sometimes occurs in a location where it can be accepted by the customer. If it is objectionable, special tooling may avoid the need for nibbling, and should be considered.

Obviously, it is especially important that questions regarding these edge conditions be discussed early in the design process, and that agreement between customer and supplier be reached in advance of production.

Likewise, "breakout," which occurs normally on all punched edges, can become a significant factor in thicker materials and should be treated accordingly. See Figure 7. For material thickness of 0.075 in. (1.9 mm) and greater, the effects of breakout should be discussed wherever hole diameters are critical or clinch hardware is to be inserted.

• **Clamp Marks.** Small indentations along the outer edge of one side of the workpiece may result from the gripping action of the workholders. These clamp marks are seldom a problem, and may be eliminated entirely by positioning the part in the workpiece sheet so that the perimeter, containing the marks, is cut away and discarded after processing.

• **Feature Location.** While specific requirements must dictate the details of part design, there are two general guidelines regarding the positioning of features which experienced designers often find useful:

1. Avoid placing holes and other features unnecessarily close to one another. Narrow webs can produce flatness problems and twisting of the material. (See Chapter 7).

2. Avoid requirements for inserting clinch hardware in holes too near the edge of the part. And, for economy, design for all clinch hardware to be inserted from one side of the part. (See Chapter 15).

Dimensioning Practices

If there is a single area where the designer can accomplish the greatest benefit, it is perhaps in communicating effectively with the supplier, using appropriate detailing practices on

drawings. Following are a few basic guidelines which can make an enormous difference:

• Select a meaningful datum in the body of the part—passing through hole centers, if possible—rather than using an edge or corner of the part. (See Dimensioning Practices in the Press Brake Chapter). There are several reasons for this suggestion.

It avoids problems of possible misalignment of the part, distortion from clamping, etc. It allows for more precise measurement by avoiding measurements from edges which may be tapered and therefore dimensionally uncertain. It facilitates accurate inspection. And, it avoids unnecessary accumulation of tolerances.

• On related hole patterns, dimensioning and tolerances should be within this pattern with only one dimension linking to the general datum. Better quality control and function of the product can be expected.

• Highlight the truly significant dimensions. Critical dimensional relationships can be protected, if they are known.

Dimensional Precision Capabilities

All machine tools are subject to finite limitations of dimensional accuracy, and the turret press is no exception. Published machine accuracy figures may not always reflect the true tolerance capability of machines in actual hard use. The electronic and mechanical inaccuracies combine for the total dimensional variation experienced in practice.

Depending on machine make, type and condition, the plus-minus feature tolerance may vary from ±0.005 in. (0.13 mm) to ±0.015 in. (0.38 mm). Program corrections can often be used to improve the inherent machine inaccuracies.

Machine repeatability, however, is 0.002 in. (0.05 mm) T.I.R. as long as lead screw progression is in one direction, since then the mechanical tolerances are not compounded.

LASER CUTTING

Just-in-time (JIT) manufacturing, smaller part runs, and limited product life cycles have increased the use of laser cutting machines in production and prototype fabrication. Laser cutters are constantly evolving, as manufacturers find new and innovative ways to apply this growing technology.

Often the capabilities of lasers and turret presses can be combined. Turret presses are very fast and generate acceptable accuracy when punching many holes of the same or different diameters. Lasers are particularly accurate and economical for profiling irregular exterior contours.

These capabilities can be combined to produce accurate, complex parts at acceptable production rates by using each machine to perform that part of the cutting operation for which it is best qualified.

Examples include turret/laser cells which use the capabilities of both machines either separately or linked together, and combination machines which have both turret and laser cutting capabilities, either of which can be selected under computer numeric control.

There are applications where the laser outperforms any other manufacturing tool. Lasers require virtually no set-up time, no special tool-

ing and, with the advent of CAD-CAM, very little engineering time. This means that a laser can be finished with a job before other machines are even set up.

It is not uncommon to produce a part from digital data (using CAD geometry) to finished blank in less than an hour. This provides a quick, smooth path from concept through pre-production to production with all changes during that evolution driven by software.

Some of the most advanced production lasers incorporate features such as automatic loading and unloading, the ability to move through multiple (which provides for the profiling of parts, holes and features *after* forming), and direct "down loading" of part programs to the laser CNC console from a CAD/CAM system.

Equipment Characteristics

The typical metal cutting laser consists of an evacuated container filled with CO_2, a high voltage system which excites the gas to emit single wavelength ("coherent") light and an optics system to focus and direct that light (see Figure 9). The optics system reduces the beam diameter to approximately 0.008 in. (0.2 mm) at the point where the beam meets the workpiece.

Several thousand watts of fiercely concentrated power are sufficient to melt or vaporize most metals. The cutting action is enhanced through the introduction of an inert shielding gas to blow away the vaporized metal.

Operation

Lasers can be operated in either the continuous wave (CW) or pulsed mode. CW operation is the faster of the two options and generates a smoother edge. It is inherently less accurate because of thermal workpiece expansion due to the higher power levels reaching the work.

When there is a need for intricate or very close-tolerance cutting, the pulsed mode generates less heat but produces a very finely serrated edge. The finished quality of the workpiece is a carefully balanced compromise between speed, workpiece cooling and edge condition.

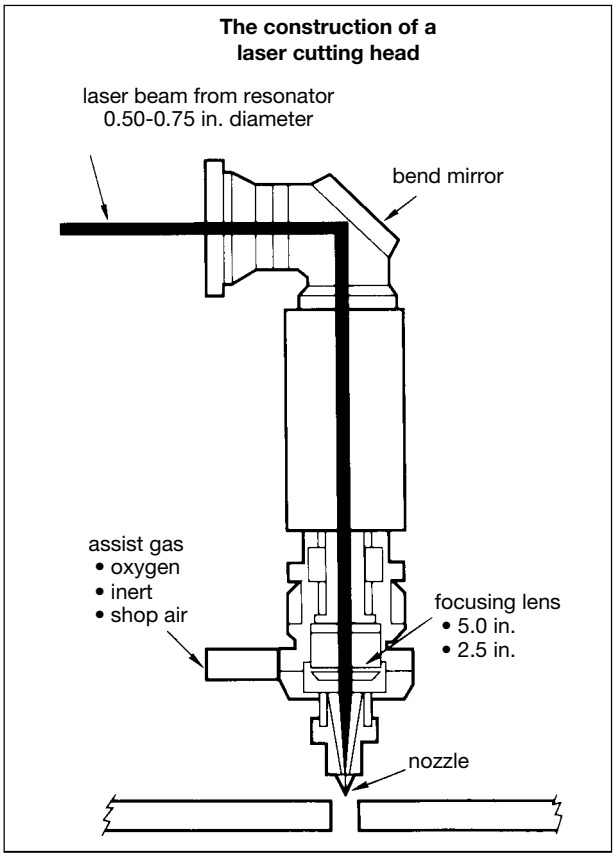


Figure 9. Typical construction of a laser cutting head.

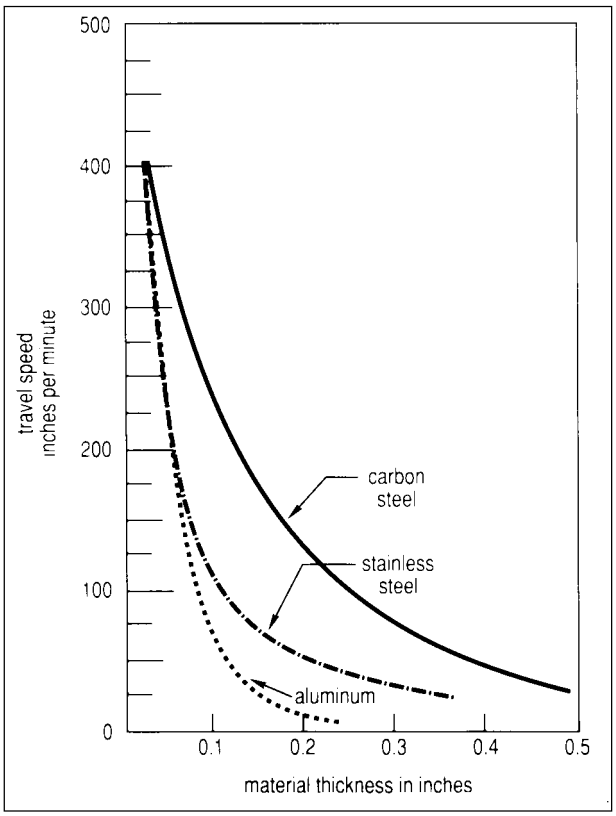
Lasers are most productive when applied to mild steel and stainless steel, and have difficulties when employed on aluminum. Aluminum and certain other metals like zinc and lead continue to reflect light when molten. This scatters the beam, requiring more power. In addition, aluminum and copper alloys conduct heat away from the cutting area which, again, requires more power.

Table I gives a comparison of laser cutting speeds on three materials using the same machine, identically focused, at a power level of 1.5 kilowatts.

Other Considerations

The knowledgeable designer considers the following characteristics of laser produced parts when designing for lasers:

Table I. Laser Cutting of Metals



• **Localized Hardening.** Lasers cut by melting or vaporizing metal can create problems when cutting heat treatable materials because the area around the part will become hardened.

Laser cut holes in stainless steel or heat treatable steel alloys which require machining (tapping, countersinking or reaming) can be particularly troublesome. By the same token, designers can employ this characteristic to their benefit when a product must be case hardened for wear resistance.

• **Edge Taper.** The laser is most accurate where the coherent light beam enters the workpiece. As the beam penetrates the part, the light scatters creating an edge taper condition similar but opposite from "breakout" in a sheared or pierced part. The hole on the side of the workpiece from which the laser beam exits is generally smaller in diameter than on the entrance side.

Thus the designer must carefully consider the final use of the part and, in some cases, may have to specify from which side the part should be cut.

• **Minimum Through-Feature Size.** The cutting laser beam is focused down to approximately 0.008 in. (0.2 mm) and is therefore capable of cutting holes and features with radii approximating 0.030 in. (0.76 mm). The limits applicable to piercing or blanking with a punch and die, such as the relationship between minimum hole size and material thickness, or the minimum distance between features to avoid distortion, do not apply when laser cutting.

However, some limitations do exist, and are also related to the material thickness. Table II is a guideline to the minimum through-features which are possible by laser. Laser cutting allows for through-features to be ⅙ to ⅛ the size when compared to die piercing.

Table II. Guide to Minimum Through-Features

Material Thickness Range		Minimum hole diameter and slot width achievable	
in.	mm	in.	mm
0-0.075	0-1.9	0.010	0.25
0.075-0.090	1.9-2.3	0.015	0.38
0.090-0.125	2.3-3.2	0.020	0.05
0.125-0.156	3.2-4.0	0.025	0.64
0.156-0.187	4.0-4.8	0.030	0.76

Also, since no mechanical force is applied, the width of material remaining between cutout features may be very narrow without distortion occurring during metal removal. A typical application would be tightly spaced, venting slots on a visually important surface.

• **Dimensioning Practices.** As a general rule, the drafting practices outlined for turret press fabrication can be applied to laser design. The designer will want to consider the economics in nesting, common line cutting, and the burr-free nature of laser parts.

It should also be recognized that the laser, like any other CNC servo driven machine, accumulates mechanical, thermal and electro-

mechanical tolerances during the production cycle. For economy and quality, critical dimensions should be highlighted and functional dimensions should be detailed in accordance with their function.

Advantages and Limitations

Laser cutting machines offer the capability of producing prototype and preproduction parts both quickly and inexpensively. No other fabrication machine can match the laser on these jobs.

As more powerful units become widely available, lasers are moving from production runs of less than 100 parts to runs of 1,000 or more. The use of lasers, in combination with turret presses, can expand this production horizon to several thousand pieces.

Good design often includes techniques such as "common line cutting," where the nested edges of two parts are cut simultaneously. Designers rely on the burr-free edge produced by a laser for certain production applications where burr removal is impractical or very costly.

Three-dimensional lasers, in particular, offer the designer the capability of producing a virtually burr-free hole or feature in a part on which the burr side may not be accessible for deburring.

Utilization of expensive materials such as titanium and monel can often approach 100% through nesting of odd profile parts on a common sheet. In addition, a blank need not be prepared for the laser. A small part can be profiled from a large sheet and the balance of the sheet stored for future use.

The use of material cutting lasers offers designers the ability to generate intricate and close tolerance designs in any material which can be burned, melted, or vaporized including a variety of plastics, wood products, ceramics and textiles. Neither designers nor fabricators have fully explored the myriad uses for this state-of-the-art production equipment.

ABRASIVE WATERJET CUTTING

Another technology in sheetmetal part production is the use of abrasive waterjet cutting. The process combines a high-pressure waterjet—in some cases above 80,000 psi—with abrasive material, to cut material quickly. Process proponents say waterjet cutting reduces setup times compared to laser cutting, allowing manufacturers to cut a variety of parts in rapid fashion without pausing to change gases or cutting heads. In addition, the process produces no heat-affected zone, thus its cutting action does not anneal or harden sheetmetal, a consideration when the finished part should not exhibit those qualities.

Abrasive waterjet cutting also creates no rough edges, often eliminating the need for finishing operations.

That said, laser cutting cuts thin steel sheet at higher speeds than abrasive waterjet cutting, and at tighter tolerances.

6

PRESS BRAKE FORMING

This section is focused on bending, the forming process most closely associated with the press brake.

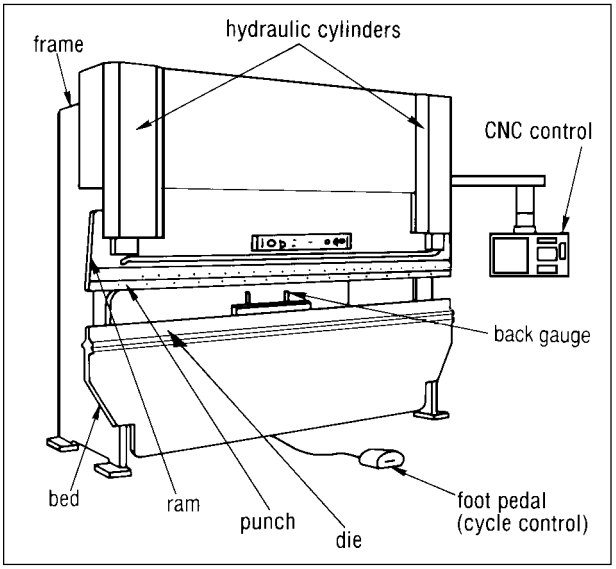


Figure 1. Elements of a typical CNC hydraulic press brake.

Equipment Characteristics

Press brakes are usually in the capacity range of 20 to 200 tons with bed lengths ranging from 4 to 14 feet (1.2 m to 4.3 m). They may be powered by mechanical, hydraulic or mechanical-hydraulic means. They may be "up-acting" or "down-acting," depending on the direction of the ram's power stroke. Figure 1 shows a down-acting CNC hydraulic press brake.

Press brakes may be equipped with one of several types of back gauges, including manually placed and adjusted gauges, pins which engage holes in the workpiece and computer numerically controlled programmable units which adjust settings after each stroke.

Operation

Most press brakes are manually fed. The operator holds the workpiece between the punch and die against the appropriate back gauge, providing the pre-set dimension for the bend (Figure 2).

Section of Press Brake Setup

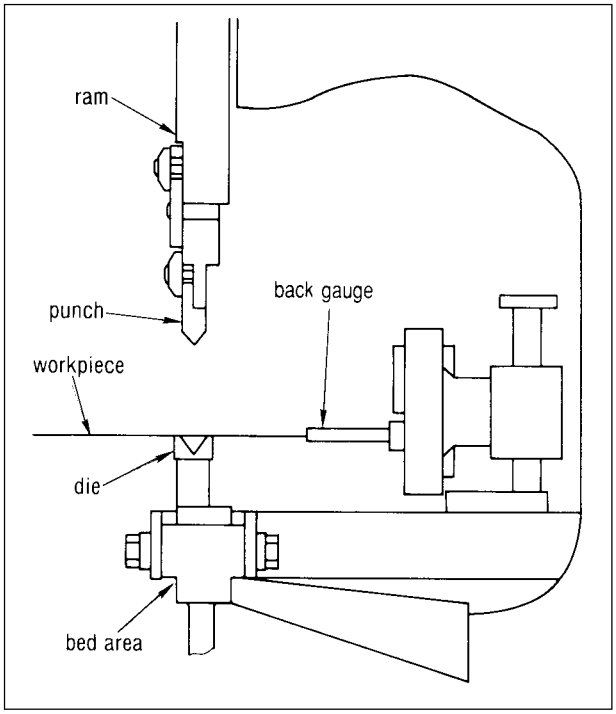


Figure 2. In this section drawing of a press brake, the workpiece is in position, showing relationship of back gauge, ram, bed and tooling.

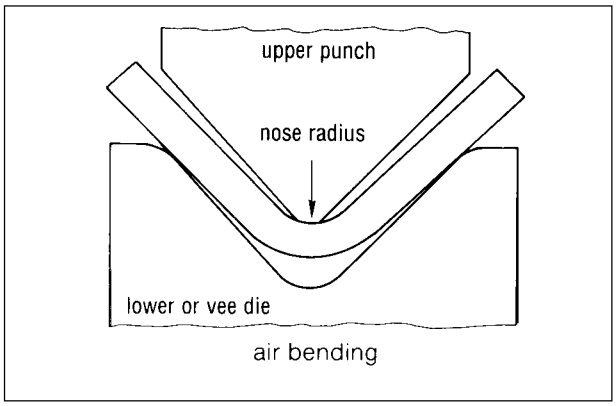


Figure 3. Example of air bending. The punch pushes the workpiece into a die cavity. The workpiece touches only the tip of the upper die and the two edges of the lower die.

Bottoming or Coining

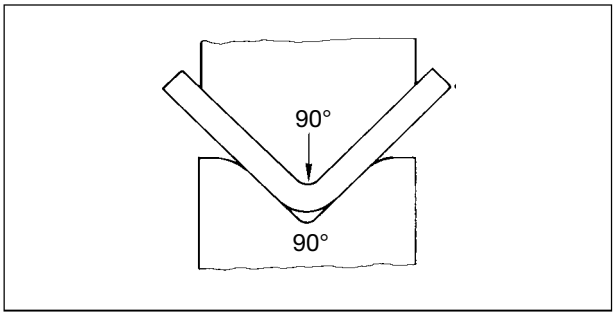


Figure 4. In "coining" or "bottoming" a punch and die is manufactured to the desired final bend angle. The workpiece is formed completely into the die.

When the blank is properly positioned the machine is activated causing the ram to move toward the bed, and the workpiece is formed between the die and punch. Then the ram returns, allowing for removal of the workpiece.

One type of press brake operation is air bending of sheet metal into a straight line angle. As shown in Figure 3, the punch pushes the workpiece into the die cavity. Throughout the entire operation, the workpiece touches only the tip of the punch and the two edges of the lower die. When the force of the upper die is released, the workpiece "springs back" to form a final angle. The amount of spring back is directly related to material type, thickness, grain and temper.

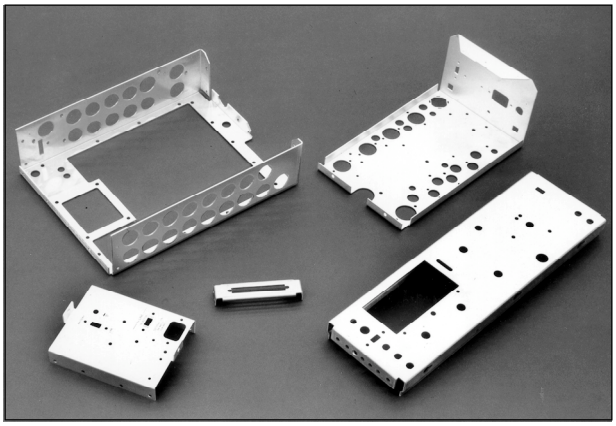


Figure 5. Examples of press brake forming.

To minimize set-up time, most tools for air bending are made with the same angle in both the punch and die. Commonly an 80° or 85° die angle is used to allow for sufficient spring-back to obtain a 90° final angle.

In situations requiring dimensional accuracy and angular precision, another forming process is required (Figure 4). This process is called "Coining" or "Bottoming." Coining requires having a punch and die manufactured to the desired final bend angle and forcing the workpiece completely into the die. Coining reduces spring-back, however this process is limited by the tonnage capacity of the press brake.

Advantages and Limitations

The fundamental advantage of the press brake as a forming tool lies in its flexibility. The use of standard vee-dies allows economical set-ups and run times on small lots and prototypes. Almost any part size and formed shape can be accommodated with the standard tooling, eliminating the cost and lead time associated with press form tooling. Figure 5 depicts the complexity of parts that can be manufactured on a press brake.

Modern press brakes with programmable back gauges using multiple die set-ups, have made this forming process much more competitive for longer runs.

In cases where product designs require specially shaped tooling, press brake die costs and lead times are relatively modest.

The enormous range of workpiece sizes which can be accommodated in the press brake is another significant advantage. Size may be limited by the length of the ram and the ability to remove the workpiece from the machine after forming.

Since die changes are accomplished quickly, a variety of standard shapes can be created at modest cost, providing considerable flexibility in configuration of the final product. Since each bend is gauged separately, every bend or operation introduces the potential for an additional dimensional variation.

Minimum Flange width Guidelines

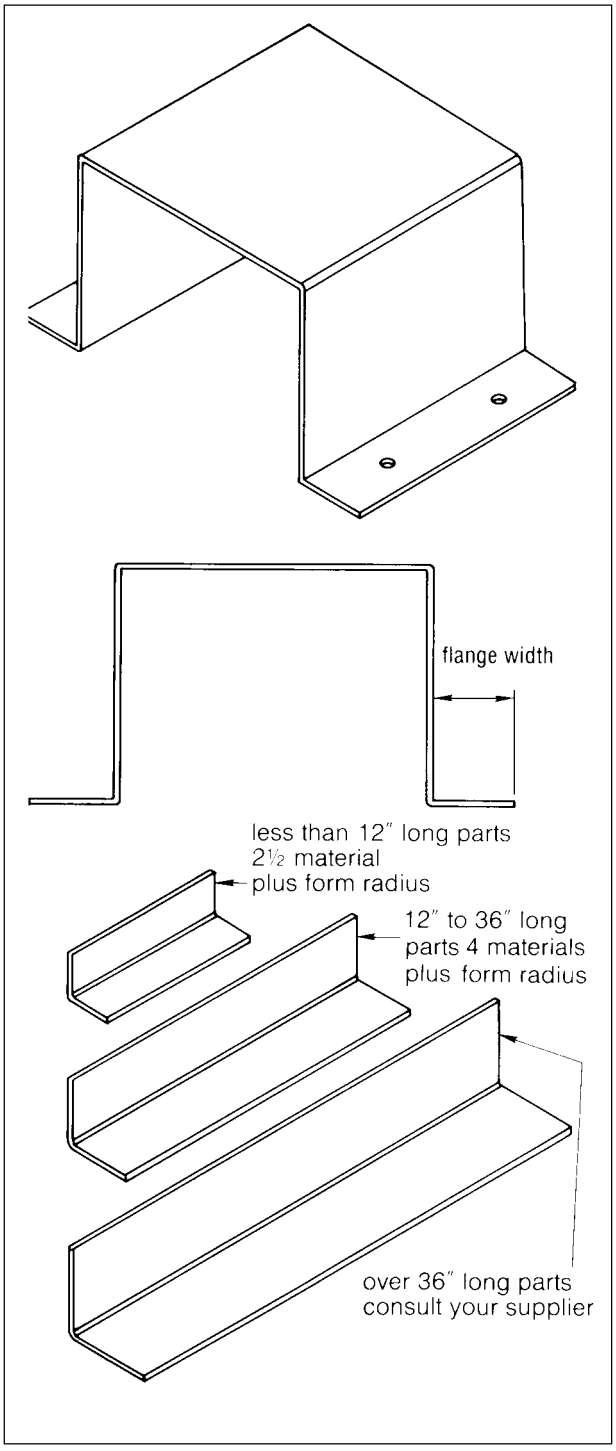


Figure 6. Minimum flange width guidelines.

Table 1. Minimum Bend Radii for Commercial Quality Steel Sheet, Strip and Plate

material	minimum bend radius in (mm)	
	bend parallel to rolling direction	bend perpendicular to rolling direction
cold rolled RB<55 drawing quality and aluminum killed	0.010 (0.25)	0.010 (0.25)
cold rolled RB*<60 commercial quality	0.010 (0.25)	0.010 (0.25)
cold rolled RB 60-75 quarter hard	1 matl. thickness	1/2 matl. thickness
cold rolled RB 70-85 half hard	not recommended	1 matl. thickness
cold rolled RB>85 full hard	not recommended	not recommended
hot rolled<2.3mm (.09) drawing quality	1/2 matl. thickness	1/4 matl. thickness
hot rolled>2.3mm (.09) drawing quality	3/4 matl. thickness	1/2 matl. thickness
hot rolled<2.3mm (.09) commercial quality	3/4 matl. thickness	1/2 matl. thickness
hot rolled>2.3mm (.09) commercial quality	1-1/2 matl. thickness	1 matl. thickness

Design Considerations

• **Inside Bend Radii.** In forming, a common radius should be specified for all bends on a part wherever possible, reducing costs and improving quality. Requirements for inside radii, which are less than the recommended minimum shown on Table 1, can create material flow problems in soft material and fracturing in hard material. For further information on bend radii, see the Material Selection Chapter.

• **Flange Size.** The minimum flange width should be at least four times the stock thickness plus the bend radius (Figure 6). Requiring too narrow a flange can overload the equipment, distort the part and damage the tooling.

• **Flange Spacing.** A minimum distance between bends is required to accommodate the tooling. Spacing between bends, as for example in "U"-shaped contour, should be reviewed with the supplier prior to completion of the design, since dimensional repeatability can be difficult to maintain without dedicated tooling.

• **"Run-Out" Flange.** It is unrealistic to add intermediate dimensions to arrive at an overall dimension. Instead, it is practical and economically desirable to allow for an accumulation of dimensional variation in the least critical feature or bend on each axis. (These accumulations are often referred to as "stack-ups" and the feature absorbing the variation is commonly termed the "run-out" flange) (Figure 7). Note use of "obround" holes to accommodate tolerance accumulation.

• **Features at or Near Bends.** Features such as holes, slots and certain notches should not be located closer than 3 stock thickness plus the bend radius from the bend. The result will cause a variety of problems including feature distortion and inability to seat clinch hardware (Figures 8, 9 and 10). If a feature must be nearer the bend than recommended, consider extending the opening past the bend line

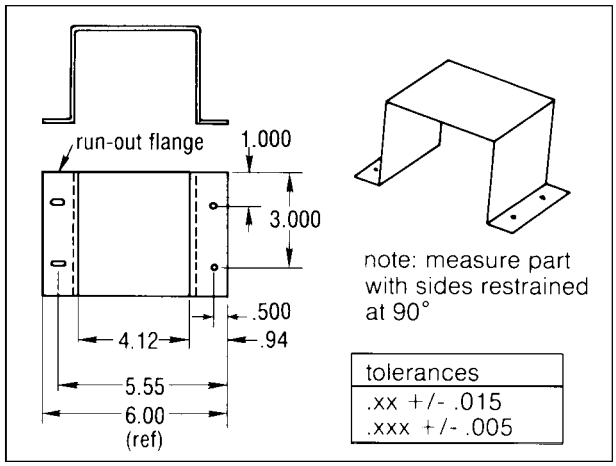


Figure 7. Accumulations of dimensional tolerances are referred to as "stack-ups" and the feature absorbing the variation is termed the "run-out" flange.

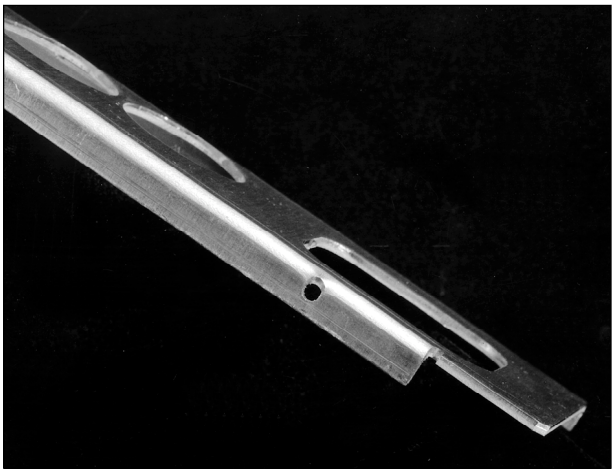


Figure 8. A hole placed to near the bend line becomes distorted in the press brake operation.

(Figures 11 and 12). If a slot dimension is functionally important use a feature as shown in Figure 11.

• **Angularity.** To assure repeatability in bend angles of less than 90° in single-bend vee-die operations it is often necessary to employ special processing and tooling—at additional cost. The use of standard 90° bends wherever possible is preferable. Consistency of angles is affected by variations in material and press repeatability.

• **Die Marks.** Slight indentations on the outside (die side) of the workpiece (Figure 13) often result from contact with the top edges of the die during forming. These are inherent in the process.

Dimensioning Practices

Practical experience has proven that dimensioning and measuring practices must both be understood and agreed on by all parties to achieve workable inspection parameters. To achieve consistent results when measuring formed parts, a standard has to be established on where and how dimensions are to be taken.

• **Form dimensions** should be measured immediately adjacent to the bend radius in order not to include any angular and flatness discrepancy. See Figure 14.

• **Feature-to-feature dimensions** on formed legs of any length on flexible parts will be assumed to be measured in constrained condition, holding the part fixtured to the prints' angularity specification. See Figure 15. This standard is appropriate for the majority of thin sheet metal parts and results in a functional product.

• **Constraining methods** vary from part to part, depending on shape and material condition. For large quantities, a measuring fixture is most practical for speed and repeatability. The relatively high cost is justified by the increased production rate and reliability gained.

The simplest constraining device is dead weight. Where applicable, the weight to be used during the measuring process should be specified, as well as the physical shape. Weight is most often used to eliminate a material out-of-flatness condition, sometimes in conjunction with an angular measurement.

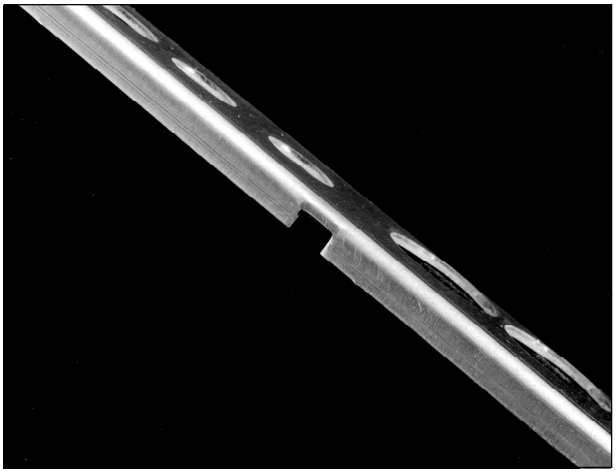


Figure 9. A notch becomes distorted.

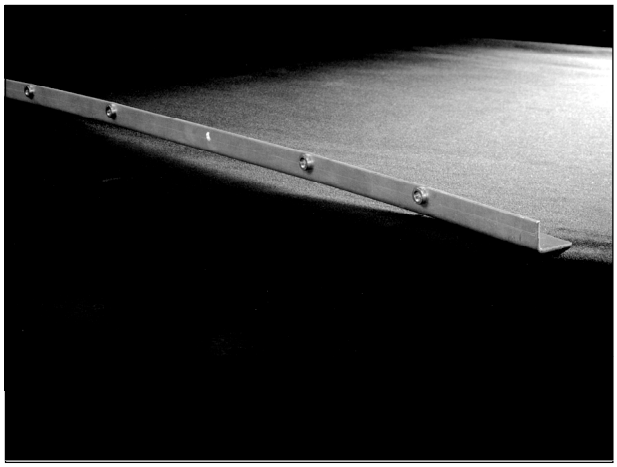


Figure 10. Seating of clinch hardware too near the edge causes the part to bow from the stress.

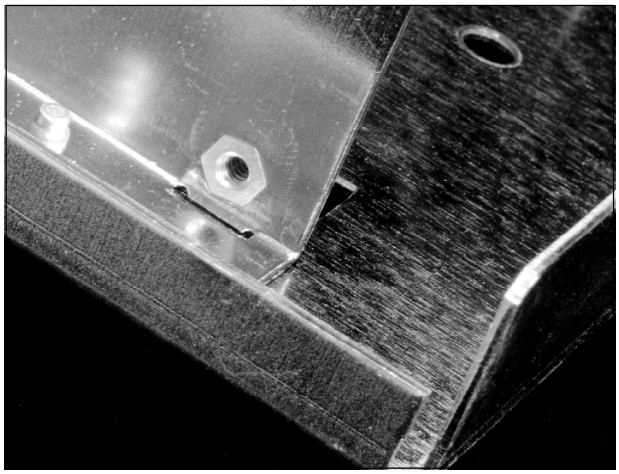


Figure 12. Here is an example of hole slotted with clinch hardware specified too near the bend. The relief slot at the bend line allows insertion without distortion.

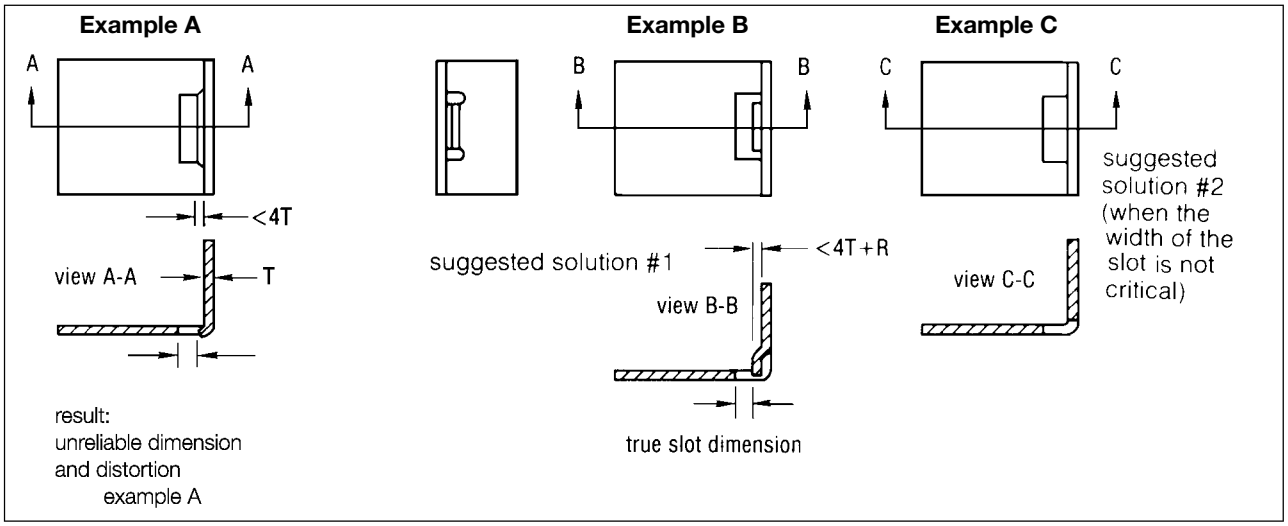


Figure 11. Alternative design practices (examples "B and C") for alleviating dimension and distortion problems associated with example "A." Example "C" is the easiest to accomplish.

As shown in Figure 15, parallel blocks by themselves, or with clamping devices, are probably the most often employed and practical constraints for occasional use, when legs need to be kept at 90° and parallel. In rare cases when restrained measurement is inappropriate, the drawing should reflect this requirement. Such cases normally result in special manufacturing steps, which may add considerable cost.

In addition to these considerations, using the following guidelines will increase the manufacturability of designs for press brake forming.

Select a single datum close to an end of the part and maintain the same datum in all related

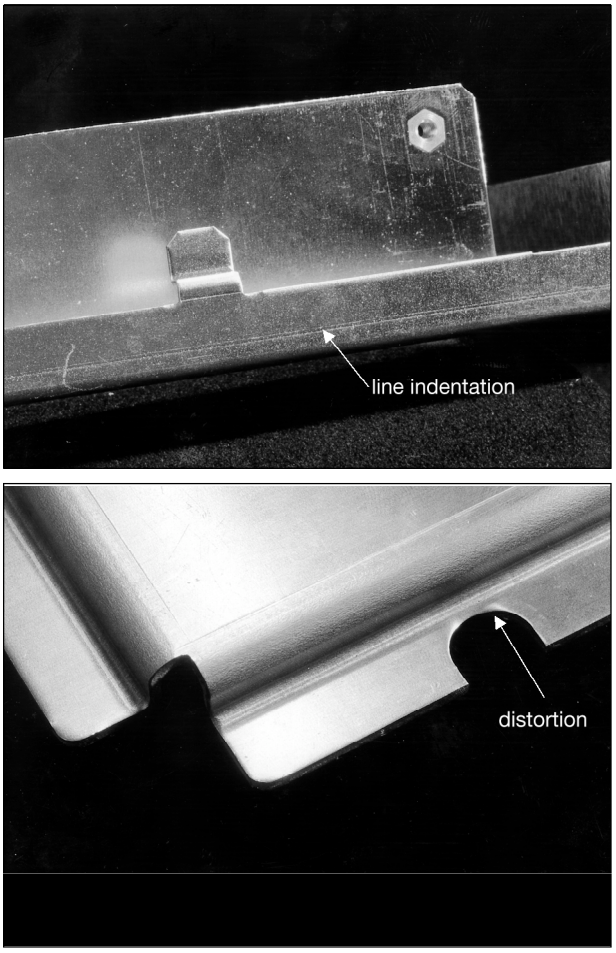


Figure 13. Top. Slight indentations on the outside (die side) of the workpiece often result from contact with the top edges of the die during forming. Notice on the bottom photo the distortion in the feature too near the bend line.

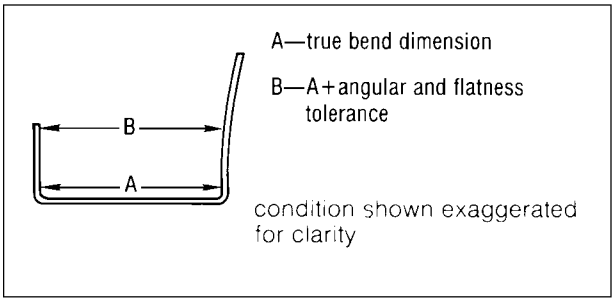


Figure 14. Correct measuring practice for form dimensions.

drawings (Figure 16). This datum should be a pierced feature in the principal flat surface of the part, selected on the basis of the sequence of bends. Early discussion with the supplier may be useful in selecting datums and dimensioning effectively.

For most economical production, dimension the part in a single direction wherever possible. Because of the sequential nature of the forming process, and the fact that dimensional variation is introduced at each bend, dimensioning in a single direction parallels the process and helps to control tolerance accumulation.

It is generally recommended that dimensioning be done from a feature to an edge. Feature-to-feature dimensions in two planes should be avoided. Feature-to-bend dimensions may require special fixtures or gauging.

Tolerances in the title block of a drawing may be unnecessarily restrictive for certain dimensions and angles, while very appropriate for others.

Almost any degree of precision can be achieved if cost is no object. For economical manufacturing, it is necessary to adopt dimensioning practices which consider the characteristics and limitations of the process and highlight truly critical dimensional relationships.

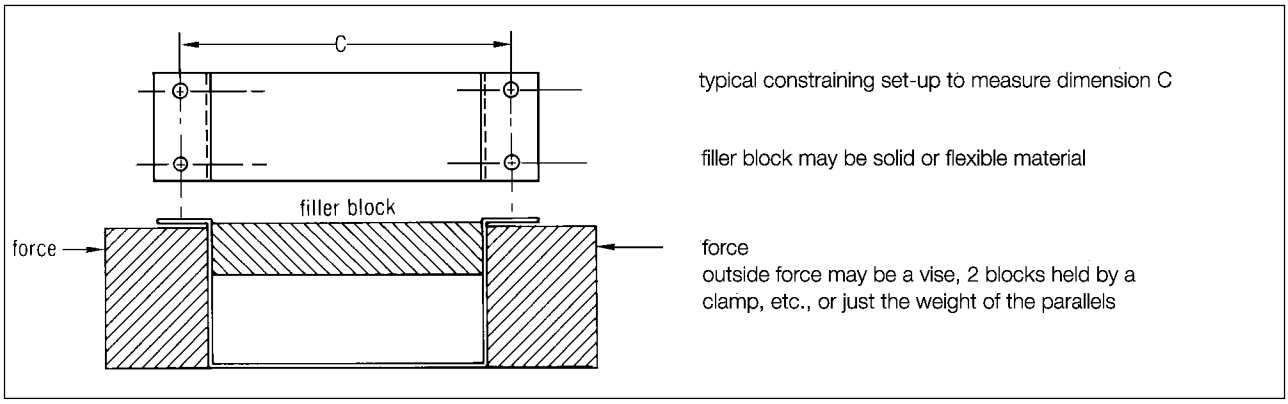


Figure 15. Example of measuring from constrained position.

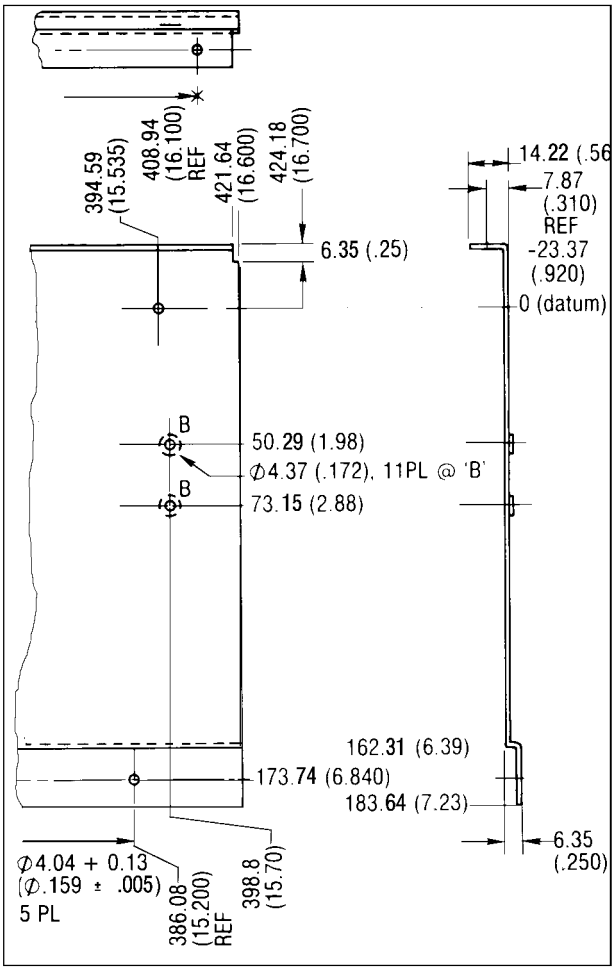


Figure 16. Example of appropriate dimensioning for parts to be formed in a press brake. A single datum (a pierced feature) is selected near the end of the part. The same datum should be retained on all related drawings.

7

STAMPING

The diverse range of metalforming operations—including blanking, piercing, forming and drawing, as well as variations and combinations of these processes—is frequently carried out with dedicated or "hard" tooling. Such tooling is used in stamping presses and slide forming machines. It is developed specifically for (i.e., dedicated to) producing one particular part configuration.

Dedicated tooling involves both upper and

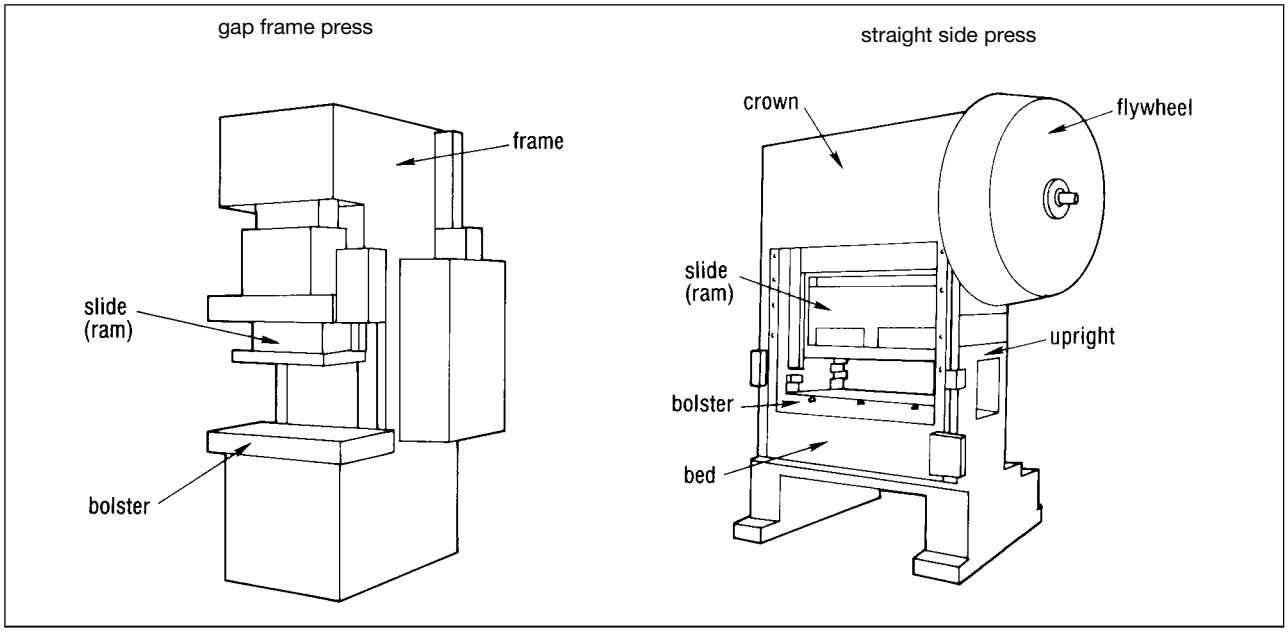


Figure 1. Examples of typical mechanical stamping presses; gap frame (left); straight side (right).

lower die components. In operation, the upper die is attached to the press slide (or "ram") which moves vertically, and the lower die is secured to the stationary bolster. As the slide descends the workpiece is shaped between the dies.

Equipment Characteristics

Fundamentally, stamping presses are machines with the space to contain and the means to actuate dedicated metalforming tooling with the force, speed and precision necessary to produce the desired part shape. Both mechanical and hydraulic stamping presses are available in several basic designs, and a wide range of sizes, tonnage capacities, stroke lengths, and operating speeds.

• **Mechanical presses** develop energy in the flywheel and translate the rotary motion and torque of the press drive into the reciprocating motion and force of the press slide through a crankshaft, eccentric shaft or eccentric gear. The two major types of mechanical presses are gap frame and straight side (see Figure 1).

Gap frame presses are available in several design variations. Open back inclinable, open back stationary and two-point gap frame designs are the most common. As a group they provide tonnage capacities from about 20 to 600 tons. Speeds range from about 20 to 800 strokes per minute (spm), and stroke lengths can vary from fractions of an inch to 20 in. (0.5 m).

The gap frame concept is versatile, provides excellent accessibility to the dies as well as convenience in feeding and ejecting parts. It is often used in applications where the stock is manually fed.

Straight side presses have frames consisting of a crown, two upright sides and a bed that support the bolster. These components are often secured in a preloaded position by four tie rods. They may also be bolted and keyed together or welded into one piece. As a result, straight side presses are stiffer vertically than gap frame units, and any deflection under load tends to be symmetrical.

Straight side presses are suitable for progressive die and transfer die applications and cover an enormous range of types, sizes and speeds. Tonnage capacities range up to 6000 tons and up to thousands of strokes per minute (spm).

In addition to gap frame and straight side presses a variety of special purpose mechanical presses are in use for applications such as fineblanking, perforating, coining, slide forming, and a wide range of precision, high-speed operations.

In general, mechanical presses are well suited for blanking parts at high speed; blanking parts automatically fed with a variety of feed lengths; shallow drawing; and work requiring an easily controlled depth of stroke.

• **Hydraulic presses** deliver a controlled force generated by hydraulic pressure used to move one or more rams in a predetermined sequence. They are housed in a variety of types of frames, including C-frames, straight sides, H-frames, four-column and other shapes, depending on the use (Figure 2).

Hydraulic presses cover a wide range of capabilities. Very large bed sizes 72 in. x 48 in. (1.8 m x 1.2 m) for example, are available with only 20 tons of pressure. Conversely, a 200-ton press may have a small 36 in. x 36 in. (0.9 m x 0.9 m) bed area. Stroke lengths of 24 in. (0.6 m) and longer are readily available.

Important characteristics of hydraulic presses include: the ability to deliver full power at any point in the stroke; adjustable tonnage, with overload protection; and adjustable stroke length and speed.

In general, hydraulic presses are well suited for deep drawing; short runs with frequent die changes; blanking with a form, or coin, or other secondary operation in a single stroke; lower-speed high-tonnage blanking with long feed lengths; and work requiring repeatable pressure rather than repeatable depth of stroke.

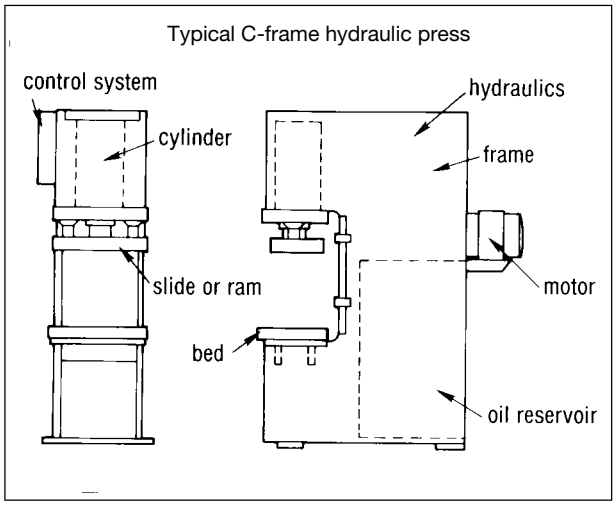


Figure 2. Example of hydraulic stamping press.

Basic Operations

Because dedicated tooling is designed for a specific part configuration, it is capable of producing very complicated shapes, such as multiple bends, tabs, protrusions and extrusions, with great precision, on each press stroke.

Simple, two-dimensional parts become more economical to produce in dedicated tooling through multiple punch and pierce operations per stroke. Complex curved and shaped parts can be produced using specific-purpose design unachievable by multi-purpose tooling.

The following operations are commonly performed in dedicated single-purpose dies.

• **Blanking** is the cutting of flat metal sheet or strip stock into the required size and shape. Here, tooling consists of a die, a punch, a set of guides and a stripper. Typically, the entire periphery, which may include rounded corners and irregular shapes, is cut in one stroke of the press.

Designers who are in the testing stage of products that will ultimately run at high volume in dedicated tooling might consider the use of "pancake" (simple push-through) dies for blanking of prototype parts. In contrast, quantities up in the thousands or more merit production units that feed strip or coil to limit handling and keep blanking operations as economical as possible.

In practice, different types of blanks are used, depending on the next operation in the manufacturing sequence, such as drawing or forming. Tool development for a drawn part may involve the building of the draw die before the blanking die to establish the final blank size.

• **Piercing** generally refers to cutting openings such as holes and slots in sheet stock, strip material, or a part. This operation is similar to blanking, but here the slug produced by piercing is scrap.

Where possible, all holes and openings in a part are pierced in one stroke. This results in a much more consistent part than punching features in separate strokes of the press. Since all punches are permanently mounted in the same master die and enter the workpiece at the same time, dimensional repeatability of all features is high.

Other types of piercing operations require special punches, among them: pierce-and-extrude (for an extruded hole), lance and form (for a small feature formed from the body of the part), slotting, countersinking, and cutting of tabs (see Figure 3). Additionally, just about any operation—blanking, drawing, forming—can be combined with piercing.

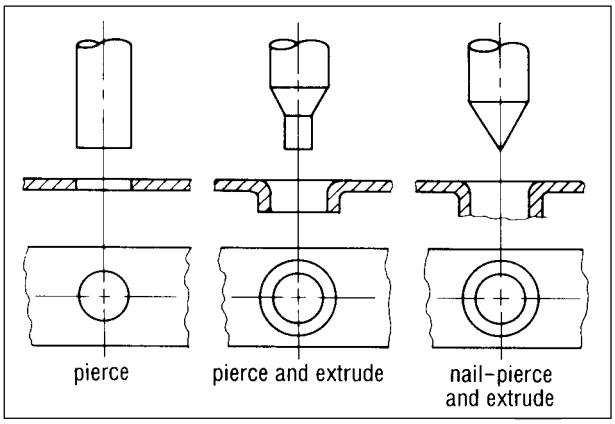


Figure 3. Basic piercing operations used to create holes, slots, etc, and corresponding tooling.

• **Forming** can be considered a bending operation. Unlike drawing, which can significantly stretch and deform the metal, forming generates shapes with virtually no change in thickness. Part configurations include those with simple flanges, V-bends, U-shaped channels, and more complex contours (see Figure 4).

Typically, basic tools like V-punches and wipe dies are built into standard holders. As with blanking and piercing operations, repeatability and high precision are readily achieved.

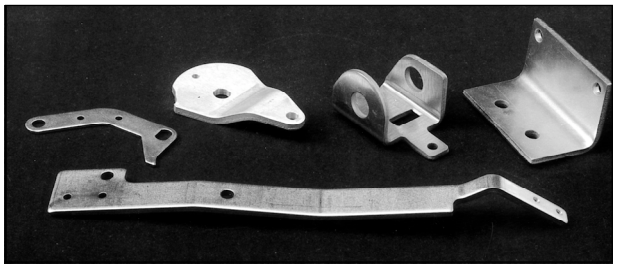


Figure 4. Example of various part configurations achieved through forming.

• **Drawing** is broadly defined as stretching sheet metal stock, commonly a blank that is restrained around its periphery, into a cuplike, cylindrical or box shape. In practice, there's virtually no limit to the shapes that can be drawn. (See Figure 5 for typical drawn shapes).

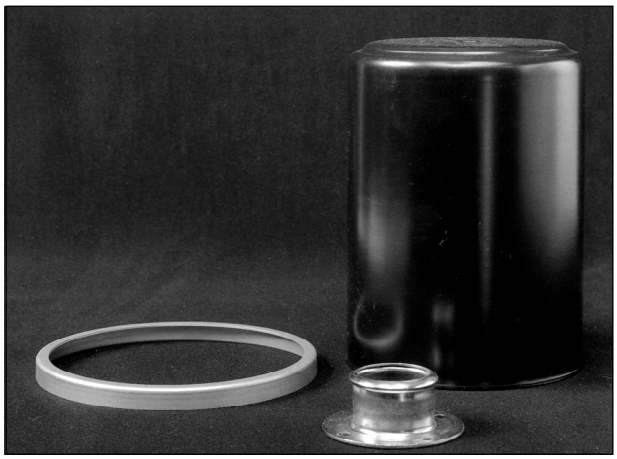


Figure 5. Typical drawn shapes.

Drawing usually takes place in either a mechanical or a hydraulic press, where a tool (punch) forces the metal to flow into a cavity (die) creating the basic shape. Deep drawing and shallow drawing are the two main variations, classified by the amount of deformation. In most instances, a trimming operation is required—either a pinch trim or a cam trim—to remove the scalloped edge (see Figure 6).

As with most other dedicated-tool operations, drawing can be done with single-action, double-action and compound dies (most commonly for blanking and drawing), as well as progressive dies and transfer die systems.

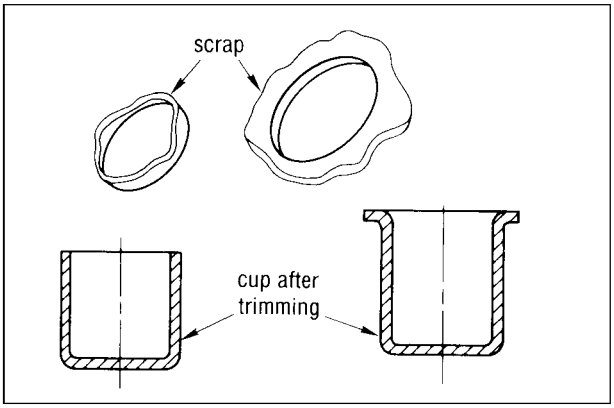


Figure 6. Drawn cups are usually trimmed by cutting the wall (left) or the flange (right). Resulting scrap is shown above.

Tooling/Process Options

For increased producitivity, two or more basic metalforming operations can often be combined in dedicated tooling. Beyond the single operation per press-stroke, other options with dedicated tooling include compound dies, progressive tooling, transfer die systems, and slide forming.

• **Compound dies** are dedicated-tooling options that allow two or more operations to be combined into one. A compound blank and pierce, for example, permits the entire perimeter and all holes to be cut in one stroke of the press.

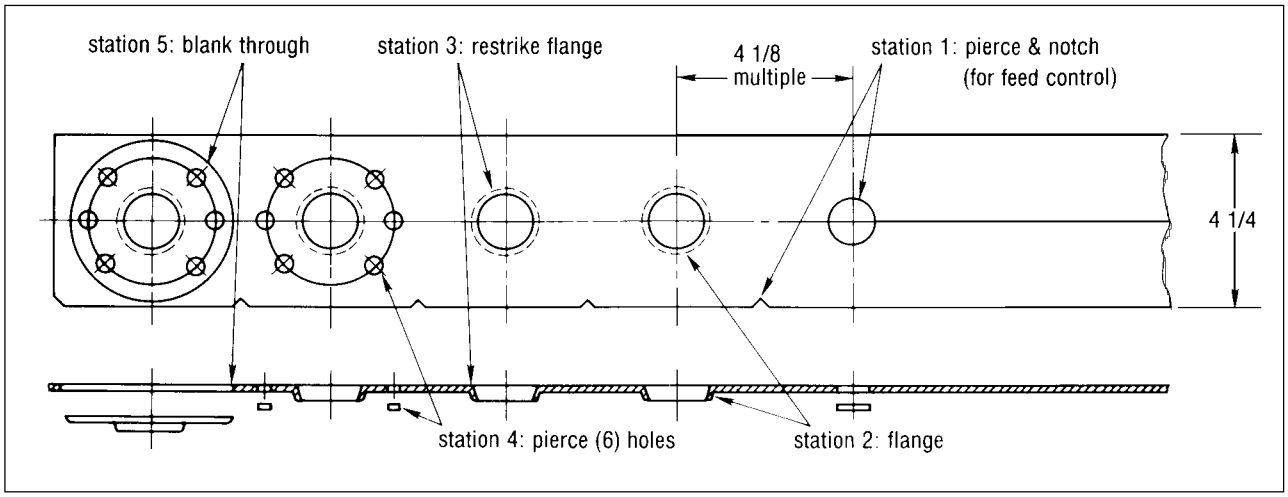


Figure 7. Strip development via progressive dies for a ring-shaped part.

This produces the closest feature-to-feature tolerances, flattest part, and easiest to control burr height. In addition, all burrs are formed in the same direction.

Metalformers who specialize in smaller production runs (up to thousands of pieces) often utilize a compound system that is built into a master die set. In production, parts typically run slightly slower than normal blanking, but much faster than separate blanking and piercing. In effect, an additional operation is gained in the process.

Similarly, compound dies can combine other operations; blanking and forming or blanking, piercing and forming.

• **Progressive tooling** makes use of one die in which multiple operations are performed in consecutive stations (see Figure 7). Normally, stock is automatically fed by a feed mechanism. The workpieces remain attached to a strip or ribbon of the material, and are thereby advanced from station to station.

Unlike single-operation dies, progressive dies do only a portion of the work at each station. With blanking, for example, single-operation dies cut an entire periphery at once, while progressive dies may cut the periphery in sections.

Good progressive tool design allows the incorporation of multiple forming and piercing operations for economy and reproducibility.

Other operations such as tapping, staking, riveting and insertion of clinch hardware may be accomplished at separate stations. Piloting holes or tooling holes are sometimes necessary to register the strip for sequential operations, depending on a part's geometry. Typically, progressive dies produce burrs in both directions and may exhibit parting lines.

• **Transfer-die** systems differ from progressive tooling in that individual workpieces are moved from one die station to the next between press strokes by mechanical fingers, levers or cams which are built into or mounted on the press. Transfer operations often require additional equipment, such as strippers, eject pins, and die cushions. High production volumes are a prerequisite for transfer-die systems, which often require specially designed transfer presses.

Economic Advantages and Limitations

Compared to CNC fabrication using single-purpose or universal tools, dedicated tools generally provide superior dimensional precision

and uniformity of product throughout a production run, and good reproducibility from one lot to another. Being generally more complex and costlier to design and build, they also require longer lead times.

In selecting the appropriate tooling method, the designer weighs the lower tooling cost, short lead times and relatively low production rates of CNC fabrication against the higher tooling cost, greater precision, longer lead times and higher operating efficiencies of dedicated tooling. Ultimately, the total production quantity is often (but not always) the deciding factor.

Many products begin as CNC fabrication prototypes, then evolve into hard-tooled operations when production quantities reach higher levels. Early consultation with the metalforming vendor regarding total anticipated quantities is essential in planning the appropriate tooling approach.

Size of the part and the degree of dimensional precision may also affect selection of the tooling method, regardless of the quantities involved. Parts with extremely large plan-view areas (greater than 30 x 30 in. (762 mm) for example) may be too large for all but the very largest specialized tooling and press equipment.

Likewise, some parts inherently require a degree of dimensional precision unachievable with CNC fabrication. However, certain classes of parts—particularly those with selectively perforated areas within the body of the part—are often more economically run in numerically controlled presses.

Fundamental Considerations

When part drawings are submitted to metalformers, they can only be accurately interpreted when they follow accepted engineering drawing practices for dimensioning and tolerancing. In addition, the co-engineering concept, which emphasizes early supplier involvement during the design stage, is essential for optimum cost and performance in component designs. Other fundamental considerations include:

• **Tooling Amortization.** Because tooling costs must usually be absorbed over the length of production, careful consideration must be given to part quantities when tooling options are evaluated. Larger quantities usually justify more sophisticated tooling. However, optimum cost effectiveness can sometimes be achieved for all production quantities by using standard components for blanking, piercing, forming and drawing.

Typically, standard fixtures with quick-change inserts can be used to hold tool segments, thereby reducing costs of conventional die sets. In hole punching, for example, the use of "stock" hardened-steel punches helps keep tooling costs to a minimum. Similarly, hundreds of standard tool holders and fixtures are available to simplify tooling set-ups for forming and drawing.

For large quantities, an additional investment in tooling may be warranted. Although prototype or universal tooling may do the job for smaller runs, more efficient production using upgraded tooling can significantly reduce the unit cost. That is why it is important to discuss potential quantities and the expected quality level (including cosmetic requirements) with the metalformer prior to establishing the tooling method.

Numerous factors can drive up tooling costs: larger part size, increased complexity, restrictive tolerances, workpiece material characteristics, and very thin or thick stock. To keep the costs of tooling down, restrictive tolerances should be specified only where needed, and all alternatives should be considered when special material characteristics are needed. If tight tolerances and material of a specific temper are not required, less expensive sheet steel can sometimes be substituted for strip stock.

• **Material Utilization Affects Costs.** Nesting parts in sheet or strip stock can significantly reduce the amount of scrap generated in blanking operations, and is particularly successful with large L- and C-shaped parts. The amount of material that can be saved by slightly changing

the design without changing its function is often worthwhile. An example is shown in Figure 8.

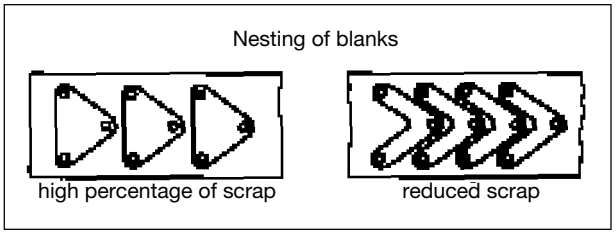


Figure 8. Nesting of blanks, as evidenced by this redesign of a V-shaped part, can dramatically increase material utilization thereby cutting material cost.

The slide forming process allows the fabrication of many parts using the net strip width and little or no scrap between blanks, see Figure 9.

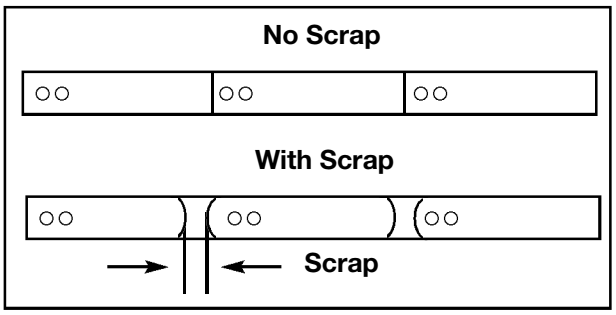


Figure 9. Examples of parts fabricated using net material width.

• **Material Characteristics.** Variations in material affect precision in the metalformed part. Such effects are more evident in forming operations than in piercing. Dimensions and properties vary more with sheet stock than with strip.

A pertinent example: dimensional variations in forming operations that result directly from thickness variations in the workpiece material. Because thickness tolerances on standard sheet vary, (see Material Selection chapter 3), the designer should be aware that the dimension from a hole to the edge of the bend can vary by the thickness tolerance. If that tolerance is not acceptable, the designer should specifiy controlled-thickness material at extra cost.

• **Engineering changes** are very costly, but are often unavoidable. If a product is in the developmental stage, the designer should consider use of CNC fabrication or cost-effective hard tooling. Low-cost hard tooling, which uses standard components for separate operations to blank, pierce and then form parts, responds to design changes more readily than progressive, transfer, or compound dies. The latter should only be considered when part designs have been firmly established.

Pre-Design Basics

The effective design of parts is determined by the inherent characteristics of the metal forming process. Functional features, tolerances, and dimensional relationships all have well-established guidelines. Before getting into design specifics, however, discussion of some basics may help to explain certain constraints in metalforming.

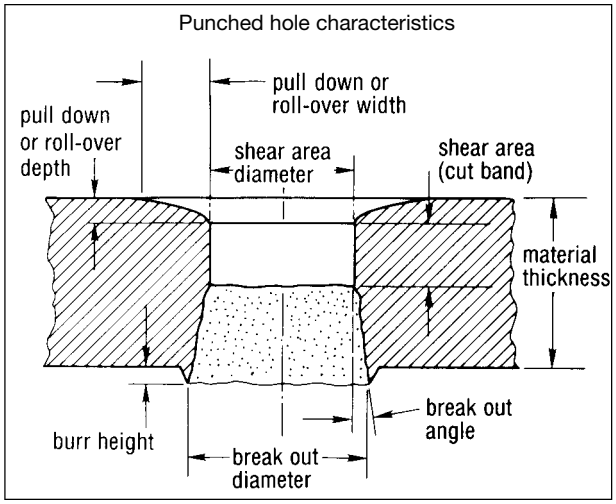


Figure 10. Standard terminology that refers to cutting or shearing metal with a punch and die. In practice, dimensional measurements are made at the shear area.

When a punch and a die are used to cut or shear metal, approximately the upper third of the material's thickness is essentially cleanly cut, and the remaining portion fractures and breaks through. In the process, a slightly depressed area

on the upper surface is formed. This characteristic is called "roll-over" or "pull down."

In practice, pull down is affected by two factors: temper of the material and structure. Softer materials usually increase pull down.

Dimensional checks are made at the shear area or "cut band" (Figure 10). Punched holes and slots are measured from the punch side because on the opposite side, the break out of the material—influenced by necessary die clearance—may affect the accuracy of the opening. Material type, ductility and die clearance can have an effect on size and reproducibility of openings.

Punched tabs are normally fabricated in one of two ways. Most commonly, a special punch is used to make a horseshoe-shaped cut, which is then bent in a secondary operation. The other method is to shear form, where the tab is lanced and bent at the same time. The latter approach creates more burr and is slightly less accurate (Figure 11).

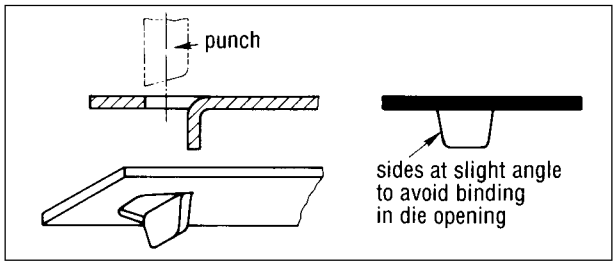


Figure 11. Specially shaped tool is used to punch a tab in either a one or two-step operation, depending on design requirements.

Design Guidelines for Blanked Features

Regarding blanking, specific recommendations should be followed to obtain the most economical and functional part design.

• **Corners** may be designed sharp (less than 0.015 in. (0.4 mm) radius), but often this involves additional cost to address increased die wear and burr formation. Generally, radii for corners should be ½ of the material thickness or greater, with a 0.015 in. (0.4 mm) minimum radius preferred (Figure 12).

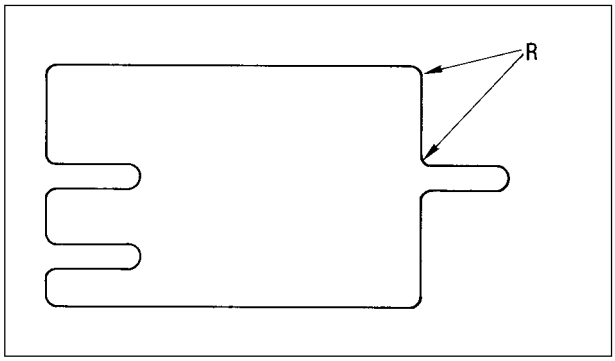


Figure 12. Generally, radii for corners should be 1/2 of the material thickness or greater, with a 0.015 in (0.4 mm) minimum radius preferred.

• **Notches and tabs** on blanks should generally not be narrower than 1.5 times the material thickness. With a 0.060 in. (1.5 mm) stock thickness, a 0.090 in. (2.3 mm) wide notch or tab is readily cut.

Typically, notch and tab lengths can be up to five times the width. In marginal cases, the metalformer can use a heavier die, punch or stripper at a slight cost increase. Alternately, notches and tabs can be extended and narrowed slightly if they are tapered (Figure 13).

Depending on the material, hardness and shear characteristics, notches and tabs can be designed with widths as small as one material thickness and with lengths up to six or seven times the width—usually at additional tooling cost.

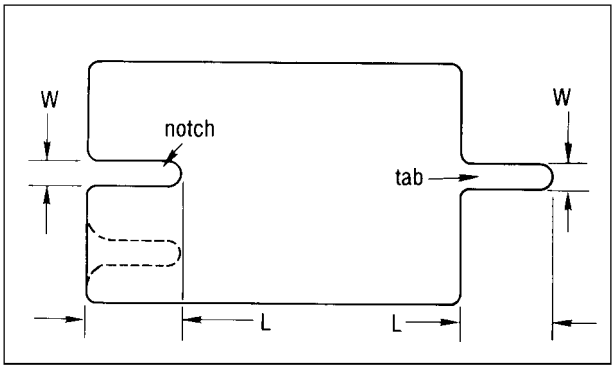


Figure 13. Notches in blanks should not be narrower than 1.5 times the material thickness. Notches can be extended and narrowed slightly if they are tapered.

Notches and tabs should not be too close to another feature or too long and narrow because of die weakening. If close proximity to notches is necessary, secondary operations may be required.

• **Cutoffs.** Three basic types of cutoffs apply to blanking: straight or square cut-off; half-round or partial radius; and full radius (Figure 14), with square being the most economical.

The full radius option is not recommended because the tangential blending of the radius into the outside material edge creates a condition where there is no material to be cut. This is called "feather edge" and in this condition the material will extrude along the die edge for an unavoidable, large burr. (See Figure 14 for design solutions.)

Guidelines for Piercing

For both economy and performance, the following general recommendations should be followed for piercing.

• **Holes.** Minimum hole diameter should be equal to or greater than 1.2 times the material thickness. With stainless steels and other high tensile strength alloys, two times the material thickness is recommended. (For hole size prior to tapping consult the chapter on Designing For Machining.)

If hole sizes are less than the recommended minimum diameters special hole punches must be used at increased initial costs and expensive upkeep, or drilling (a more expensive operation) may be required.

Punched features are measured from the

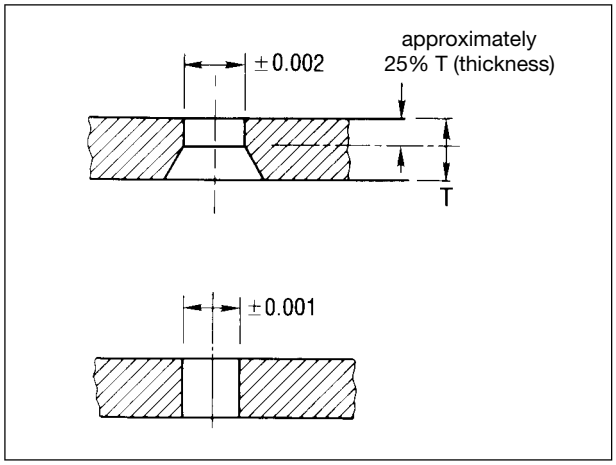


Figure 15. Reaming or shaving is required at extra cost where straight holes are necessary.

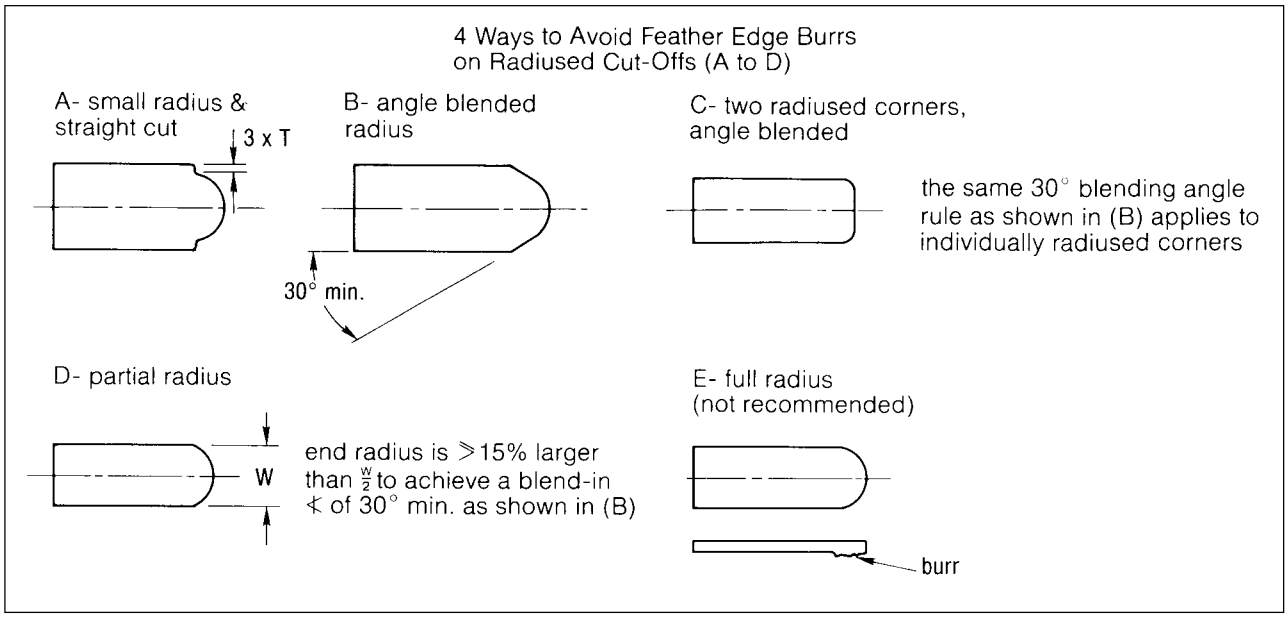


Figure 14. Four ways to avoid feather edge burrs on radiused cut-offs (A to D). Example E is not recommended.

punch side of the material, because the hole dimension on the burr side is typically larger and less easily controlled. If straight holes are necessary, reaming or shaving is required at extra cost (see Figure 15).

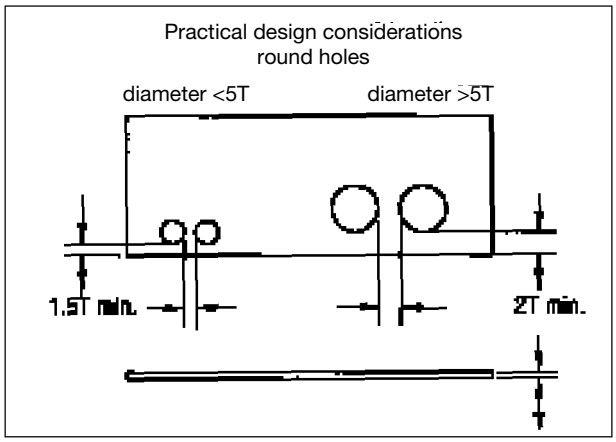


Figure 16. Recommended minimum hole spacing (edge-to-edge) is 2 times T.

The dimension between hole and edge—should be a minimum of two stock thicknesses (Figure 16). For long slots, this dimension should be three to four times the stock thickness (see Figure 17). With holes, webs equal to one stock thickness produce a slight edge bulge, which increases as the web decreases.

If webs are not two times the thickness, distortion may occur, or harder materials may crack. However, there are alternatives: an ear around the hole, or a notch (Figure 18). The former increases blank size and cost, while the latter does not.

• **Edge-to-hole** spacing should be maintained at a mimimum of two times stock thickness (see Figure 16).

• **Hole-to-form** spacing is normally 2.5 times the material thickness plus the bend radius. Otherwise, the hole distorts (Figure 19). If the hole is to be tapped, slightly less spacing is needed, but the hole must be tapped after forming to avoid thread distortion.

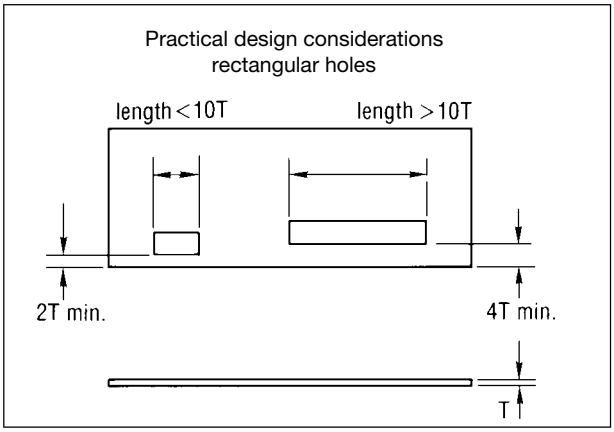


Figure 17. Minimum distance of a slot edge from another feature like a hole should be at least 2 times the material thickness (T).

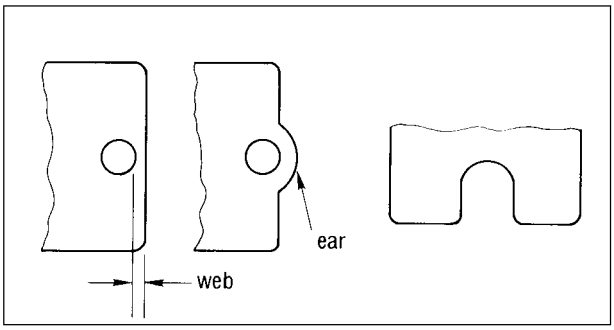


Figure 18. Webs should be at least 2 times the stock thickness (T) to avoid distortion or bulging. Alternate designs include a notch or, a pierced hole within an ear.

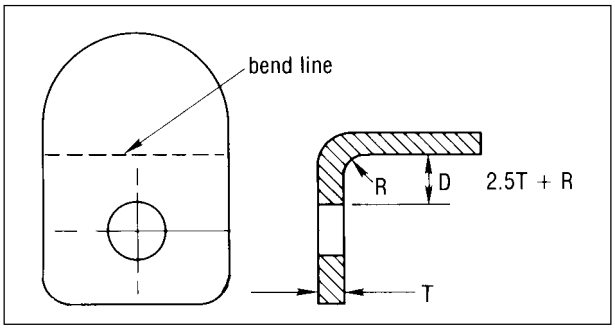


Figure 19. To avoid distortion, holes should be located a minimum distance (D) from forms. D = 2.5T + R, where T = material thickness and R = bend radius.

• **Slot-to-form** spacing for long slots (Figure 20) should be at least four times the material thickness plus the bend radius. If the slot is the only opening in the part, additional cost is minimal. If other holes are required, the holes must be punched first, the part is formed, and then the slot is punched. This approach involves added operations. Another alternative is to punch out the entire area (Figure 21).

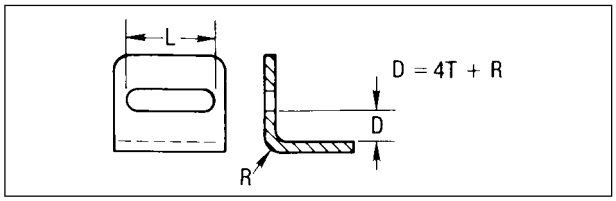


Figure 20. Long slots should be positioned at a minimum distance (D) from forms. D = 4T + R. T = material thickness and R = bend radius.

Guidelines for Formed Features

Forming, too, has its own set of guidelines, all of which are formulated to avoid potentially costly design pitfalls.

• **Formed features** that do not meet the minimum recommended length, generate additional expense, since the part must be formed long and then trimmed to size. The short portion beyond the form should have a minimum length equal to 2.5 times material thickness plus the radius, as measured from top of the form to end of the blank (Figure 22).

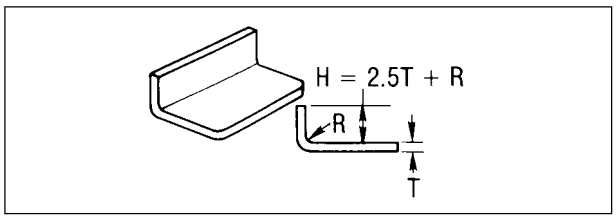


Figure 22. Form height (H) should be at least equal to 2.5T + R. T = material thickness and R = bend radius.

• **Form-to-hole** spacing should be great enough so that hole distortion does not occur (see hole-to-form section under piercing design).

• **Restricted tolerances** on the outside of a V-shaped form may require bend relief notches (Figure 23). Without bend relief, edge pucker (bulging) will result.

• **Formed, L-shaped Parts.** Designers should include a bend relief notch to avoid cracking or fracture (Figure 24).

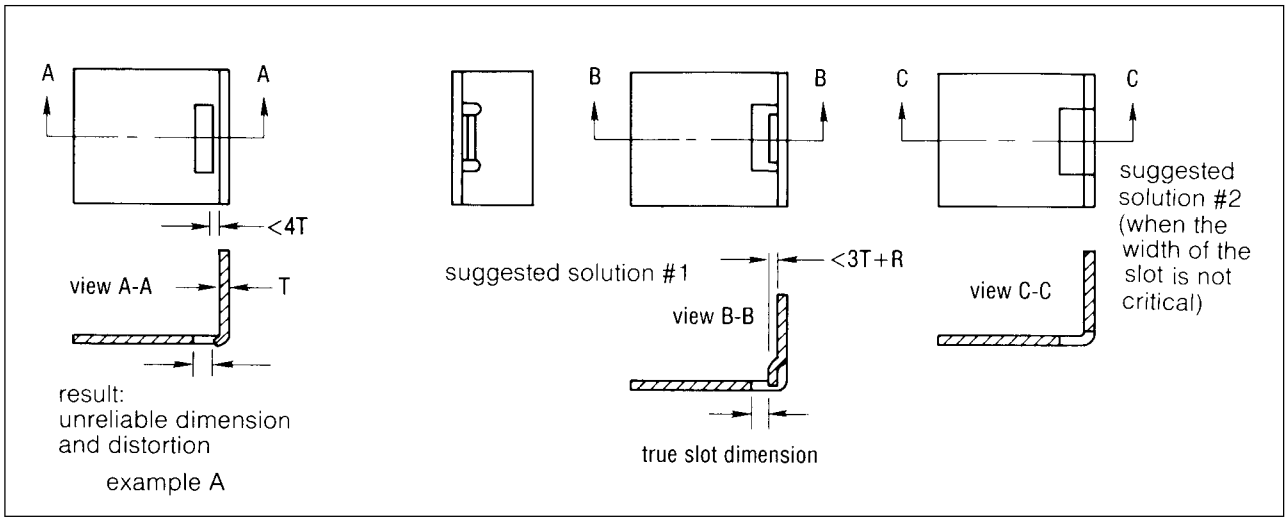


Figure 21. Design alternative to following recommended slot-to-form spacing is punching out the entire area.

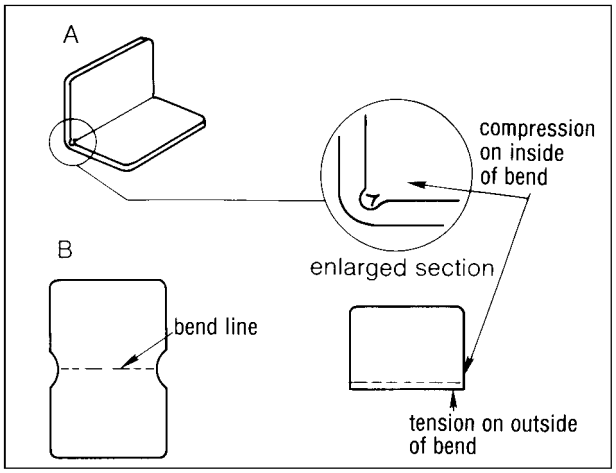


Figure 23. When bulging is not acceptable, bend relief on a V-shpaed form is required.

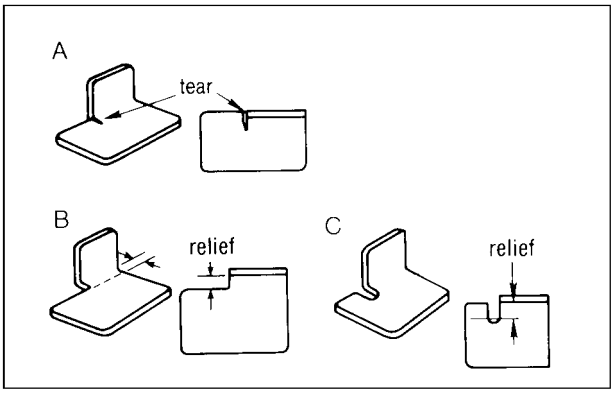


Figure 24. Notches on formed L-shaped parts. Example A is not reccommended. Examples B and C are recommended designs. Notch width = 2 times material thickness, min. 0.060 in. (1.5 mm). Notch depth = radius plus one material thickness.

• **Grain-direction** constraints are particularly important in harder stock. The line of a sharp V-bend should not be parallel with the grain direction, otherwise cracking or fracture is likely to occur. Many parts function just as well with the grain in the longitudinal direction. When forming harder materials with the grain direction, an appropriately large inside radius is required to avoid cracking (see Material Selection Chapter).

• **Burrs** on the outside of a bend can create "checks" or small fractures. This is particularly evident in parts with two or more bends made in opposite directions (Figure 25). The effect is more predominant with harder-temper alloys and can be eliminated either by deburring prior to forming or punching additional holes to relieve stress.

Guidelines for Drawing

The following recommendations apply to the design of drawn parts:

• **Shapes** are virtually unlimited because of the ability to perform multiple draws. Round is the easiest to draw, followed by square with adequate corner radii. Irregular shapes and those that combine two basic shapes into one are much more difficult and costly to produce.

• **Radii** should be as generous as possible to facilitate drawing. Normally, the punch radius and die radius (R1 and R2 in Figure 26) should be a minimum of four times the material thickness.

The part radius (R3 in Figure 26) should be a minimum of six times the material thickness with suitable drawing-quality material. Small parts may require larger radii. Generally, the larger the radius, the easier and less costly it is to draw the shape.

Depending on the height of the drawn parts, corners can be designed to a certain degree of sharpness by successive drawing operations that progressively reduce the corner radii (Figure 26).

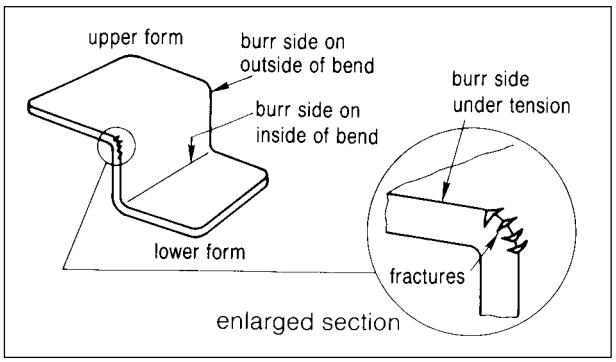


Figure 25. Under tension from forming, the burr side of a blank may develop fractures, which may affect cosmetic appearance.

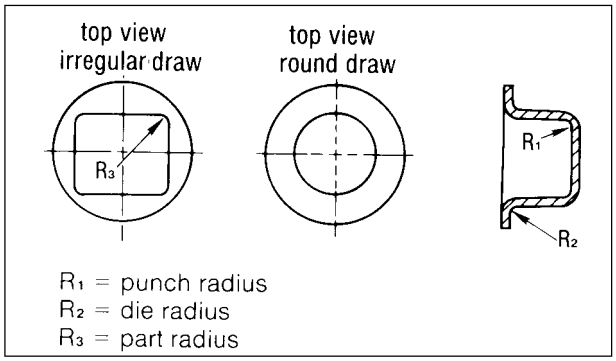


Figure 26. Generous radii are recommended for drawn shapes.

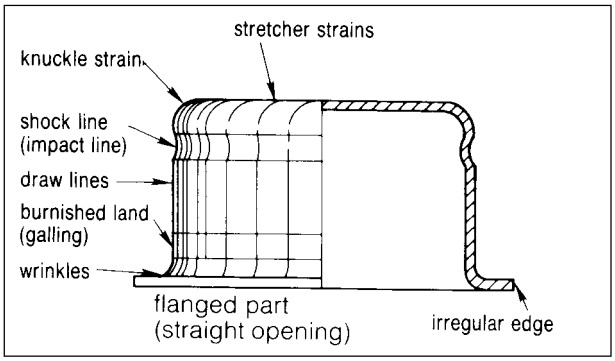


Figure 27. Die marks characteristic of drawing.

Additional Considerations

• **Burr direction** should be indicated on the part drawing. Otherwise, for flat parts, burrs are assumed to be on the "near side" of the drawing. On formed parts burrs are assumed to be on the inside of the form. Some slide forming equipment allows the placement of burrs on either side of the form.

• **Squareness** (angularity). Normal variation on formed 90° bends is usually ±1°.

• **Feature** distortion is more likely to occur when various design feature like holes or slots are too close to an edge, form, or each other.

• **Die marks** are most apparent in drawn parts, which undergo much more deformation than formed ones (Figure 27). Likewise, grippers, if required to hold down a part, may result in significant marking on the part surface. Other types of tooling may also cause marking.

•**Flatness** should not be over-specified. Requiring flatness of less than 0.003 in./in. (0.08 mm) may require a secondary operation at added expense.

Fine Blanking

Fine blanking is the most precise of the stamping technologies. Originally developed to stamp gears and other precise components for the watch industry, it has grown as a specialty branch for close tolerance parts rivaling machined and or powdered metal parts.

The fine blanking stamping technique permits neat cutting in one operation with exceptionally smooth edge surfaces throughout the thickness of the material. The co-action of the fine blanking press and the fine blanking stamping die prevents any fracture in the cutting zone.

Typically, production stamping of holes or features is up to 30% shear on the metal thickness and the balance fracture. In fine blanking, the shear is 90% to 100% of the metal thickness. Fine blanked stampings have the advantage of being less expensive than machined components and greater strength than powdered metals in many applications.

If the cut surfaces of your stampings must meet close tolerance functional requirements, it may be worthwhile to consider fine blanking. A large market for fine blanking is the automotive industry. Gear racks are fine blanked for window opening and closing systems, seat adjustment, door locks, and gear drives. Other major markets for fine blanking are in the electronics and computer industries.

Slide Forming

Slide forming is another option for high-volume production of formed stampings and wire

forms. Various operations such as piercing, trimming, and extruding, as well as assembling, tapping and welding are carried out on coil stock in multiple slide forming machines. Like progressive and transfer systems, all operations take place sequentially. A machine with several cam driven slides as well as a press section does the work instead of a complex progressive die.

Slide forming equipment is used for the production of wire forms, formed stampings and assemblies as shown in Figure 28.

Equipment capabilities range in material sizes from the smallest to ½" (12.7 mm) diameter wire and strip sizes to 3/16" (4.76 mm) thick and 8" (203.2 mm) wide.

• **Fourslide machine.** A machine, either horizontal or vertical, used to fabricate formed metal stampings and wire forms, usually by the action of four forming slides acting upon a stationary mandrel or center tool. See Figure 29.

• **Multiple slide machine** is similar to the fourslide, capable of producing complicated stampings that require features including tapping, coining and assembled contacts. See Figure 29.

• **Rotary slide machine** is a vertical forming machine with the ability to place several forming slides radially around the center tool to produce intricately formed stampings and wire forms. See Figure 29.

• **Linear forming machine** is a vertical forming machine with the ability to place several opposing slides arranged in a linear fashion on both the front and back sides of the tooling area providing the ability to produce very complicated stampings and assemblies. See Figure 29.

Machine Operation

The basic slide forming machine operates as follows: (1) wire or strip stock is pulled off a stock reel by a positive grip feed; (2) the material is advanced through a press section or attachment; (3) a blank is then severed from the strip by the cut-off unit; (4) the metal is bent around the mandrel by the action of a number of cam driven forming tools; (5) a stripping motion posi-

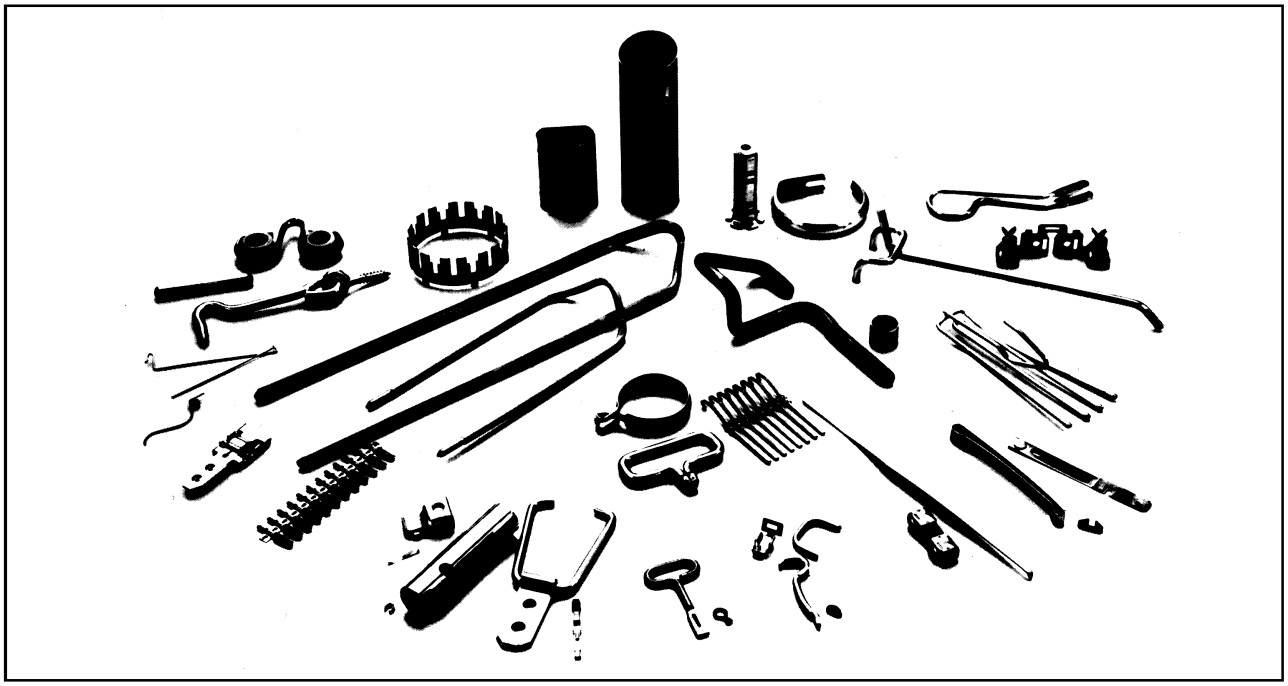


Figure 28. Typical wire forms, formed stampings and assemblies produced on slide forming equipment.

tively clears the part from the mandrel.

The relative simplicity of tooling and the economic advantage of the slide forming process can be observed by comparing the fourslide method of production with the progressive die method illustrated in Figure 30.

Advantages of the Slide Forming Process

Figures 31 and 32 illustrate two major advantages of the slide forming process: (1) the bends are perpendicular to the grain direction, resulting in a stronger part; and (2) in many instances there is no need for a carrier, reducing material requirements. Other advantages include the ability to adjust or rework individual slide mounted tools, control of burr direction and the ability to include value added operations such as threading or assembly. Wire as well as strip stock can be formed with equal ease.

Limitations

Limitations of the process include the lack of high press tonnage, and the inability to complete deep drawn shapes.

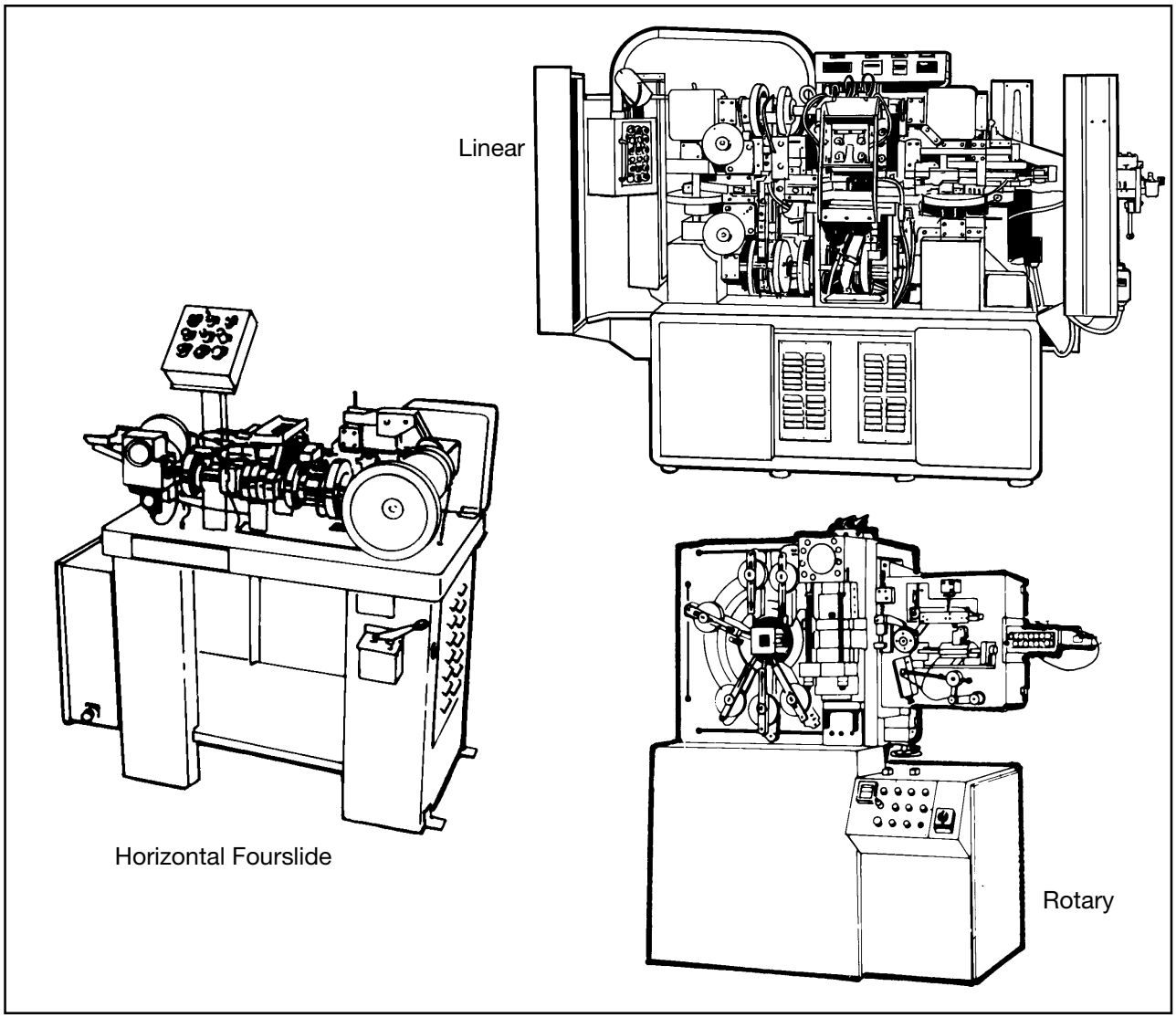


Figure 29. Examples of slide forming equipment.

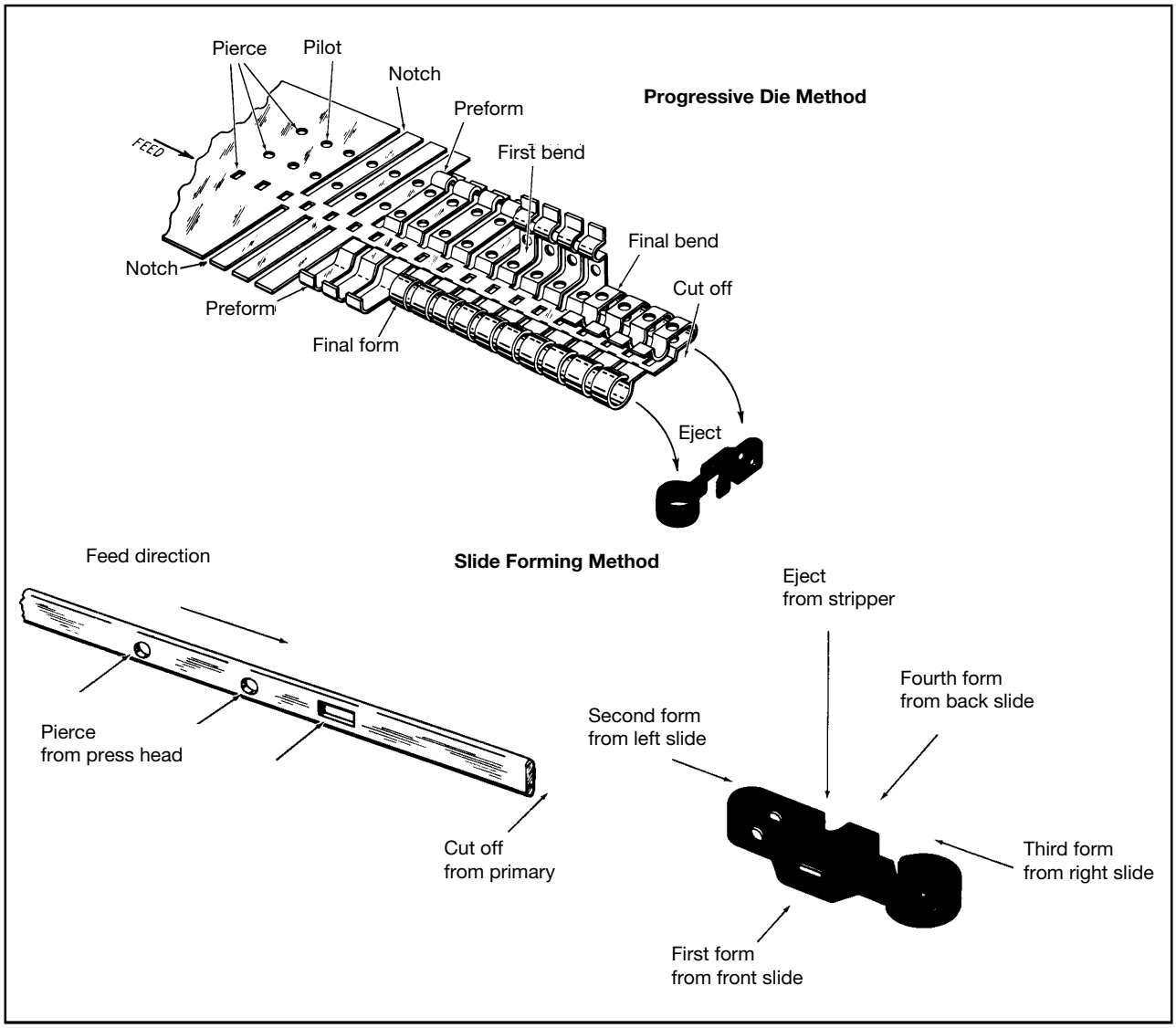


Figure. 30. The relative simplicity of tooling and the economic advantage of the slide forming process are illustrated in this comparison of the slide forming method of production with the progressive die method.

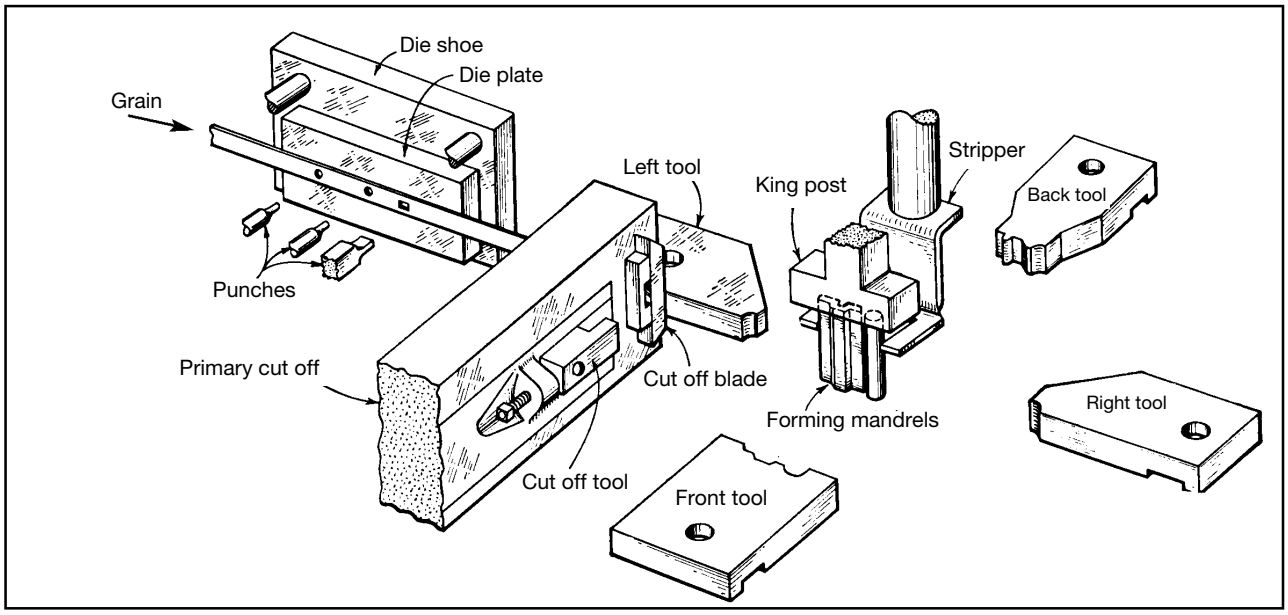


Figure 31. Configuration of tooling in a typical slide forming operation.

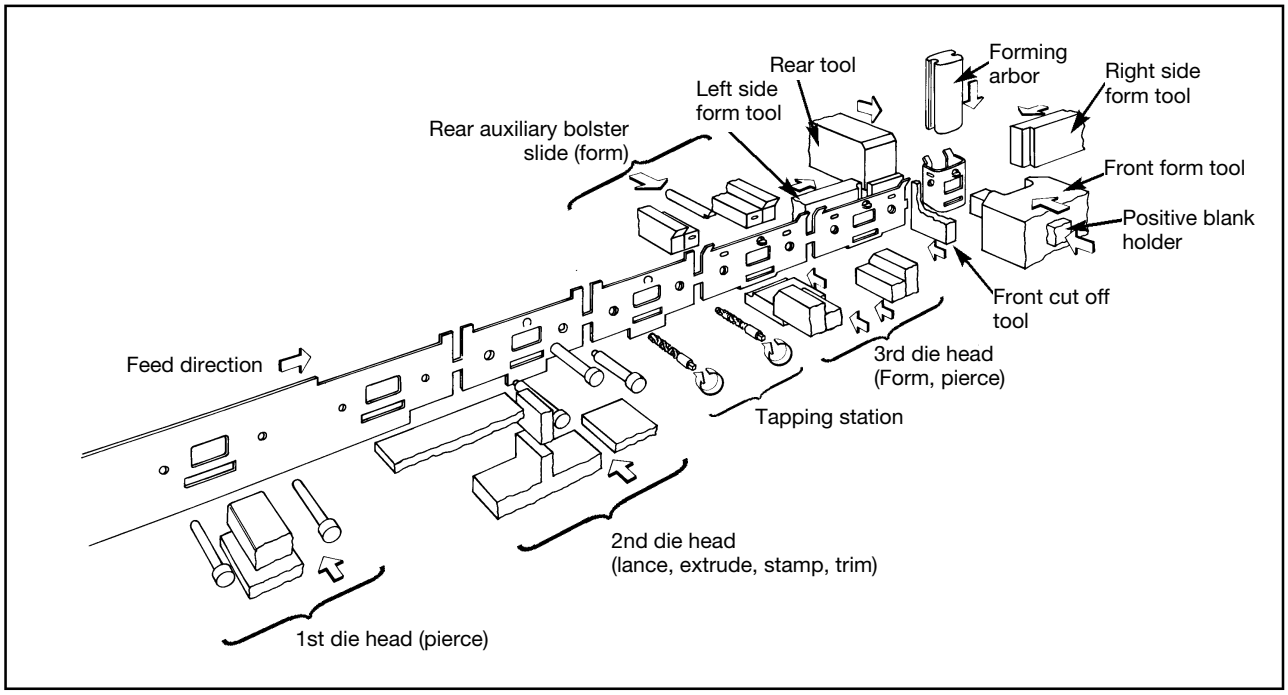


Figure 32. The mechanical and tooling capabilities of a typical multiple slide forming machine are extensive.

8

ROLL FORMING

Roll forming is a continuous bending operation in which sheet or strip metal is plastically deformed along a linear axis. While most materials can be roll formed at room temperatures, some ultra high strength materials and composites are hot formed at elevated temperatures to improve plasticity. Tandem sets of rolls (known as roll stations) shape the metal in a series of progressive stages until the desired cross-sectional configuration is obtained. Because of the progressive manner in which the bending takes place, there is little or no change in cross-sectional area of the work-piece.

Draw a continuous line of any shape on a piece of paper. As long as the line does not cross itself, the roll forming process can probably produce that shape. Potential applications for roll formed shapes are limited only by the imagination. When designing a product, designers should not restrict their thinking. Instead, it is important to think in terms of bending metal into the functional configuration that is really needed.

As a continuous process, roll forming is ideal for producing parts with long lengths or in large quantities. Virtually any material that can be formed by sheet forming techniques can be roll formed. The process typically runs at speeds from 30 to 600 ft/min., depending on the desired configuration, tolerances required and material being formed.

By its very nature, the roll forming process produces a high quality product. It permits close tolerances for both heavy and light gauge material and provides uniform shapes and dimensions. Finished shapes have excellent surface finish and exhibit fine detail.

Some of the best applications for roll forming are large quantities of parts with a constant, complex cross section. The process is ideal for producing shapes of any length.

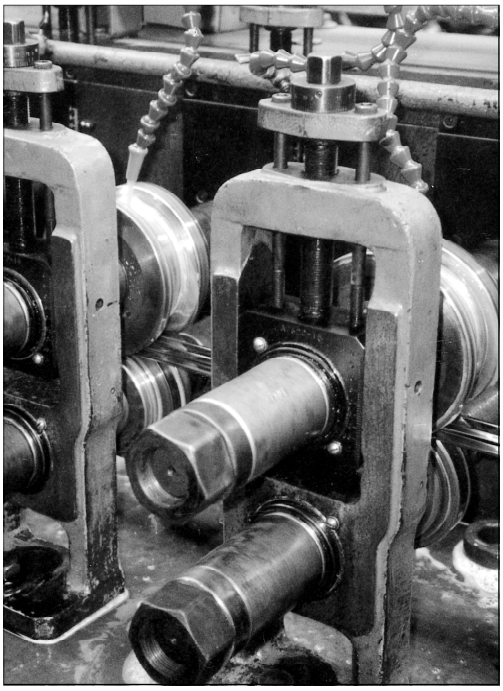
How Can Roll Forming Solve Your Problems?

- Stable, quality-oriented process
- Close tolerances
- Uniformity throughout the part
- Superior surface finish
- Part length unlimited by the process
- Production of thin wall hollow or semi-hollow shapes

- Large production volumes
- Energy efficient, requiring no process heat
- Additional operations performed in line
- Holes or slots where you need them
- Strength for structural rigidity
- Same tooling used for different materials
- Appropriate for any bendable material
- Simultaneous forming of two materials
- Two parts can be run together to form one assembly.

Process Evolution and Roll Forming Equipment

The draw bench was the forerunner of the modern day roll forming machine. Originally, metal blanks were pulled through stationary dies, imparting the desired contour to the part. Later these stationary dies were replaced by a series of idling rollers which progressively deformed the metal. The first generation of modern roll forming machines were being built commercially as early as 1921. Initially, they were used to form blanks that had been sheared from sheet metal. As coil material became more popular and readily available in the 1930s and 1940s, roll forming evolved into the process we know today—a continuous, high production process with driven rollers that cause the coil material to flow through the dies. Door and window frames, automobile radiator tubing, decorative trim and roof decking were among the products being roll formed by the 1940s. With improved equipment, tremendous advances in raw material, and a much better understanding of roll forming technology, the process is now being used to produce components for applications as diverse as appliances, material handling equipment and the space shuttle.





A roll forming line can typically be divided into four major parts: material entry section, roll forming machine, cutoff press, and exit section.

At the entry section of a roll forming line, material may be fed in sheet form, transferred directly from another operation (such as piercing) or more commonly, fed from a continuous coil. Roll forming machines generally consist of roll stations, a drive system to power the rolls and drive the material, a brake that prevents "coasting" after shutdown, and a coolant/lubricant system, to reduce tool wear and energy requirements as well as galling and material buildup on rollers. A straightener is usually located following the last set of rolls. The third

major element of a roll forming line is the cutoff press. Due to the continuous nature of the roll forming process, flying die cutoff techniques are frequently utilized. Flying dies accelerate to the speed of the moving strip, synchronizing with the material, to perform the cutoff stroke. The exit section of the roll forming line is the fourth stage and as with the cutoff press, it may affect the maximum line speed. Normally the roll formed shape exits the roll forming line onto a table or roller conveyor where it is manually removed. When parts can be conveniently stacked, a drop table is often employed. Schematics of simple and complex roll forming lines are found on page 89.

Recent Trends

Computer-Aided Tooling Design is in widespread use to generate what are known as flower diagrams, depicting the anticipated flow of material through the dies. CAD/CAM roll design systems scientifically produce tooling designs for forming roll formed profiles. Once the number and configuration of the roll tooling stations have been mathematically defined in the computer, it is a relatively simple matter to output this information to a numerically controlled lathe, which cuts the rolls.

Programmable Logic Controllers (PLCs) and microprocessors are being utilized to help control processing on roll forming lines. More accurate measurement instruments are allowing hole placement and length tolerances to become tighter and more accurate. A single controller or monitoring system may be used to track critical conditions on multiple roll forming lines simultaneously.

Welding technology advancements have increased roll forming's capability. Shapes can be open or closed (hollow). Closed shapes have typically been produced using a lock seam to mechanically fasten the two edges. Resistance and electric induction welding are more often used today to join strip edges. Roll formers have also used laser welding for several years, but due to limited capacity and high cost of industrial lasers, it was used mostly to weld light gauge aluminum sections. With increased wattage and reduced costs, the new generation of lasers can efficiently weld aluminum, stainless steel, high strength steels and galvanized steel up to .120" thick, depending upon the weld penetration required and production speed. Lasers can have many advantages over TIG, high frequency, and other types of welding. Each project needs to be evaluated for the best manufacturing process.

Tool Material Selection should be based upon the commerical life of the cross section, tolerances required, material to be formed, and annual volumes. Roll tool materials can range from plastic to soft steel to sophisticated hardened and coated tool steels. It is not unusual to obtain several million linear feet of product from high quality tools before reworking is required.

Improved Changeover techniques for tooling and cutoff dies have allowed for smaller batch sizes to be processed more economically and rapidly to meet customers' just-in-time requirements.

Value-Added Services are particularly suited to roll forming operations. Secondary operations can often be incorporated in-line eliminating unnecessary handling and reducing cost. What can't be done in line can be done after the shape is formed. Custom roll formers can perform hole punching, bending, cutting, parts cleaning, welding and joining, finishing, assembly and fabrication, buffing, polishing, deburring, and even heat treating, if necessary.

Attributes

Uniformity of roll formed shapes allows them to be easily bent. When producing rings or segments of rings, shapes can be curved to uniform radii at the rolling machine without wrinkles and without disturbing a pre-finished surface. Helices are also possible. Material elongation should be considered in designing parts

for rings to help eliminate wrinkles and fractures. Usually, the more elongation a material has, the easier it is to bend. Where curves are not a constant radius, the uniformity of roll formed shapes makes them ideal for stretching or tangent bending.

Prepiercing is the fabrication of a series or pattern of holes in the flat strip stock before forming. It is done in one continuous operation together with roll forming and, therefore, can be a cost saver. Repetitive piercing, as in wallboard plaster bead or shelf posts, will minimize the piercing tool cost because a small die can be used.

Postpiercing is done in-line but after the part is formed. It is part of a sequence of operations performed without handling and thus is very efficient. Often this is less expensive and more desirable than prepiercing because better accuracy from the end of the part can be obtained.

Welded dimples or projections can be formed while the parts are being rolled to improve accuracy and economy in the finished part. Tabs, stops and raised areas can also be formed.

Almost any material available as coil or sheet can be roll formed. The material should be as ductile as design strength will allow to permit crisp, sharp corners and easy bending. When high-strength alloy steels, heat-resistant steels, titanium and other alloys are used, bend radii specified by the mill should be followed.

Designing for Economy

• Roll formed shapes should not be too deep. Profiles that are deep require larger diameter forming rolls that are more expensive and require larger machines. One rule-of-thumb for average size machines is that maximum form depth should be four inches. Greater depths are also available but require the use of larger machines and more expensive tooling.

• Parts should have uniform thickness throughout since the raw stock is sheet or strip. Thickness may be increased by folding the material back on itself.

• If wide, flat areas are required at the edge of a part, consider using small stiffening ribs. The part will stay flatter and be much stronger.

• When planning a leg, as with an angle or channel, the length of the leg should not be less than three times the material thickness (3T) past the tangent point. Legs shorter than 3T are difficult to form because it is hard to get enough leverage to bend the leg up. This also applies when hemming or bending the material back on itself.

• To plan prepiercing where hole location is not critical, design the pattern to be repetitive without specifying the location of the beginning of the pattern from the end of the part.

• When the prepiercing pattern is critical and not repetitive within the part, try to design it to have the minimum number of hole or notch patterns within the part.

• If a piercing pattern is used that requires holes in a specific area relative to the end of the part, try to keep it more than 1/2 in., but within 4 in. of the end of the part.

• Use maximum bend radii permissible. An inside bend radius of less than the material thickness will lessen roll life and increase power requirements.

• Design parts to be as symmetrical as possible to eliminate twist in the finished shape.

• Design parts so that holes, slots and notches are not distorted due to placement too close to or directly on a bend line. It is desirable to have the edge of a hole or slot at least three times the material thickness away from the tangent point of the nearest bend.

• If piercing, notching or tabbing is required at either or both ends of the part, keep the pattern of holes and notches close to the end of the part, so that these operations need not repeat throughout the full length of the part.

• Do not ask for tolerances that are closer than necessary. Doing so will greatly increase the cost of both the tooling and the finished part.

Materials

Virtually any bendable metal or material can be rollformed. Following is a list of many of the

Roll Forming Design Tips

Instead of this… **Try this**

Tip #1



Legs, such as this one on the outside of metal building panel stock, when rolled straight, will be wavy. A slight bend designed into the leg will help keep it flat.

Tip #2



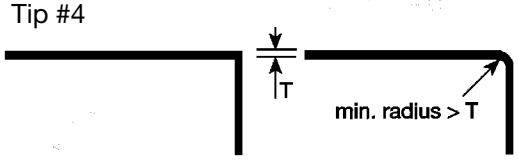
When roll formed, the flat 180° hem will be wavy. Forming the hem in a tear drop shape will keep the edge flat.

Tip #3



Forming a 90° sidewall adds more forming passes, increases roll wear and may result in tooling marks on the leg. Leaving sufficient draft, as with a 75° angle, reduces the number of roll stations needed to form the shape and should prevent scoring of the workpiece.

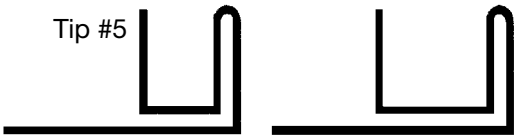
Tip #4



Sharp inside radii are difficult to form without marking the outside radius or causing cracks in prepainted materials or materials with poor ductility. A larger radius reduces this problem. If sharp corners are necessary, they can be achieved by beading thin stock or grooving thick stock.

Instead of this… **Try this**

Tip #5



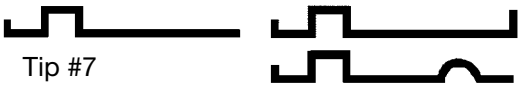
Narrow slot designs can lead to roll breakage. A wider slot design will alleviate the problem.

Tip #6



Extremely short legs can be difficult to form. Design leg length to be at least three times material thickness past the tangent point.

Tip #7



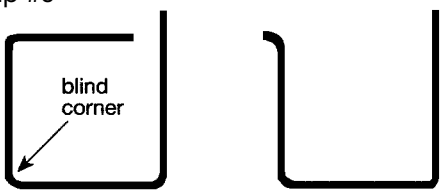
Adding a bead or a leg to wide flat areas will help maintain straightness and avoid the tendency toward waviness or other irregularities.

Tip #8



Wide sweeping radii may be difficult to control when the material is not formed beyond its elastic limit. Put a bend in each end to keep it straight.

Tip #9



Blind corners are less accurate and more difficult to control because roll tooling cannot contact both sides of the stock. If close tolerances or precise bends are required, try a design in which both sides of the stock can be controlled by rolls.

metals being roll formed today. Some metals that could be roll formed, such as tool steel, are not included on this list because they are not readily available in coil or sheet form.

- Aluminum—common and heat treatable alloys
- Brass • Bronze • Bi-metals • Bi-materials
- Two metals rolled simultaneously—such as rolling thin stainless tubes on the outside of thicker carbon tubes to take advantage of the low cost and high strength of carbon steel and the attractive appearance of stainless
- Coated metals—clad, galvanized, prefinished, preplated, prepainted, vinyl laminated, tin plated
- Coated alloys—for aerospace, petrochemical and military applications
- Composites

• Copper and copper alloys
• Exotic alloys—niobium, tantalum, zirconium
• High temperature alloys such as Hastelloy, Inconel and heat resistant nickel-based alloys
• Lead • Magnesium alloys • Nickel alloys
• Precious metals
• Steel—carbon, alloy and stainless, HSLA, cold rolled, hot rolled, all commercial quality steel, aluminized steel
• Tin alloys • Titanium • Zinc

Tolerances for Roll formed Shapes

Dimensional variations in roll formed parts are based on material, equipment and application. Tolerances vary due to material springback, variations in material width and thickness, material properties, tooling quality and wear, machine condition and setup, and operator skill.

Whenever possible supply a sample assembly drawing to illustrate the end use of the part and areas where tighter tolerances are required. The drawing of the shape should become part of the purchase order once an agreement is reached with the roll former.

While the greatest economies are usually realized when specified tolerances are as generous as possible, tolerances tighter than those cited below are routinely achieved. Often dimensional problems can be avoided by ordering the material to be formed with somewhat tighter than commercial quality tolerances.

The following tolerances are given as general guidelines only. Far tighter tolerances are possible but may add to the cost due to greater tooling expense, longer development time, or the need for a higher grade material. If more restrictive tolerances are required the designer should clearly define them and discuss them with the custom roll formed shape producer.

Tolerances

Cross-sectional

±0.031 in. for fractional dimensions
±0.010 in. for decimal dimensions
±1° for angular dimensions

Straightness (bow or camber)

0.015 in. maximum deviation per ft. of length

Twist

1/2° maximum deviation per ft. of length

Length

±0.015 in. for parts up to 36 in. long
±0.030 in. for parts from 36 to 96 in. long
±0.060 in. for parts from 96 to 144 in. long
±0.250 in. for parts longer than 144 in. long

Applications for Roll Formed Shapes

Roll formed shapes are formed in material 0.005 in. thick, weighing ounces, to 3/4 in. thick sections as long as 100 ft. or more that weigh in at over a ton. End use applications for roll formed shapes are numerous and diverse.

The degree to which roll formed shapes have become integral to almost every industry is illustrated by the following list of end use applications. By no means is this list all-inclusive. It is however representative of some of the many areas in which shapes are being used today. In spite of the numerous applications detailed below, the most innovative use of roll formed shapes has yet to be discovered, but is still locked in the imagination of the designer.

Agriculture

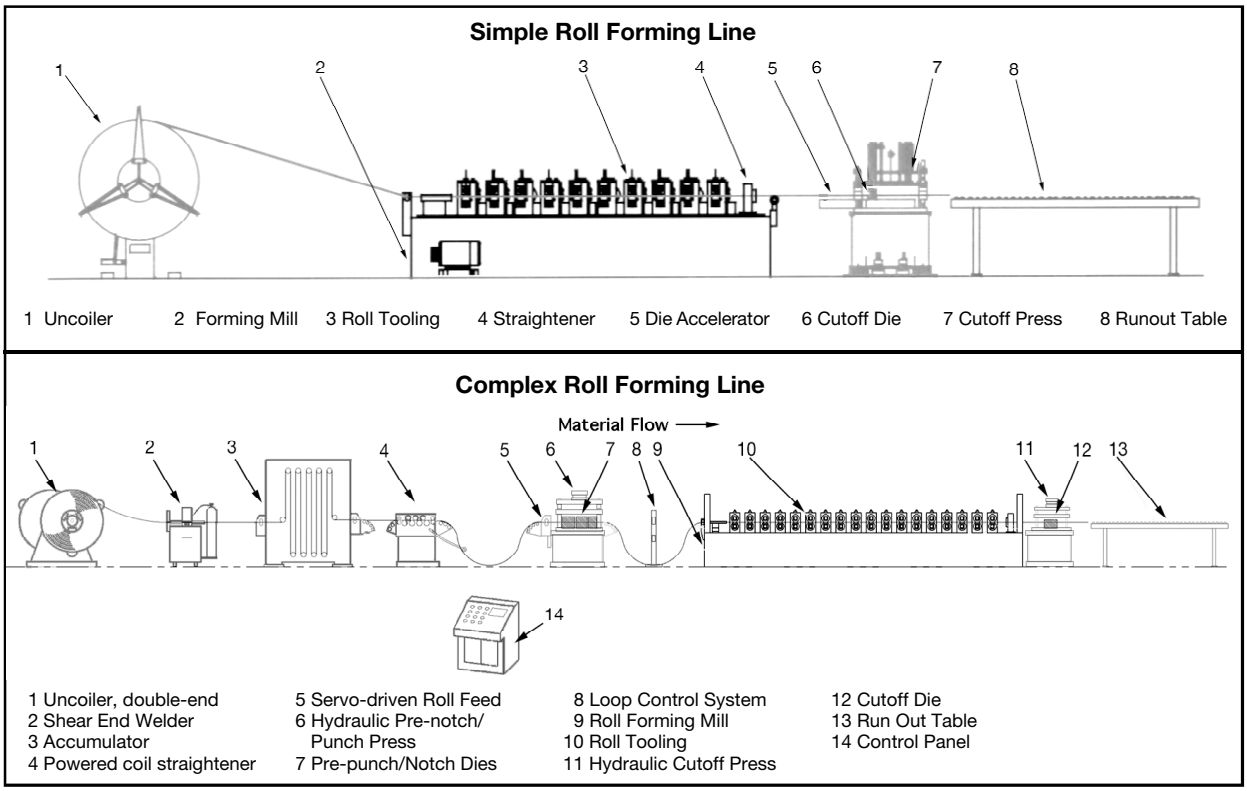
Grain bin floors, chicken roosts, trim and structural shapes for tractors and other farm equipment, fence posts, grape arbor stakes, lawn and garden equipment components.

Aircraft/Aerospace

Airframe stringers and longerons, interior components such as trim and window frames, stiffeners and jet engine components such as honeycomb seals, shrouds and backing rings, leading edges of composite helicopter blades.

Appliance

Panels for refrigerators, stoves, microwave ovens, laundry and vending machines; refrigerator shelves, shell fronts and ladder supports,



Drawings courtesy of Roll-Kraft/Ardcor

door seal retainers, appliance handles, control panel trim, decorative trim, drawer slides for ovens and trash compactors, structural components for appliances.

Building products

Bleacher sections, interior supports for window reinforcements, sliding door and window tracks, elevator interiors and trim, escalator components, curtain wall sections and window frames, slatted wall dividers and studs, residential steel framing, metal roof decks and siding panels, decorative interior components, gutters and down spouts.

Bridge & highway products

Road signs, highway guardrail, bridge deck reinforcement panels.

Heating, ventilating & air conditioning

Electric heater housings, air conditioner cases, HVAC ducts, pattern control diffusers, air filter frames, cooling tower louvers, solar collector panel components.

Home, office & store furniture and fixtures

Indoor and outdoor furniture, hardware accessories, modular and sliding partitions, work surface reinforcements, shelves, drawer fronts and slides, kitchen and file cabinets, lighting fixtures, metal picture frames, decorative trim, department store display racks and cases, trim for frozen food cases, store fixtures and supermarket shelving.

Transportation

Components used in automobiles, trucks, buses, trailers, subways, ships and boats; vehicle trim and grill members, window tracks, bumpers, division bars, reinforcement bars, structural components, bus and subway car hand rails, truck trailer and railroad car structural members.

9

METAL SPINNING

Metal spinning is a forming process which produces hollow parts that are typically circular in cross-section. The basic spinning process starts with a flat metal disc (blank) which rotates on a lathe. This rotating blank is pressed against a tool (mandrel, chuck) which duplicates the interior of the part. This pushing action over the tool results in a formed part.

The basic metal spun shapes are the hemisphere, cone, cylindrical shell, and venturi as well as others, depicted in Figure 1 below.

Products produced by spinning are utilized in many industries: aerospace, agricultural, computer, ventilation, lighting, marine, food service, automotive, etc.

Metal spinning used to be associated with prototypes and low volume production only. However, with the introduction of automation

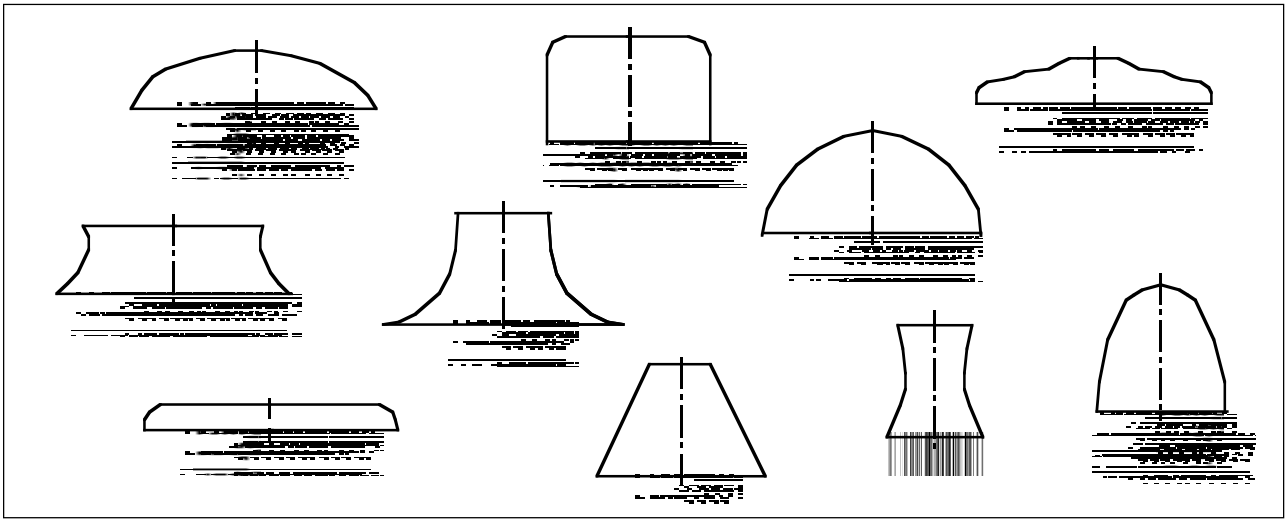


Figure 1. Typical shapes produced by the metal spinning process.

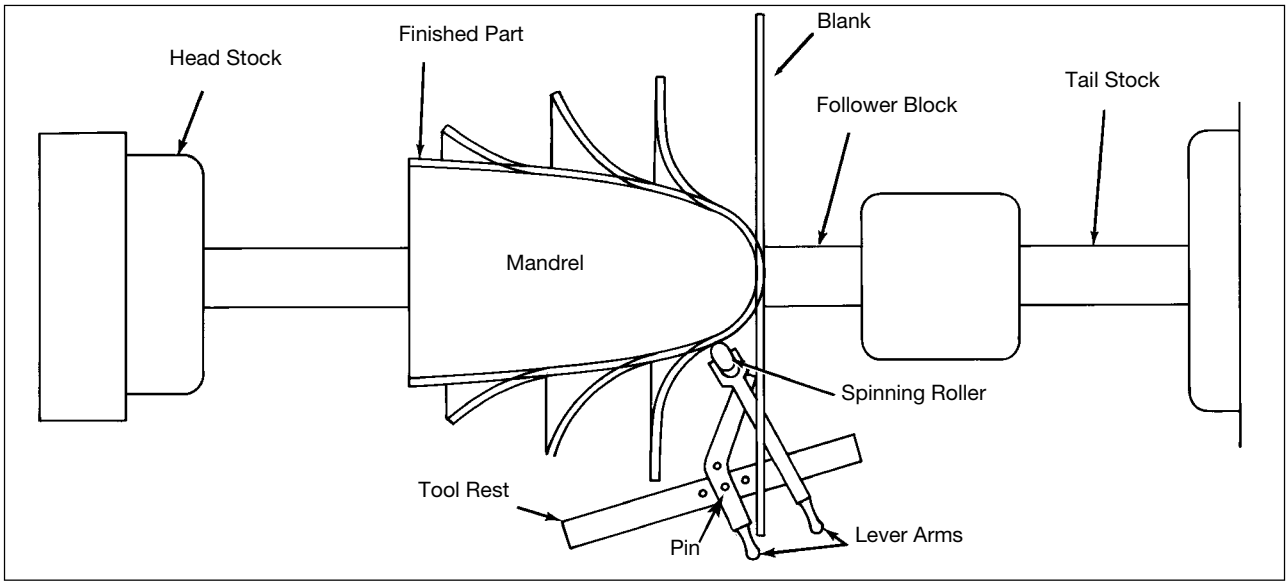


Figure 2. Manual spinning. The sequential development of the finished part in several passes is shown.

technology, spinning is now a cost effective option for both medium and high volume production. The relatively inexpensive tooling price for spinning still makes this forming method a cost effective fabricating solution.

The Metal Spinning Process

The diagram below shows a basic setup for a horizontal spinning lathe. The mandrel is mounted to the headstock of the lathe. A Follower Block is mounted to the tailstock. A circular blank is then clamped to the tool by advancing the Follower Block.

The tool rest and pin provide a support system for the lever arms, a scissor-like apparatus. The operator, using lever arms, applies pressure to the blank via a spinning roller or other forming tool. The movement of the roller across the blank is called a pass. A series of passes, which ultimately forms the completed part, is achieved by repositioning the lever arms incrementally.

Metal Spinning Equipment

Metal spinning lathes can be grouped into three broad categories: manual, power assisted, and automatic. Each paragraph below provides a brief outline of the equipment and typical applications.

• **Manual Spinning** lathes typically accommodate blanks ranging from 0.25 in. (6.35 mm) to 72 in. (1.8 m) in diameter. Larger manual lathes are available to accommodate blanks of up to 160 in. (4.1 m) in diameter.

• **Power Assisted Spinning** is manual spinning augmented by hydraulic cylinders which provide additional force on the workpiece rather than only human force. This additional power is useful when forming strong metals such as stainless steel and exotic alloys.

• **Automatic Spinning** is a cost-effective option for medium and high volume production since it offers high repeatability and fast cycle times. This process is based on Computer Numerical Control (CNC) and Programmable Numerical Control (PNC). See Figure 3. For PNC, the lathe is programmed through a "teach" mode where the first workpiece is manually spun while the computer records the movements. Once this initial workpiece has been spun, the lathe is put into "playback" mode for production. Blanks are positioned in the lathe by the operator and the playback cycle is initiated. The workpiece is then formed

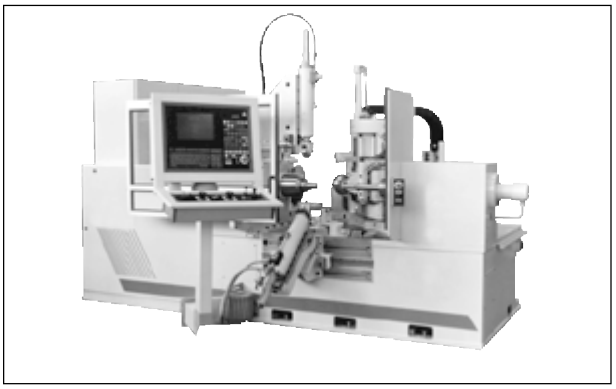


Figure 3. A modern playback/CNC-controlled spinforming machine can produce parts of various materials in varying volumes. Such machines cost effectively produce prototypes or large quantities of parts.

automatically, exactly duplicating the movements of the manual spinning.

Finally, automatic spinning can incorporate secondary operations such as edge treatment, machining and turning as an integral part of the machine cycle. Modern CNC/PNC systems can accommodate multiple station tooling turrets, automatic loading system and robotic machine tending.

Basic Operations of Metal Spinning

In forming a part by spinning, a combination of processes may be utilized to complete a part. These processes include: preforms, conventional spinning, shear spinning, edge treatment (trimming, beading, curling, hemming) as well as secondary operations.

• **Preforms.** A preform is a partially formed part which is used to increase the efficiency of the next forming process. Preforms may be in the shape of cylindrical shells, cones, and more. These preforms can be achieved through spinning or other forming operations such as drawing.

• **Conventional Spinning.** The spinning process usually involves a series of passes to complete the formed part. During each pass the metal is stretched thus thinning out the material. This thin-out characteristic is typical of the conventional spinning process. If necessary thin-out can be minimized.

• **Shear Spinning** is a variation of conventional spinning. Shear spinning refers to the formation of a part in just one pass. This process allows for an accurate prediction of finished material thickness. Shear spinning is typically associated with conical and cylindrical shapes.

• **Edge Treatment.** The edges of a spun part can be finished in many ways. Parts can be trimmed for a straight edge, hemmed for a folded edge, or beaded for a rolled or curled edge. These edge treatments can be performed in a spinning lathe or on a separate machine.

• **Secondary Operations.** Often spun parts require secondary operations. This may range from piercing holes, to heat treating, to powder coating, to laser cutting. Many metal spinning companies perform these operations in-house or will subcontract them for you.

Tooling Composition

Tooling for spinning can be fabricated from various materials. Many factors determine which material is most appropriate: production volume, finish, tolerancing, metal, etc. The three basic alternatives are wood, plastic and steel.

• **Wood** tools are made from a variety of materials: maple, fine grain particle board, etc. Wood tools are typically used for parts where tolerancing and/or finish is not critical.

• **Plastic.** A paper-based plastic is also used for tooling. As compared to wood, plastic tooling is generally more durable, provides a superior surface finish and will maintain closer tolerances.

• **Steel** tools are mainly used to form shapes fabricated from stainless steel or other strong metals. Due to the relatively hard, smooth surface of steel tools, parts spun on steel tooling can achieve a superior surface finish and maintain

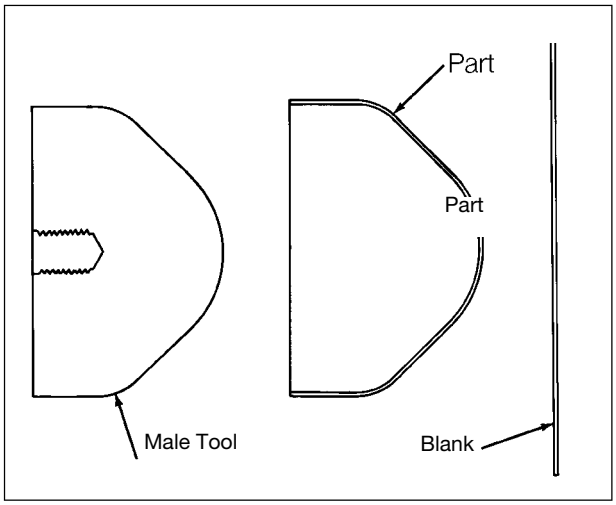


Figure 4. Relationship of male tool, finished part and starting blank.

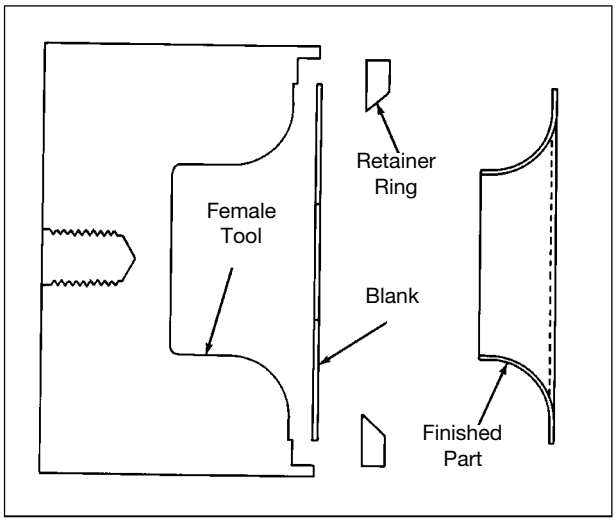


Figure 5. Relationship of female tool, starting blank and finished part.

close tolerancing. Steel tools can be fabricated from both mild steel and tool steel. The life of the tool can be increased through heat treating.

Tooling Design

Spinning tooling can be grouped into three broad categories: male, female, and collapsible.

• **Male Tool.** A male tool is the most common type of spinning tool. It duplicates the interior dimensions of the part. See Figure 4.

• **Female Tool.** A female tool conforms to the exterior dimensions of the part. This type of tool is often used to form flanges and returns. See Figure 5.

• **Segmented or Sectional Chuck.** A segmented tool is required when the diameter of the part becomes smaller as the part is formed. If a male tool is used this smaller diameter or neck prevents the part from being removed from the tool; therefore, a segmented tool is required. See Figure 6. A segmented tool has a removable center core which keeps the perimeter pieces in place during spinning. After the part is spun, the core is removed which permits access to the perimeter pieces. The use of a segmented tool involves assembling and disassembling the tool for each piece spun.

Advantages and Limitations of Metal Spinning

The metal spinning process has both advantages and limitations.

Advantages:

• Spinning mandrels are relatively inexpensive due to their simplicity and composition.

• This simplicity translates into short lead times for new parts.

• Design changes can usually be made at a minimum of expense again due to the inexpensive nature of the tooling.

• The factors above combine to make spinning ideal for prototypes.

• Spinning is typically a cold working

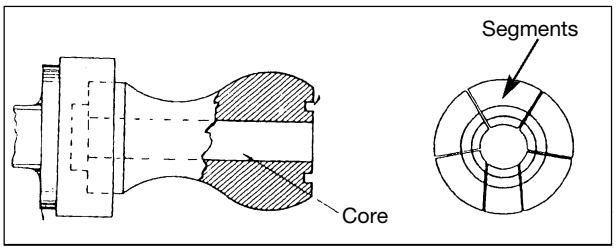


Figure 6. Segmented or sectional chuck.

process; therefore, spinning increases the tensile strength of the material.

• The spinning process can accommodate very large parts in excess of 120 in. (3.0 m) in diameter as well as parts requiring thick material such as 0.500 in. (12.7 mm) stainless steel.

Limitations:

• Tight tolerancing requirements may dictate the use of secondary operations.

• Manual spinning is more labor intensive than automatic spinning or other forming processes such as drawing.

• The uniformity of a manually spun part is closely associated with the skill of the operator.

Pre-Design Basics

The following design guidelines for metal spinning can affect quality and cost.

• It is preferrable to specify the inside diameter (I.D.) and associated tolerance since the outside diameter will vary due to material thin-out. If necessary, a specific outside diameter (O.D.) can be maintained.

• If uniform wall thickness is required, identify the portion of the part which is affected. Additional operations may be required to achieve this uniform wall thickness.

• Corner radii should be specified at 2 to 3 times material thickness. Tighter radii can be achieved on thicker material and through secondary operations.

• If concentricity is critical, specify the total indicated runout (TIR) and indicate if this applies in the restrained or unrestrained condition of the part.

• Working closely with your spinning supplier during the design phase may significantly improve formability and reduce cost.

• If tight tolerancing is required in a small area only, specify that area. The erroneous assumption that the tight tolerancing applies to the entire part will dramatically increase the price of the part.

• Surface finish is affected by the material, thickness, tool condition, forming speed, and other factors. If the specified surface finish cannot be achieved through spinning, secondary operations can be performed.

• Any formable metal can be spun. The stronger the material the more difficult the spinning.

Tolerances

For tolerances see Table I

Table I. Tolerances for metal spun parts which are typical for most applications.

Diameter of Finished Part	Commerical Applications	Special Applications
Up to 24" Diameter (600 mm)	±0.015" to 0.031" (0.38 mm to 0.79 mm)	±0.001" to 0.005" (0.025 mm to 0.13 mm)
25" to 36" Diameter (600 mm to 900 mm)	±0.031" to 0.047" (0.79 mm to 1.19 mm)	±0.005" to 0.015" (0.13 mm to 0.38 mm)
37" to 48" Diameter (900 mm to 1200 mm)	±0.047" to 0.062" (1.19 mm to 1.57 mm)	±0.010" to 0.030" (0.25 mm to 0.76 mm)
49" to 72" Diameter (1200 mm to 1800 mm)	±0.062" to 0.094" (1.57 mm to 2.39 mm)	±0.015" to 0.045" (0.38 mm to 1.14 mm)
73" to 96" Diameter (1800 mm to 2400 mm)	±0.094" to 0.125" (2.39 mm to 3.17 mm)	±0.020" to 0.060" (0.51 mm to 1.52 mm)
97" to 120" Diameter (2400 mm to 3000 mm)	±0.125" to 0.156" (3.17 mm to 3.96 mm)	±0.025" to 0.090" (0.64 mm to 2.29 mm)

10

DESIGNING FOR DRILL PRESS WORK

Machining processes for stampings and sheet metal fabrications are secondary operations performed to accommodate specific design features and mating parts, or to facilitate assembly by a variety of fastening methods. While drilling, tapping, countersinking and counterboring operations are basically straightforward machining, special considerations apply when these operations are performed on sheet metal parts.

Since these machining operations are usually employed on holes that have been previously punched, positioning (hole-to-hole, hole-to-edge, hole-to-form, etc.,) should follow the recommendations set forth in the chapters on CNC Turret and Laser Fabrication and Stamping Production. As is the case with metalforming operations, keeping tolerances as liberal as possible while preserving design function helps minimize machining costs.

• **Drilling** to make or enlarge a hole is less common with stampings because holes can be economically punched. Drilling is only done when dictated by design requirements, such as to reduce eccentricity or align the center of one hole with a second hole on another part feature (Figure 1). If a punched hole will distort during forming, drilling the hole after forming can maintain roundness and orientation (Figure 2).

Drill presses, NC and multi-spindle equipment are commonly used for drilling, countersinking and tapping operations on sheet metal components.

• **Tapping** is performed on pre-punched, extruded and drilled holes. For optimum

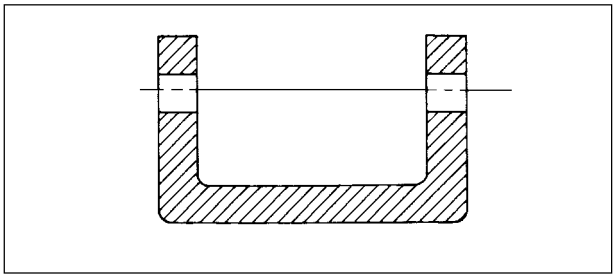


Figure 1. Drilling may be used to ensure alignment of concentric holes located on separate part features.

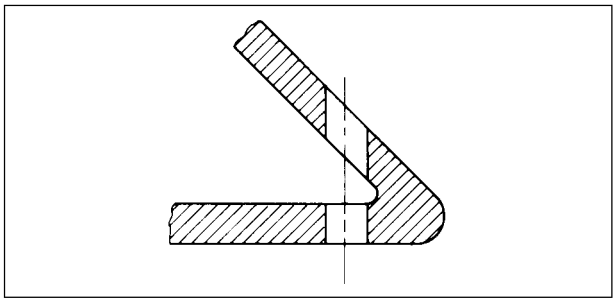


Figure 2. Drilling holes after forming may be required in particular designs to minimize distortion and/or optimize alignment.

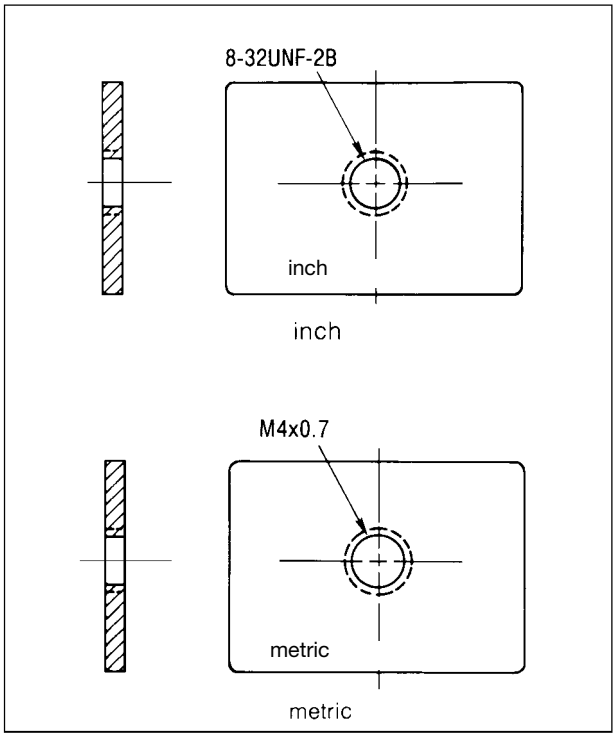
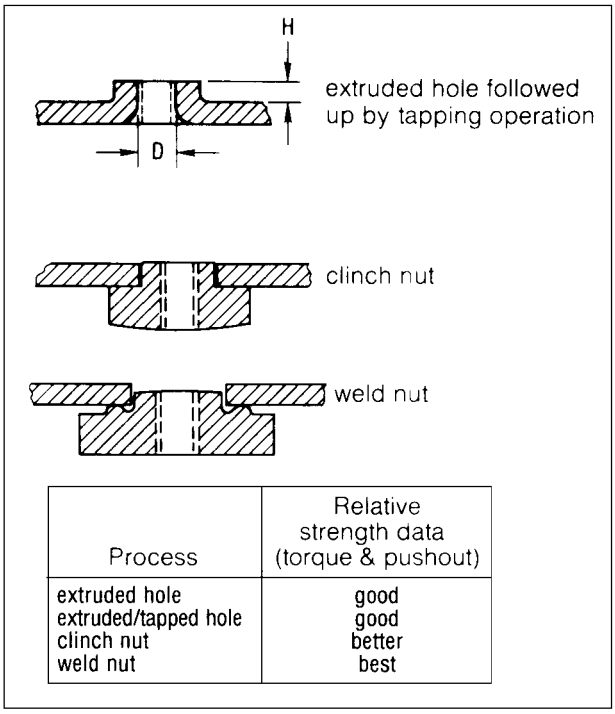


Figure 3. Specify internal threads to ANSI Y14.6. This example indicates: Nominal diameter as #8; threads/in. as 32; thread series as Unified National Fine; and thread class as 2 with the letter B designating internal threads. The Metric designation gives the major diameter and the pitch per turn.

economy, the same internal threads (size, threads/in., etc.,) should be specified throughout the part, if possible.



Process	Relative strength data (torque & pushout)
extruded hole	good
extruded/tapped hole	good
clinch nut	better
weld nut	best

Figure 4. Relative strength of various thread forming processes.

Tapped holes should be specified on the part drawing according to recommended practice per ANSI Y14.6 (Figure 3). Recommended hole sizes prior to tapping follow set standards based on the thread diameter, two choices of taps, cutting and thread forming. Listed first, on Tables I and II are the core hole sizes for internal threads generated by cutting taps.

In most sheet metal applications, thread rolling taps are preferred over thread cutting taps for several important reasons:

- The operation is slightly faster and, hence, more economical.
- Thread rolling taps generate fewer burrs, reducing potential operator and user safety hazards.
- Thread rolling taps eliminate metal showings which may later become detached and cause failure of electronic components.

Table I. Standard American Cut Threads and Core Hole Diameters

Nominal thread size	Outside diameter (mm)	Root diameter (mm)	Hole diameter				Nominal thread size	Outside diameter (mm)	Root diameter (mm)	Hole diameter			
			60%	65%	70%	75%				60%	65%	70%	75%
0-80	.060 (1.52)	.038 (.97)	0.52 (1.32)	.0501 (1.30)	0.51 (1.28)	.050 (1.27)	8-36	.164 (4.17)	.116 (2.94)	.146 (3.71)	.144 (3.67)	.143 (3.63)	.141 (3.59)
1-56	.073 (1.85)	.042 (1.07)	.061 (1.56)	.060 (1.54)	.059 (1.51)	.059 (1.49)	8-40	.164 (4.17)	.121 (3.07)	.148 (3.75)	.146 (3.72)	.145 (3.68)	.144 (3.65)
1-64	.073 (1.85)	.046 (1.17)	.063 (1.60)	.062 (1.57)	.061 (1.55)	.060 (1.53)	9-24	.177 (4.50)	.105 (2.66)	.150 (3.81)	.148 (3.75)	.145 (3.69)	.143 (3.64)
1-72	.073 (1.85)	.049 (1.24)	.064 (1.63)	.063 (1.61)	.062 (1.59)	.062 (1.57)	9-30	.177 (4.50)	.119 (3.03)	.155 (3.95)	.154 (3.90)	.152 (3.85)	1.50 (3.81)
2-56	.086 (2.18)	.055 (1.40)	.074 (1.89)	.073 (1.87)	.072 (1.84)	.072 (1.82)	9-32	.177 (4.50)	.123 (3.12)	.157 (3.98)	.155 (3.94)	.153 (3.89)	1.52 (3.85)
2-64	.086 (2.18)	.059 (1.50)	.076 (1.93)	.075 (1.91)	.074 (1.88)	.073 (1.86)	10-24	.190 (4.83)	.118 (2.99)	.163 (4.14)	.161 (4.08)	.158 (4.02)	.156 (3.97)
3-48	.099 (2.52)	.063 (1.60)	.085 (2.17)	.084 (2.14)	.083 (2.11)	.082 (2.08)	10-28	.190 (4.83)	.128 (3.25)	.167 (4.24)	.165 (4.19)	.163 (4.14)	.161 (4.09)
3-56	.099 (2.52)	.068 (1.72)	.087 (2.22)	.086 (2.20)	.085 (2.17)	.085 (2.15)	10-30	.190 (4.83)	.132 (3.36)	.168 (4.28)	.167 (4.23)	.165 (4.18)	.163 (4.14)
4-32	.112 (2.85)	.058 (1.47)	.092 (2.33)	.090 (2.29)	.088 (2.24)	.087 (2.20)	10-32	.190 (4.83)	.136 (3.45)	.170 (4.31)	.168 (4.27)	.166 (4.22)	.165 (4.18)
4-36	.112 (2.85)	.064 (1.62)	.094 (2.39)	.092 (2.35)	.091 (2.31)	.089 (2.27)	12-24	.216 (5.49)	.144 (3.65)	.189 (4.80)	.187 (4.74)	.184 (4.68)	.182 (4.63)
4-40	.112 (2.85)	.069 (1.74)	.096 (2.43)	.094 (2.40)	.093 (2.36)	.092 (2.33)	12-28	.216 (5.49)	.154 (3.92)	.188 (4.90)	.186 (4.85)	.184 (4.80)	.181 (4.75)
4-48	.112 (2.85)	.076 (1.93)	.098 (2.50)	.097 (2.47)	.096 (2.44)	.095 (2.42)	12-32	.216 (5.49)	.162 (4.11)	.196 (4.97)	.194 (4.93)	.192 (4.88)	.191 (4.84)
5-36	.125 (3.18)	.077 (1.95)	.107 (2.72)	.105 (2.68)	.104 (2.64)	.102 (2.60)	1/4-20	.250 (6.35)	.163 (4.15)	.218 (5.53)	.215 (5.46)	.212 (5.39)	.209 (5.32)
5-40	.125 (3.18)	.082 (2.08)	.109 (2.76)	.107 (2.73)	.106 (2.69)	.105 (2.66)	1/4-28	.250 (6.35)	.188 (4.78)	.227 (5.76)	.225 (5.71)	.223 (5.66)	.221 (5.61)
5-44	.125 (3.18)	.086 (2.18)	.110 (2.80)	.109 (2.77)	.108 (2.74)	.107 (2.71)	5/16-18	.313 (7.94)	.217 (5.51)	.277 (7.03)	.274 (6.96)	.271 (6.88)	.268 (6.80)
6-32	.138 (3.51)	.084 (2.13)	.118 (2.99)	.116 (2.95)	.114 (2.90)	.113 (2.86)	5/16-24	.313 (7.94)	.241 (6.12)	.286 (7.26)	.284 (7.21)	.281 (7.15)	.279 (7.09)
6-36	.138 (3.51)	.090 (2.28)	.120 (3.05)	.118 (3.01)	.117 (2.97)	.115 (2.93)	3/8-16	.375 (9.53)	.267 (6.78)	.334 (8.49)	.331 (8.41)	.328 (8.32)	.324 (8.24)
6-40	.138 (3.51)	.095 (2.41)	.122 (3.09)	.120 (3.06)	.119 (3.02)	.118 (2.99)	3/8-24	.375 (9.53)	.303 (7.69)	.348 (8.84)	.346 (8.78)	.343 (8.72)	.341 (8.67)
7-30	.151 (3.84)	.093 (2.37)	.129 (3.29)	.128 (3.24)	.126 (3.19)	.124 (3.15)	7/16-14	.438 (11.11)	.314 (7.98)	.392 (9.95)	.388 (9.85)	.384 (9.75)	.380 (9.65)
7-32	.151 (3.84)	.097 (2.46)	.131 (3.32)	.129 (3.28)	.127 (3.23)	.126 (3.19)	7/16-20	.438 (11.11)	.351 (8.93)	.4.06 (10.30)	.403 (10.23)	.400 (10.16)	.397 (10.89)
7-36	.151 (3.84)	.103 (2.61)	.133 (3.38)	.131 (3.34)	.130 (3.30)	.128 (3.26)	1/2-13	.500 (12.70)	.367 (9.32)	.450 (11.43)	.446 (11.33)	.442 (11.22)	.438 (11.11)
8-30	.164 (4.17)	.106 (2.70)	.142 (3.62)	.141 (3.57)	.139 (3.52)	.137 (3.48)	1/2-20	.500 (12.70)	.413 (10.50)	.468 (11.88)	.465 (11.81)	.462 (11.74)	.459 (11.67)
8-32	.164 (4.17)	.110 (2.79)	.144 (3.65)	.142 (3.61)	.140 (3.56)	.139 (3.52)							

• Thread rolling taps use a slightly larger core hole, which helps prevent tool failure when piercing small holes for tapping in heavier gauge materials.

• Because they are cold formed, rolled threads are stronger than cut threads. Core hole sizes are listed for both American and Metric thread rolling taps, see Tables III and IV.

When specifying threads in very thin sheet material, extruded holes or mechanical fasten-

Table II. Standard Metric Cut Threads and Core Hole Diameters

Size & pitch	Threads /inch (in)	Outside diameter (in)	Root diameter (in)	Drill diameter (in)			
				60%	65%	70%	75%
1.6 x .35	(72.572)	1.6 (.063)	.99 (.039)	1.37 (.054)	1.35 (.053)	1.33 (.053)	1.32 (.052)
1.8 x .35	(72.572)	1.8 (.071)	1.19 (.047)	1.57 (.062)	1.55 (.061)	1.53 (.060)	1.52 (.060)
2 x .4	(63.500)	2 (.079)	1.31 (.051)	1.74 (.069)	1.72 (.068)	1.70 (.067)	1.68 (.066)
2.2 x .45	(56.445)	2.2 (.087)	1.42 (.056)	1.91 (.075)	1.88 (.074)	1.86 (.073)	1.84 (.072)
2.5 x .45	(56.445)	2.5 (.098)	1.72 (.068)	2.21 (.087)	2.18 (.086)	2.16 (.085)	2.13 (.084)
3 x .5	(50.800)	3 (.118)	2.13 (.084)	2.68 (.105)	2.65 (.104)	2.62 (.103)	2.59 (.102)
3.5 x .6	(42.333)	3.5 (.138)	2.46 (.097)	3.11 (.122)	3.08 (.121)	3.05 (.120)	3.01 (.119)
4 x .7	(36.286)	4 (.158)	2.79 (.122)	3.55 (.136)	3.51 (.134)	3.47 (.132)	3.43 (.131)
4.5 x .75	(33.867)	4.5 (.177)	3.20 (.126)	4.01 (.158)	3.97 (.156)	3.93 (.155)	3.89 (.153)
5 x .8	(31.750)	5 (.197)	3.61 (.142)	4.48 (.176)	4.44 (.175)	4.39 (.173)	4.35 (.171)
6 x 1	(25.400)	6 (.236)	4.27 (.168)	5.35 (.211)	5.30 (.209)	5.24 (.206)	5.19 (.204)
7 x 1	(25.400)	7 (.276)	5.27 (.207)	6.35 (.250)	6.30 (.248)	6.24 (.246)	6.19 (.244)
8 x 1	(25.400)	8 (.315)	6.27 (.247)	7.35 (.289)	7.30 (.287)	7.24 (.285)	7.19 (.283)
8 x 1.25	(20.320)	8 (.315)	5.83 (.230)	7.19 (.283)	7.12 (.280)	7.05 (.278)	6.99 (.275)
10 x 1.25	(20.320)	10 (.394)	7.83 (.308)	9.19 (.362)	9.12 (.359)	9.05 (.356)	8.99 (.354)
10 x 1.5	(16.933)	10 (.394)	7.40 (.291)	9.03 (.355)	8.94 (.352)	8.86 (.349)	8.78 (.346)
12 x 1.25	(20.320)	12 (.472)	9.83 (.387)	11.19 (.440)	11.12 (.438)	11.05 (.435)	10.99 (.432)
12 x 1.75	(14.514)	12 (.472)	8.97 (.353)	10.86 (.428)	10.77 (.424)	10.67 (.420)	10.58 (.417)

ers may be required to provide additional material to accommodate a sufficient number of threads (Figure 4). When threads must sustain high torque, extruded holes surpass punched holes in performance because of the greater number of threads and work hardening of material.

• **Thread forming screws** in extruded holes are the most economical way to fasten sheet metal parts while providing equivalent strength to an extruded and tapped hole. Made by the thread rolling process, these fasteners can be as much as 20% stronger than screws with cut or ground threads.

Table III. American Roll Formed Threads Recommended Hole Sizes

Size & pitch	Outside diameter (mm)	Root diameter (mm)	*Hole diameter			Size & pitch	Outside diameter (mm)	Root diameter (mm)	Hole diameter		
			65%	70%	75%				65%	70%	75%
0-80	.060 (1.52)	.038 (.97)	.054 (1.38)	0.54 (1.37)	.054 (1.36)	8-32	.164 (4.17)	.110 (2.79)	.150 (3.81)	.149 (3.79)	.148 (3.76)
1-64	.073 (1.85)	.046 (1.17)	.066 (1.68)	.066 (1.67)	.065 (1.65)	8-36	.164 (4.17)	.116 (2.94)	.152 (3.85)	.151 (3.83)	.150 (3.81)
1-72	.073 (1.85)	.049 (1.24)	.067 (1.70)	.066 (1.69)	.066 (1.67)	10-24	.190 (4.83)	.118 (2.99)	.172 (4.36)	.170 (4.32)	.169 (4.29)
2-56	.086 (2.18)	.055 (1.40)	.078 (1.98)	.078 (1.97)	.077 (1.95)	10-32	.190 (4.83)	.136 (3.45)	.176 (4.48)	.175 (4.45)	.174 (4.42)
2-64	.086 (2.18)	.059 (1.50)	.079 (2.01)	.079 (2.00)	.078 (1.98)	12-24	.216 (5.49)	.144 (3.65)	.198 (5.02)	.196 (4.98)	.195 (4.95)
3-48	.099 (2.52)	.063 (1.60)	.090 (2.28)	.089 (2.26)	.088 (2.24)	12-28	.216 (5.49)	.154 (3.92)	.200 (5.09)	.199 (5.05)	.198 (5.02)
3-56	.099 (2.52)	.068 (1.73)	.091 (2.31)	.091 (2.30)	.090 (2.28)	1/4-20	.250 (6.35)	.163 (4.15)	.228 (5.79)	.226 (5.75)	.225 (5.70)
4-40	.112 (2.85)	.076 (1.93)	.101 (2.56)	.100 (2.54)	.099 (.252)	1/4-28	.250 (6.35)	.188 (4.78)	.234 (5.95)	.233 (5.92)	.232 (5.89)
4-48	.112 (2.85)	.076 (1.93)	.103 (2.61)	.102 (2.59)	.101 (2.57)	5/16-18	.313 (7.94)	.217 (5.51)	.288 (7.33)	.287 (7.287)	.285 (7.23)
5-40	.125 (3.18)	.082 (2.08)	.114 (2.89)	.113 (2.87)	.112 (2.85)	5/16-24	.313 (7.94)	.241 (6.12)	.295 (7.48)	.293 (7.45)	.292 (7.41)
5-44	.125 (3.18)	.086 (2.18)	.115 (2.92)	.114 (2.90)	.113 (2.88)	3/8-16	.375 (9.53)	.267 (6.78)	.347 (8.82)	.345 (8.77)	.343 (8.72)
6-32	.138 (3.51)	.084 (2.13)	.124 (3.15)	.123 (3.13)	.122 (3.10)	3/8-24	.375 (9.53)	.303 (7.69)	.357 (9.06)	.355 (9.02)	.354 (8.99)
6-40	.138 (3.51)	.095 (2.41)	.127 (3.22)	.126 (3.20)	.125 (3.18)						

**percentages indicated are the percentages of full thread at specified core diameter.*

Table IV. Metric Roll Formed Thread Diameters Recommended Hole Sizes

Size & pitch	Threads /inch (in)	Outside diameter (in)	Root diameter (in)	*Hole diameter (in)		
				65%	70%	75%
1.6 x .35	(72.572)	1.6 (.063)	.99 (.039)	1.45 (.057)	1.43 (.056)	1.42 (.056)
1.8 x .35	(72.572)	1.8 (.071)	1.19 (.047)	1.65 (.065)	1.63 (.064)	1.62 (.064)
2 x .4	(63.500)	2 (.079)	1.31 (.051)	1.82 (.072)	1.81 (.071)	1.80 (.071)
2.2 x .45	(56.445)	2.2 (.087)	1.42 (.056)	2.00 (.079)	1.99 (.078)	1.97 (.078)
2.5 x .45	(56.445)	2.5 (.098)	2.11 (.083)	2.30 (.091)	2.29 (.090)	2.27 (.089)
3 x .5	(50.800)	3 (.118)	2.13 (.084)	2.78 (.109)	2.76 (.109)	2.75 (.108)
3.5 x .6	(42.333)	3.5 (.138)	2.46 (.097)	3.23 (.127)	3.21 (.127)	3.19 (.126)
4 x .7	(36.286)	4 (.158)	2.79 (.110)	3.69 (.145)	3.67 (.144)	3.64 (.143)
4.5 x .75	(33.867)	4.5 (.177)	3.85 (.152)	4.17 (.164)	4.14 (.163)	4.12 (.162)
5 x .8	(31.750)	5 (.197)	3.61 (.142)	4.65 (.183)	4.62 (.182)	4.59 (.181)
6 x 1	(25.400)	6 (.236)	4.27 (.168)	5.56 (.219)	5.52 (.217)	5.49 (.216)
7 x 1	(25.400)	7 (.276)	5.27 (.207)	6.56 (.258)	6.52 (.257)	6.49 (.256)
8 x 1	(25.400)	8 (.315)	6.27 (.247)	7.56 (.298)	7.52 (.296)	7.49 (.295)
8 x 1.25	(20.320)	8 (.315)	5.83 (.230)	7.45 (.293)	7.41 (.292)	7.36 (.290)
10 x 1.25	(20.320)	10 (.394)	7.83 (.308)	9.45 (.372)	9.41 (.370)	9.36 (.369)
10 x 1.5	(16.933)	10 (.394)	7.40 (.291)	9.34 (.368)	9.29 (.366)	9.24 (.364)
12 x 1.25	(20.320)	12 (.472)	10.92 (.430)	11.45 (.451)	11.41 (.449)	11.36 (.447)
12 x 1.75	(14.514)	12 (.472)	8.97 (.353)	11.23 (.442)	11.17 (.440)	11.11 (.437)

*percentages indicated are the percentages of full thread at specified core diameter.

Although holes for self-threading screws do not need to be tapped, the core diameter does need to be specified. Hole sizes for this screw type depend on the thickness and type of sheet metal, the screw size, the screw type, and the method used to create the hole. Hole sizes for Type AB steel thread forming screws for use in aluminum are shown in Table V. Table VI shows recommended hole sizes for Type AB thread forming screws in steel, stainless steel & brass sheet. Metric threadforming screw sizes are shown in Tables VII and VIII.

• **Counterboring** is the enlarging of a hole to create a recessed flat area to provide clearance for hardware (Figure 5). In thinner stampings and fabrications, the designer should review sheet-metal thickness and the fastener selected if a flush installation is desired.

Since counterboring is a machining operation very similar to drilling (accuracy relies on the counterbore tool utilized), dimensional tolerances are about the same. However, close tolerances on the diameter or depth may require a special tool and incur additional cost. Usually, a counterbore follows the pilot hole, which makes it self-centering.

In contrast to counterboring, spotfacing only provides a flat bearing surface for a fastener head or nut. Normally only the diameter is called out (Figure 6).

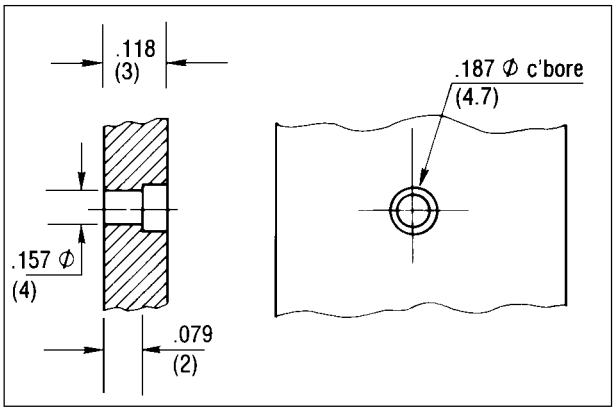


Figure 5. Typical illustration and dimensioning for counterbored holes.

Table V. ALUMINUM "AB" THREAD FORMING SCREWS
approximate clean punched or extruded hole size for
american type "AB" thread forming screws in aluminum sheet

Nominal screw size thread	Metal thickness (mm)	Clean punched hole size (mm)	Extruded hole size (mm)
#2	.024 (.61) .030 (.76) .036 (.91) .048 (1.22) .060 (1.52)	.063 (1.60) .064 (1.63) .066 (1.68) .068 (1.73) .069 (1.75)	.064 (1.63) .066 (1.68) .068 (1.73) .070 (1.78) .072 (1.83)
#4	.030 (.76) .036 (.91) .048 (1.22) .060 (1.52) .075 (1.91) .105 (2.67)	.084 (2.13) .085 (2.16) .086 (2.18) .088 (2.24) .089 (2.26) .092 (2.34)	.086 (2.18) .087 (2.21) .088 (2.24) .090 (2.29) .094 (2.39) .096 (2.44)
#6	.030 (.76) .036 (.91) .048 (1.22) .060 (1.52) .075 (1.91) .105 (2.67)	.101 (2.57) .103 (2.62) .104 (2.64) .106 (2.69) .109 (2.77) .111 (2.82)	.103 (2.62) .106 (2.69) .107 (2.72) .109 (2.77) .111 (2.82) .116 (2.95)
#7	.030 (.76) .036 (.91) .048 (1.22) .060 (1.52) (.075) (1.91) .105 (2.67)	.110 (2.79) .112 (2.84) .114 (2.90) .119 (3.02) (.135) (3.43) .139 (3.53)	.112 (2.84) .115 (2.92) .117 (2.97) .122 (3.10) .137 (3.48) .142 (3.61)
#8	.030 (.76) .036 (.91) .048 (1.22) .060 (1.52) .075 (1.91) .105 (2.67) .125 (3.18)	.114 (2.90) .118 (3.00) .121 (3.07) .129 (3.28) .135 (3.43) .141 (3.58) .145 (3.68)	.117 (2.97) .119 (3.02) .124 (3.15) .135 (3.43) .139 (3.53) .145 (3.68) .148 (3.76)
#10	.036 (.91) .048 (1.22) .060 (1.52) .075 (1.91) .105 (2.67) .125 (3.18)	.140 (3.56) .142 (3.61) .144 (3.66) .146 (3.71) .148 (3.76) .152 (3.86)	.142 (3.61) .145 (3.68) .147 (3.73) .149 (3.78) .152 (3.86) .155 (3.94)
#12	.048 (1.22) .060 (1.52) .075 (1.91) .105 (2.67) .125 (3.18)	.159 (4.04) .164 (4.17) .169 (4.29) .176 (4.47) .180 (4.57)	.162 (4.11) .169 (4.29) .174 (4.42) .179 (4.55) .185 (4.70)
1/4	.048 (1.22) .060 (1.52) .075 (1.91) .105 (2.67) .125 (3.18)	.192 (4.88) .196 (4.98) .199 (5.05) .202 (5.13) .206 (5.23)	.195 (4.95) .199 (5.05) .203 (5.16) .207 (5.26) .211 (5.36)

*Be aware that these are approximate values for a medium-high torque insertion.

Table VI. STEEL "AB" THREAD FORMING SCREWS
approximate clean punched or extruded hole size for
american type "AB" thread forming screws in steel, stainless steel & brass sheet

Nominal screw size thread	Metal thickness (mm)	Clean punched hole size (mm)	Extruded hole size (mm)
#2	.015 (.38) .018 (.46) .024 (.61) .030 (.76) .036 (.91) .048 (1.22) .060 (1.52)	.063 (1.60) .064 (1.63) .067 (1.70) .070 (1.78) .072 (1.83) .074 (1.88) .077 (1.96)	.065 (1.65) .067 (1.70) .069 (1.75) .072 (1.83) .073 (1.85) .076 (1.93) .080 (2.03)
#4	.015 (.38) .018 (.46) .024 (.61) .030 (.76) .036 (.91) .048 (1.22) .060 (1.52) .075 (1.91)	.084 (2.13) .086 (2.18) .089 (2.26) .092 (2.34) .094 (2.39) .097 (2.46) .100 (2.54) .102 (2.59)	.086 (2.18) .089 (2.26) .092 (2.34) .094 (2.39) .098 (2.49) .100 (2.54) .103 (2.62) .107 (2.72)
#6	.015 (3.8) .018 (.46) .024 (.61) .030 (.76) .036 (.91) .48 (1.22) .060 (1.52) .075 (1.91) .105 (2.67)	.102 (2.59) .104 (2.64) .105 (2.67) .106 (2.69) .109 (2.77) .111 (2.82) .115 (2.92) .120 (3.05) .128 (3.25)	.104 (2.64) .105 (2.69) .108 (2.74) .110 (2.79) .111 (2.82) .114 (2.90) .118 (2.99) .123 (3.12) .132 (3.35)
#7	.018 (.46) .024 (.61) .030 (.76) .036 (.91) .048 (1.22) .060 (1.52) .075 (1.91) .105 (2.67)	.114 (2.90) .116 (2.95) .117 (2.97) .118 (2.99) .120 (3.05) .128 (3.25) .135 (3.43) .140 (3.56)	.115 (2.92) .118 (2.99) .119 (3.02) .121 (3.07) .123 (3.12) .130 (3.30) .138 (3.51) .144 (3.66)
#8	.024 (.61) .030 (.76) .036 (.91) .048 (1.22) .060 (1.52) .075 (1.91) .105 (2.67) .125 (3.18)	.123 (3.12) .124 (3.15) .126 (3.20) .128 (3.25) .135 (3.43) .140 (3.56) .147 (3.73) .150 (3.81)	.125 (3.18) .126 (3.20) .127 (3.23) .129 (3.28) .137 (3.48) .143 (3.63) .150 (3.81) .152 (3.86)
#10	.024 (.61) .030 (.76) .036 (.91) .048 (1.22) .060 (1.52) .075 (1.91) .105 (2.67) .125 (3.18)	.142 (3.61) .144 (3.66) .146 (3.71) .151 (3.84) .153 (3.89) .156 (3.96) .161 (4.09) .169 (4.29)	.144 (3.66) .146 (3.71) .148 (3.76) .152 (3.86) .155 (3.94) .158 (4.01) .164 (4.17) .173 (4.39)
#12	.024 (.61) .030 (.76) .036 (.91) .048 (1.22) .060 (1.52) .075 (1.91) .105 (2.67) .125 (3.18)	.164 (4.17) .166 (4.22) .167 (4.24) .169 (4.29) .176 (4.47) .181 (4.57) .185 (4.70) .194 (4.93)	.166 (4.22) .167 (4.24) .169 (4.29) .171 (4.34) .179 (4.55) .184 (4.67) .189 (4.80) .198 (5.03)
1/4	.030 (.76) .036 (.91) .048 (1.22) .060 (1.52) .075 (1.91) .105 (2.67) .125 (3.18)	.192 (4.88) .194 (4.93) .195 (4.95) .198 (5.03) .203 (5.16) .210 (5.33) .224 (5.69)	.194 (4.93) .197 (5.00) .199 (5.05) .201 (5.11) .206 (5.23) .213 (5.41) .230 (5.84)

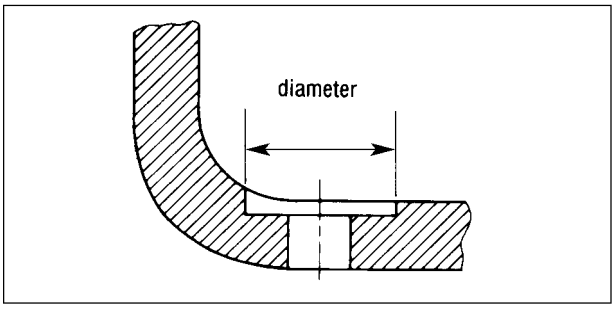


Figure 6. Spotfacing provides a flat surface for proper seating of a fastener head or nut.

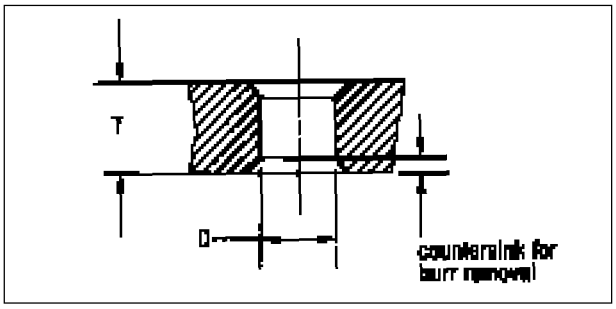


Figure 8. Countersinking is sometimes used to remove burrs from a punched hole prior to tapping. This operation may be limited by depth and diameter as shown, although this is not usually necessary.

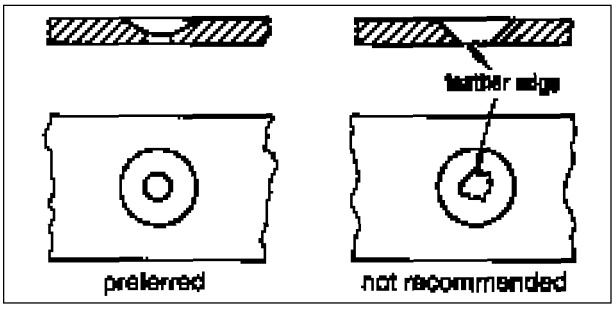


Figure 7. In very thin sheet materials, countersinking may create a feather edge on the small end of a hole and eliminates parallel sides on the through-hole. This is not recommended.

• **Countersinking**, a drilling operation performed with a countersink tool, involves the cutting of an angled or flared depression around a hole opening to allow flush mounting of countersunk-head fasteners. Angles of countersunk holes range from about 60° to 120°. Designers should specify the major diameter and the included angle of countersink. The designer should be careful to calculate the through-hole diameter that results from the above two parameters to make certain that it is not less than the required minimum through-hole diameter.

Because of the thinness of sheet metal, limitations apply to countersinking. In practice, countersinking can be performed on stock down to about $\frac{1}{32}$ in. (0.8 mm) thick. When material is very thin, insufficient thickness to accommodate the depth of the countersink can result in a feather edge on the bottom of the hole (Figure 7). To avoid this situation, the diameter of the countersink should be decreased, the angle increased, or the material thickness may have to be increased to accept the required diameter and angle.

Countersunk diameters for a punched hole can be held to 0.010 in. (0.25 mm). Closer tolerances are rarely achieved because of fluctuations in material thickness and the manual nature of countersinking. Metalforming suppliers occasionally utilize countersinks on one or both sides of small holes prior to tapping. This eliminates the potential to form burrs during tapping. When design requirements so dictate, the maximum depth of these countersinks are sometimes specified (Figure 8).

Table VII. Hole Sizes Required for Thread Forming Metric Screws in Steel, Brass and Stainless Steel Sheet

Nominal screw size	Metal thickness	Optimum hole size
M2.5 x 0.45	1.25	2.25
	2.0	2.28
	2.5	2.31
M3 x 0.5	1.5	2.72
	2.25	2.76
	3.0	2.79
M3.5 x 0.6	1.75	3.17
	2.75	3.21
	3.5	3.25
M4 x 0.7	2	3.61
	3	3.66
	4	3.70
M4.5 x 0.75	2.25	4.09
	3.5	4.13
	4.5	4.18
M5 x 0.8	2.5	4.56
	3.75	4.61
	5	4.66
M6 x 1.0	3	5.45
	4.5	5.51
	6	5.58
M7 x 1.0	3.5	6.45
	5.25	6.51
	7	6.58
M8 x 1.25	4	7.31
	6	7.39
	8	7.47
M10 x 1.5	5	9.17
	7.5	9.27
	10	9.37

Table VIII. Hole Sizes in Aluminum Sheet for use of Metric Steel Thread Forming Screws.

Screw size	Hole diameter mm	(in.)	Optimum thread engagement mm	(in.)
M2 x 0.4	1.81	(.071)	4.0	(.157)
M2.5 x 0.45	2.28	(.090)	5.0	(.197)
M3 x 0.5	2.76	(.109)	6.0	(.235)
M3.5 x 0.6	3.21	(.126)	7.0	(.276)
M4 x 0.7	3.64	(.143)	8.0	(.315)
M4.5 x 0.75	4.11	(.162)	9.0	(.354)
M5 x 0.8	4.58	(.180)	10.0	(.394)
M6 x 1.0	5.48	(.216)	12.0	(.472)
M7 x 1.0	6.48	(.255)	14.0	(.551)
M8 x 1.25	7.35	(.289)	16.0	(.630)
M10 x 1.5	9.22	(.363)	20.0	(.787)

Note: Due to the extreme difference in tensile strength among various aluminum alloys, it is recommended that tests be conducted for the intended application.

11

DEBURRING

"The easiest burr to live with is the one you allow for."

Barrel and vibratory finishing are the two mass-finishing processes most commonly used to deburr metal stampings and sheet metal fabrications. Although the two processes are similar, differences exist in terms of equipment, part size and thickness, and how the treatment affects particular design features.

Deburring is normally done for three main reasons: (1) for safe handling (in-service and during manufacture); (2) to avoid abrasive/cutting effects (for example, on insulated wires); and (3) to enhance surface appearance. A more aesthetically pleasing surface finish can be generated by camouflaging an obvious scratch by blending it into a continuous pattern of smaller, nondirectional scratches.

Other reasons to deburr include removing discoloration from welding or brazing, as well as removing unwanted foreign contaminants, oxidation, rust, and scale from heat treatment.

How Deburring Works

With both barrel and vibratory finishing, abrasive media interacts with a cleaning solution and the parts, removing oil, other foreign contaminants—and most importantly—sharp edges and burrs. Figures 1 and 2 compare the main features of these two deburring processes. In practice, barrel and vibratory finishing cannot be used to selectively remove metal to precise dimensions.

Typically, the media utilized is material specific. For cold rolled and stainless steels, ceramic media is normally used. For aluminum, copper and brass alloys, plastic media is occasionally substituted. Burnishing media can be used for aesthetic purposes on all metals to provide a finer surface finish.

Design Considerations

• **Part size** along with **shape** are the key factors in determining suitability for the deburring process. Generally, small parts are most suitable for deburring, but size, wall thickness and strength are interrelated. To be candidates for

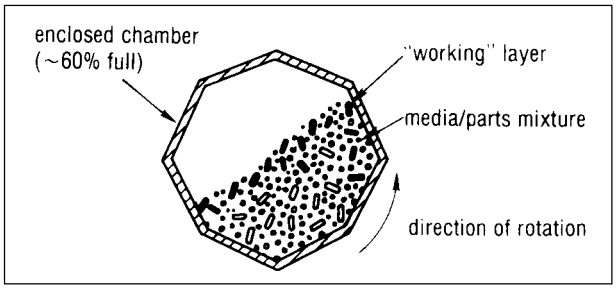


Figure 1. Barrel finishing takes place in a totally enclosed, rotating tub where parts are deburred by various media. Compared to vibratory methods, it permits larger batches of parts to be deburred.

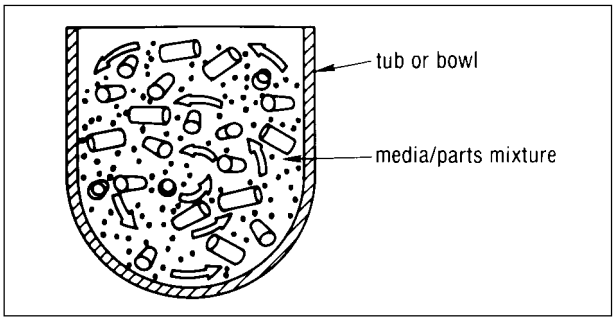


Figure 2. Vibratory finishing makes use of an oscillating channel. Here, too, various media remove the burrs.

the process, parts have to be sturdy enough to withstand the constant acceleration and deceleration of the media and part bulk combined, without distorting.

• **Finish** is a function of material. While cold rolled steel is ideal for most deburring operations, other materials may discolor, or their finish may be dulled. Bright, scratch-free finishes cannot be retained during mass deburring.

With aluminum, discoloration may result even if anodizing is done after deburring. A dull-to-bright finish effect from tumbling may influence the appearance of the part.

The deburring process in itself produces a dull finish on stainless steels, copper and brass alloys. The latter two may also discolor. When deburring is necessary for these materials, it should be restricted to non-cosmetic parts.

However, if appearance is a concern, supplementary processes at additional cost can be performed for brighter finishes. Consult your supplier for more information.

Pre-plated, anodized or pre-painted sheet metal parts are not suitable for deburring by barrel or vibratory methods.

• **Grain direction** cannot be retained for aesthetic appearance purposes when deburring is specified. If deburring is specified and grain direction must be preserved, an additional sanding operation is required to re-establish the grain.

• **Protruding features** are not well suited for mass deburring since bending and distortion will occur. This is especially important with thin materials (see Figure 3).

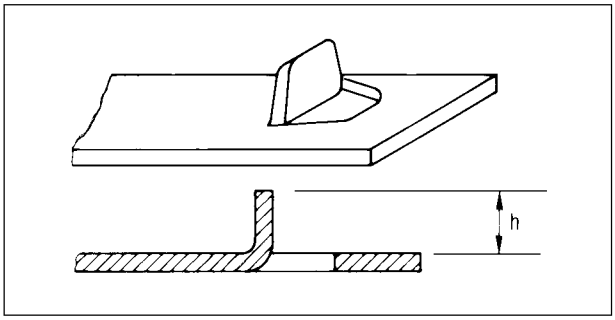


Figure 3. To avoid distortion sheet metal parts that incorporate protruding design features like lanced tabs, which will lock into each other, should not be deburred, especially when thin materials are used.

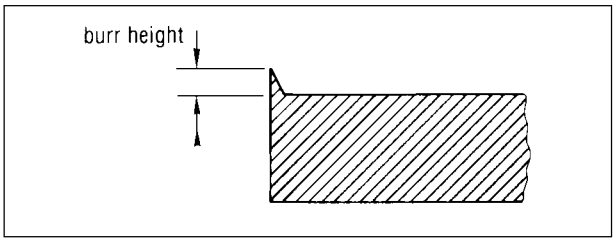


Figure 4. Burr height.

Burrs and Related Terms

By definition, metalformers and fabricators assume that all burrs are face up, when viewing a plan-view print of the part. On a form (formed feature), burr direction is assumed to be to the inside of the form.

• **Burr height** (see Figure 4) is related to material thickness. The expected burr prior to tumbling and deburring is typically less than 10% of the material thickness. If that is acceptable, no deburring is needed.

• **"Burr-free"** is generally used to describe sheet metal parts that have been deburred, resulting in a 0.002 in. (0.05 mm) to 0.003 in. (0.08 mm) rounded edge (see Figure 5).

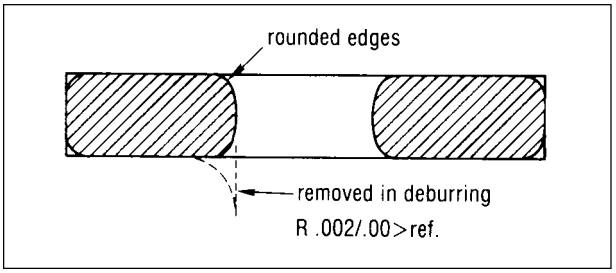


Figure 5. Deburring forms an edge similar to, although smaller than, a rolled edge created by a punch.

Deburring can often be avoided if the hole rollover is used to advantage. For instance, if the required rollover edge on a hole can be attained by controlling the punching direction (see Figure 6), deburring might be avoided. To use this feature, specify the burr side and allowable burr height on the drawing.

Dimensional Effects

When deburring is specified, its effects on dimensions and part features should be considered. Although dimensional effects may vary depending on media selected and available equipment, a good rule of thumb is to expect a 0.003 in. (0.08 mm) maximum rounding on edges.

When specifying deburring it is important to keep close tolerance holes in mind. Hole diameters are made slightly smaller during the deburring process because of the bumping and interlocking of media during tumbling.

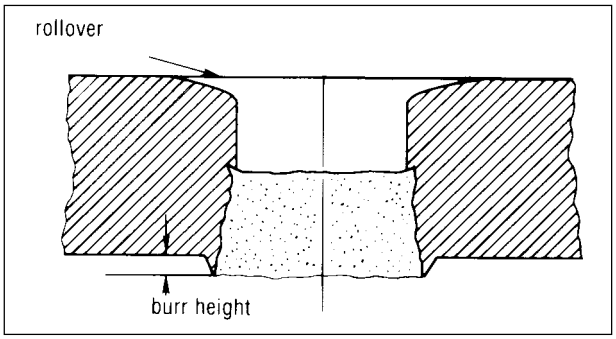


Figure 6. Punched hole characteristics.

Review 'Critical' Parts

Parts classified as "critical" should be reviewed by the designer prior to specifying deburring.

With all parts—not only critical ones—the designer should always review appearance criteria, hole diameter tolerances, thickness of the material, and the need for extended tabs. In some cases, a redesign may be in order.

The common specification "remove all sharp edges and corners" is seldom appropriate, and deserves special mention. To literally remove all sharp edges and corners from a part is usually an excessive requirement, and is therefore not cost effective. The knowledgeable designer specifically addresses the actual need by indicating only those areas of the part which require deburring to meet subsequent functional requirements (see Figure 7). This may often provide several more cost-effective options for the metalforming supplier.

For safe-handling situations—for instance, where service personnel may have to access components through an opening—deburring is undoubtedly required.

If burrs up to 10% of the material thickness are acceptable, it is cost effective to allow for this through a specific burr height call-out on the drawing.

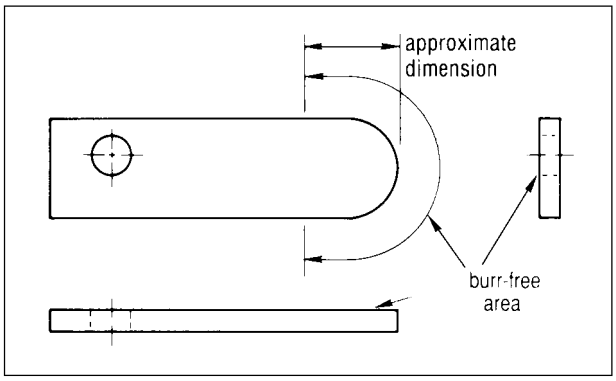


Figure 7. To perform an intended function, some sheet metal designs require only selective deburring. This is normally specified as shown.

Alternative Processes

Various processes can be used instead of barrel or vibratory finishing methods. Belt sanding, etching, and coining all have their own characteristics.

Belt sanding is often the only appropriate deburring option for parts which can be damaged by tumbling or which are too large for vibratory deburring. Belt sanding does remove burrs from a flat plane, but does not totally remove sharp edges. Burrs that were previously perpendicular to the surface have a tendency to be pushed over the edge or into holes. Belt sanding creates an artificial grain direction, while tumbling during barrel or vibratory finishing disguises grain direction.

Thermal deburring uses a 6000°F flash gas burn for removing burrs. This process is not a viable method for sheet metal parts in general, because of the inherent large surface area of sheet metal and consequent heat absorption and warpage.

Chemical etching processes have their place for burr removal and surface appearance alteration of metals, but are not in general use because of cost and environmental considerations.

Coining, as another alternative, uses a die in a punch press to compress the burr into the edge of the material, effectively rendering the area burr free.

12

ABRASIVE SURFACE PREPARATION

Any type of mechanical finishing operation—belt sanding, grinding, polishing or buffing—is expensive because these operations are labor and material intensive. Even when the process is semi-automated, such finish requirements can substantially increase cost of stampings and sheet metal fabrications. Sanding and grinding for blending and smoothing purposes also create difficult quality control problems, as noted in the potential defects section.

Belt Sanding

Belt sanding is undoubtedly the most common of the abrasive surface preparations, and can be applied to all ferrous and non ferrous alloys. The most common belt-sanding operations are to deburr flat blanked parts and to impart an aesthetically appealing grained surface finish. Sanding is normally designated to mean deburring only—without cosmetic characteristics.

Wherever possible, the preferred deburring method utilizes barrel tumbling or vibratory finishing—processes which are more fully described in Chapter 11. However, many parts are too large for these preferred processes and must be sanded for burr removal. Unlike the tumbling and vibratory processes, sanding removes standing burrs but does not eliminate sharp edges.

Typical equipment employs a 12 to 48 in. (0.3 to 1.2 m) wide conveyor with an abrasive belt that removes the burrs and yields a grained finish.

While belt sanding is successfully performed on all metals, soft aluminum alloys usually require a finer grit to avoid fracturing along the grain lines during subsequent forming, especially when bend lines run parallel to the abrasive grain. When requirements dictate forming with the grain, a finer grit abrasive reduces this tendency although, depending on the radius, some fracturing along the bend line may still be experienced.

Graining for Appearance

Graining is the standard term used in the metalforming industry for cosmetic abrasive finishing of sheet metal. In contrast, sanding, a

process similar to graining, is used to remove standing burrs from large, flat sheet metal parts.

The term "graining" should be used on drawings only when cosmetic finishing is required. If burr removal is required, the drawing should simply specify "remove burrs" and indicate the area of concern, leaving the selection of the best process to the supplier.

Graining is linear (straight-lined) in nature. It is used to hide surface defects in materials by creating uniform "scratches" over the entire metal surface with an even light-reflective value.

Generally, graining is performed on material while in the flat state, with a minimum length of approximately 6 in. (150 mm). Flat parts can be fed through the machine with good efficiency. Shorter parts and some formed parts can be grained, but require fixturing by placing them on a dedicated carrier at a substantial extra cost. Some of the most modern machines come equipped with a vacuum activated belt which can hold smaller parts, but not without limitations dictated by the opposing forces. Consult your supplier for available capabilities.

When forming operations are incorporated into the punching process on parts with graining specifications, the upper side of the sheet will be grained prior to punching and forming upward. Upon completion of the punching/forming operation, the burr (down) side of the part will be run through the belt sander by using a special carrier. This is generally only done when a cosmetic finish on both sides of the material is a requirement. Obviously belt sanding both sides doubles the number of operations and the cost.

When specifying graining of aluminum to be subsequently chemically etched, it is important to run the grained finish along the same axis as the natural material grain. Otherwise a cross-hatch pattern will appear after heavy etching.

Graining of already formed, and perhaps assembled and welded parts, calls for an entirely different process referred to as "platen graining." This is a completely manual process involving a powered abrasive belt and operator dexterity to manipulate the part (or belt in some cases) to obtain the desired finish. This is the most costly of the grain finishing processes.

Grained Finish Specifications

The best finish graining specification identifies the grit of the abrasive belt and the type of abrasive. For cosmetically critical parts, a set of samples should be produced and shared, which show the top and bottom limits of the finish desired. These should be accompanied by written cosmetic standards which include viewing time and distance, viewing angle, type of lighting and number of surface defects allowable.

The type of abrasive is of consequence because aluminum oxide has a cubic structure and breaks down slowly in use. It is best suited for all ferrous materials.

Silicon carbide has a spire-like structure and breaks down quickly, exposing new, sharp points to do the job. This abrasive is used for soft material, especially aluminum, because it does not "load up," i.e. get clogged with metal dust.

The same mesh number grit of aluminum oxide and silicon carbide will produce a very different appearance on all materials. Well worn belts will produce a finish of as much as 50 mesh numbers finer than a new belt. These facts make it important to establish quality control limits through samples as mentioned earlier. See Table I for grit mesh and application guidelines.

Figure 1 shows the finish range in micro meters and micro inches to be expected from corresponding grit sizes.

Grinding

Grinding, usually accomplished with an abrasive wheel on handheld equipment, is typically used to remove weld metal on the outside of a part and blend it into the part with a radius. For example, reducing the weld bead on the corners of a box.

Because grinding is a very costly manual operation, the best recourse is to avoid grinding on exterior part surfaces. When possible, welds

Table I. Grit mesh numbers and application guidelines for abrasive belts and disks.

Grit number		Abrasive belts and disks application guidelines
#80	coarse	For thick rough materials only, covers blemishes well.
#100	medium coarse	Coarsest used on steel of large cabinet quality, corner posts, etc.
#120	medium	Most common grit for general use on steel panels, shelves, etc. Normally the coarsest used on all.
#150	medium fine	For finishes on steel requiring medium silk screening.
#180	fine	Most common silicon-carbide grit for decorative aluminum panels and in aluminum oxide for fine silk screened steel parts.
#220	extra fine	Special purpose only, mini silk screened parts, reflective surfaces, etc. Does not hide blemishes well, costlier to apply.

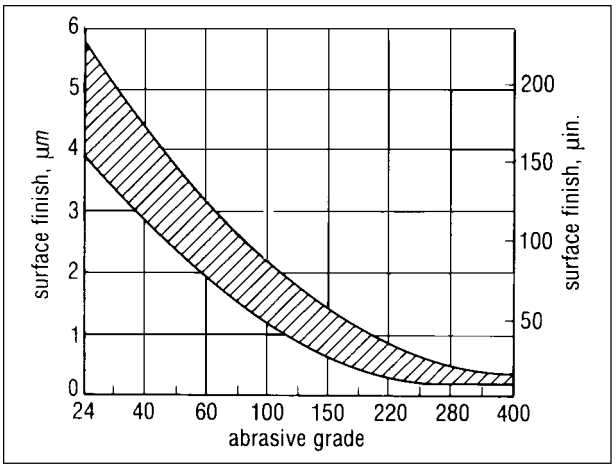


Figure 1. Surface finishes obtained with varying grades of belts.

should be located inside a component so that grinding is not necessary. This avoids any grinding-related quality concerns.

Potential Defects

Sharp corners, weld failure and grinding marks, all can be minimized through proper design and processing techniques. For example, if fusion welding is possible, grinding may not be necessary.

• **Sharp corners** are a frequent concern. Usually welded for structural reasons, corners become sharp as a result of grinding and sanding operations. Consequently, corners need to be rounded to make them cosmetically acceptable. After the corner is ground square, it requires beveling, accomplished by starting a radius with the grinder oriented at about 45°. Finally, the corner is rounded out by filing or by orbital sanding.

• **Weld failure** is another potential defect. With MIG- or TIG-welded components, grinding a welded feature flush may cause problems. For instance, without adequate weld penetration, grinding could remove most of the weld metal, resulting in weld failure (e.g., via cracking) or structural weakening. Consequently, the amount of metal removed becomes more critical in terms of ensuring structural integrity.

• **Grinding marks** on subsequently plated parts are commonplace and are not normally considered defects. A perfectly smooth, polished surface is not to be expected on plated parts, because plating does not have the defect-hiding power of paint. If a very smooth surface is required, the appropriate pre-plating finish must be specified on the print. This elimination of grinding marks, scratches, pits, etc. requires extra operations and associated charges.

Parts to be painted to high cosmetic requirements also demand extra effort, such as going from coarse to medium to fine media. To completely prevent grinding marks from showing through, additional orbital sanding or filler applications may be necessary, sometimes combined with a second coat of paint.

Polishing and Buffing

Polishing and buffing of stampings and sheet metal parts are feasible, but not common

except in specialized industries. High luster requirements contribute to the expense of finishing since they typically succeed a rough form of mechanical finishing like grinding. Both operations should be avoided in the interest of cost-effectiveness, when alternate processes can be substituted to produce an acceptable finish. Taken together, the two processes—polishing, then buffing—are sometimes used to produce the ultimate in reflective surfaces.

Polishing takes grinding or sanding operations one step further, resulting in a more lustrous appearance. Like grinding, abrasive media is permanently bound to a wheel or belt, but here the backing is usually flexible, and a finer abrasive is used. In practice, polishing removes scratches, pits, etc. created by grinding, yielding a smoother, more suitable surface for plating or electroplating. Success of the operation depends heavily on how well previous grinding operations have been carried out.

After polishing, buffing is the next step ordinarily used to produce mirror-like surfaces. Normally, a buffing wheel (usually with polishing compound applied) smooths a metal surface even further. Depending on the degree of buffing and process variation used, scratches, etc., can be made virtually invisible to the naked eye.

Obtaining optimum lusters through polishing and buffing is an art in itself, with success relying heavily on experience. In addition, results may vary widely, depending on the equipment, type of metal and condition, grain size, and other factors.

13

SPOT WELDING

Spot welding is often selected for joining sheet metal fabrications, stampings and assemblies because it is fast, reliable and economical. However, numerous design considerations can affect the quality and cost of the weld, among them: size of the spot weld, accessibility, positioning, materials, thicknesses and the number of spots needed to attain the desired strength.

This section will focus primarily on resistance spot welding (RSW) and resistance projection welding (RPW) since these processes are most commonly used due to their speed and flexibility. See Figure 1, for schematics of RSW and RPW.

Applications include attachment of reinforcing braces and stiffeners, functional brackets, hinges and other parts. Often, spot welding is the method of choice for assembly of entire enclosures, cabinets and multipart assemblies.

Thickness of the majority of parts joined by spot welding ranges up to ⅛ in. (3 mm) for each member, although parts up to ¼ in. (6 mm) thick can be successfully spot welded.

General Design Considerations

Based on the experience of stampers and fabricators, general guidelines can facilitate spot welding of a sheet metal design, no matter what metalforming process is used to make it. It is always useful to consult with the metalformer in the design stage when questions arise regarding the part design, application of spot welding or, control of spot welding cost for a particular design.

Knowledgeable designers avoid overspecifying the number of welds, weld size and location. After evaluating strength requirements, it usually suffices to specify "a minimum number of spot welds equally spaced," thereby leaving the most economical positioning up to the metalformer.

If other joining methods are specified, in addition to spot welding, it may be more economical to redesign so that one or the other method is eliminated.

Dimensional precision is often overspecified, sometimes unintentionally. CAD systems default to three or four digits of precision

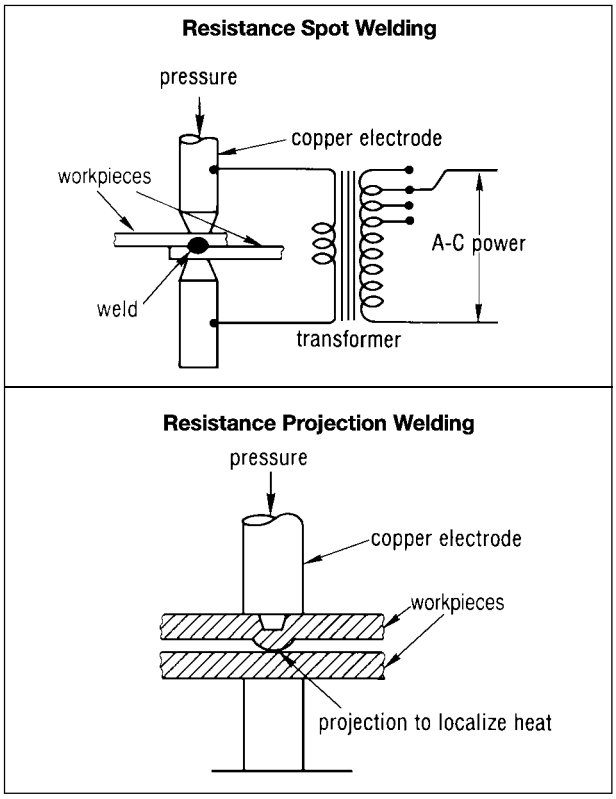


Figure 1. In resistance spot and projection welding, two sheet metal parts under pressure are heated by electrical resistance, melting the metal and forming a weld "nugget." Circular in shape in a plan view, the nugget has an oblong cross-section that, ideally, penetrates both thicknesses equally.

unless instructed otherwise. Where possible, spot welding should be shown schematically without dimensions.

Weld Size and Strength

Weld size (nugget diameter) is typically slightly less than the diameter of the impression the electrode creates on the material. These dimensions and other spot welding parameters are given in Table I for aluminum and stainless steel. For simplicity, such standards can be specified by the designer as the controlling print information on spot welds.

Base metal strength and spot weld strength are interrelated. Table I gives realistic strength expectations for design purposes. For economy, avoid over-specification of welds.

In applications where space is limited, one weld may produce a stronger bond than two spots, which may be limited in size and integrity because of constraints in positioning, accessibility and shunting effects (current loss).

Depending on workpiece thickness and the type of material used, typically, diameters of spot welds range from about ⅛ in. (3 mm) to ½ in. (13 mm). When the size of spot welds is designated, the designer should specify only one size throughout an assembly in the interest of manufacturing economy and total part cost.

Weldability of Materials

Low-carbon steel is one of the most readily spot welded materials. It can be spot welded to many ferrous and non-ferrous alloys with varying success, depending on the combination of metals joined.

Higher carbon and low-alloy steels can also be spot welded, although with reservations, because of a tendency to form harder welds, which may degrade weld performance. As carbon content increases, so does brittleness, with an associated propensity for cracking and weld separation.

In addition, higher strength steels may require special techniques or treatments such as tempering after welding. Spot weldability of HSLA (High-Strength Low-Alloy) steels is directly related to composition and type of microalloying elements. It is advisable to check with the supplier before specifying spot welding.

Stainless steels are spot weldable, some grades more readily than others. Austenitic grades of the 300 series are the most commonly welded types, followed by ferritic. Martensitic stainlesses are the least common because welded joints are much more brittle. All stainless steels require careful adjustment of welding parameters and/or special methods to obtain optimum quality welds.

Highly conductive materials like aluminum require very high power to form quality spot

Table 1. Typical recommendations and strength expectations for spot welding.

Resistance spotwelding parameters for stainless, steel, and aluminum.
These are average values, not to be used for strength calculation purposes.

Thinnest material thickness		Recommended electrode contact diameter		Fused zone diameter expected		Recommended flange overlap (minimum)		Recommended single-spot weld spacing		Expected shear strength in lbs./spot (kg. /spot)					
										Aluminum alloy 5052-H34		Low carbon steel		Stainless steel	
in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	lbs.	kg.	lbs.	kg.	in.	kg.
0.010	0.25	0.13	3.0	0.10	2.5	0.38	10.0	0.75	19	70	154	130	286	170	374
0.021	0.53	0.19	5.0	0.13	3.0	0.44	11.0	0.75	19	120	264	320	704	470	1034
0.031	0.79	0.19	5.0	0.16	4.0	0 44	11.0	1.0	25	240	528	570	1254	800	1760
0.040	1.02	0.25	6.5	0.19	5.0	0.50	13.0	1.0	25	340	748	920	2024	1270	2794
0.050	1.27	0.25	6.5	0.22	5.5	0.56	14.0	1.0	25	510	1122	1350	2970	1700	3740
0.062	1.57	0.25	6.5	0.25	6.5	0.63	16.0	1.2	31	720	1584	1850	4070	2400	5280
0.078	1.98	0.31	8.0	0.29	7.5	0.69	17.5	1 5	38	940	2068	2700	5940	3400	7480
0.094	2.39	0.31	8.0	0.31	8.0	0.75	19.0	1.8	46	1180	2596	3450	7590	4200	9240
0.109	2.77	0.31	8.0	0.32	8.0	0.81	20.5	2.2	56	1380	3036	4150	9130	5000	11000
0.125	3.18	0.38	10.0	0.33	8.5	0.88	22.5	2.5	64	1620	3564	5000	11000	6000	13200
0.180	4.57	0.38	10.0	0.35	9.0	1.0	25.0	2.5	64	1720	3784	5300	11660	6600	14520

Note: One half or less spotweld spacing as given in above table can be achieved by the use of multi-point electrodes.
The same can be accomplished with a single spot electrode on a dual circuit welder. There, a higher current is used for all subsequent spots to overcome the shunting effect. Frequent destructive testing is indicated in these cases to maintain correct settings and quality control.
Check with your weldment supplier for applicability and associated cost.

welds. However aluminum alloys are routinely spot welded (see Table I for weldability). Here, cleanliness is much more of a concern than with low-carbon steels because of aluminum's rapid surface oxidation characteristics.

For optimum quality and weld performance, expensive cleaning procedures to remove surface oxide are required. For demanding applications, equipment to monitor surface resistivity from lot to lot is necessary to assure consistency of quality.

This leads to a related consideration. If aluminum has been chosen for an important reason, such as lightweight or high strength-to-weight ratio, the added expense of ensuring a high-quality weld should be justified. If it has not, re-evaluation of the original material selection is in order or, perhaps, another assembling method should be considered.

Spot welding of very dissimilar metals, such as aluminum and steel, is generally not possible because of different melting characteristics and conductivities.

Some types of coated low-carbon steels require special techniques. Steels plated with chrome and nickel for electrical conductivity can usually be resistance welded as readily as uncoated material. Aluminum, tin, zinc and terne-coated steels are also spot weldable with special precautions and welding equipment.

Some coatings emit poisonous fumes that must be safely handled when spot welded, thereby increasing cost. Spot welding of coated substrates creates burn marks in the coating which can be unsightly and may corrode in severe environments. Designers should carefully consider the product's appearance and service requirements before specifying spot welding of pre-coated materials.

Thickness of Mating Parts

Joining equal thicknesses of two sheet metal parts produces an evenly distributed weld nugget within the two layers. Materials of dif-

ferent thicknesses also can be joined and produce a centered weld nugget by using a larger electrode on the thicker member.

At a ratio above about 3-to-1 (thickest to thinnest member), spot welding becomes difficult. At this point, another joining method should be considered—projection welding for example.

Note that weld deformation is always greater on the thinner member. For this reason, stiffeners and brackets spot welded to cosmetic parts should be thinner than or equal in thickness to the exposed surface material.

Weld Proximity and Spacing

Recommended spacing between welds, distances from a spot weld to component edges and other part features should be followed to obtain optimum weld quality and strength.

• **Weld-to-weld spacing** should be a minimum of 10 times material thickness. For 0.060 in. sheet steel, this equates to about 0.6 in. (15 mm). Ideally, 20 times material thickness is recommended to reduce shunting effects with a minimum spacing of ½ in. (13 mm). See Table I for minimum and recommended weld spacing for various material thickness of aluminum, carbon and stainless steel.

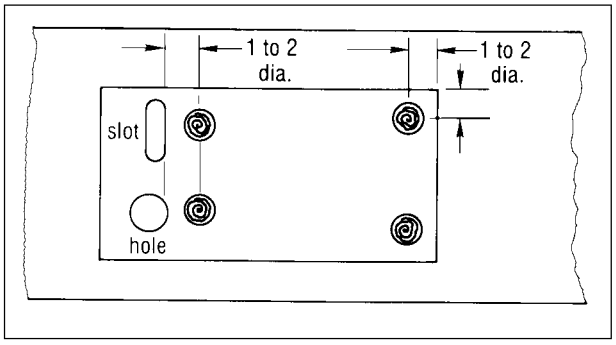


Figure 2. Recommended minimum spacing between spot welds and edges of parts to be joined also applies to slots and holes in the workpieces.

• **Weld-to-edge distance** should also conform to a minimum dimension that is a function of the weld diameter. Generally, the center of a spot weld (its location point) is positioned one to two diameters away from the edge of the part being welded or from a feature in the part being welded depending on thickness of material (Figure 2).

If this minimum-dimension requirement is not followed, a poor-quality weld, distortion of the parts being joined, or no weld at all may result. See Figures 3, 4 and 5.

• **Weld-to-form spacing** should be a minimum of one bend radius plus the spot diameter so that the electrodes can make proper contact with the surfaces being joined without shunting to the adjacent wall (Figure 6).

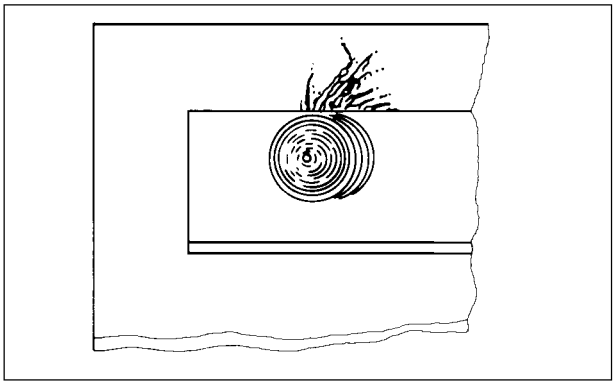


Figure 3. Improper weld. Excess metal has been expelled from the weld causing the weld to deform due to excessive indentation and surface cracks.

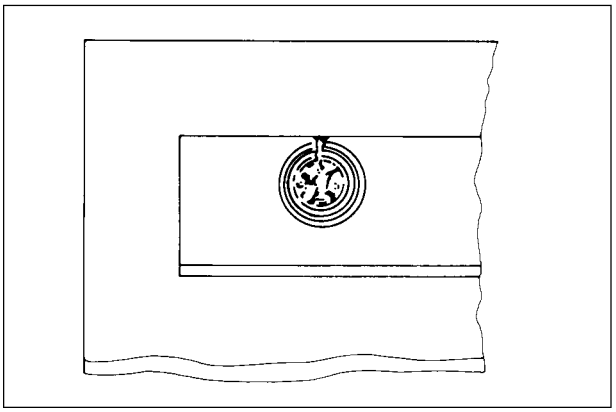


Figure 4. Existence of deep pits is cause for rejection, as are cracks and burned metal in the weld.

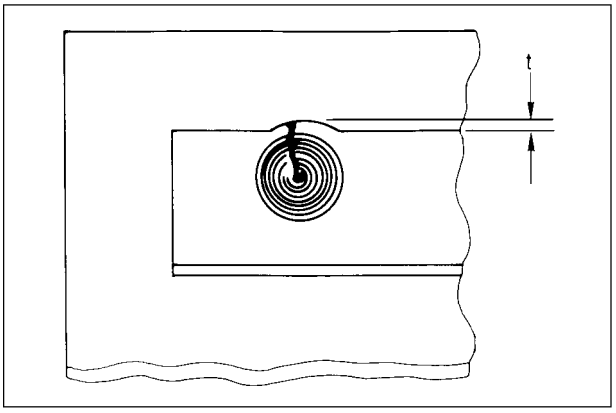


Figure 5. Excessive edge bulge, which causes weld and base metal to crack, leads to a rejectable weld.

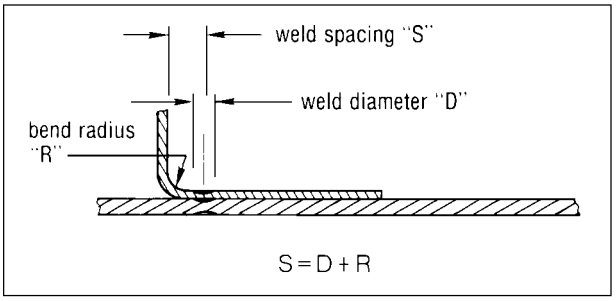


Figure 6. When a part incorporating a formed feature like a bend is joined to another sheet metal part, sufficient clearance must be maintained to form a quality spot weld.

Positioning and Accessibility

If possible, spot welding of sheet metal components should be restricted to joining flat, coplanar surfaces. Spot welding for assembly of mating parts in multiple planes should be limited to parts smaller than a "bread box" that are easy to handle.

With large, heavy parts, another fastening method, welding process or possibly a redesign should be considered unless production quantities support the initial expense of specialized spot welding equipment.

Although single- and double-bend electrode tips are available to reach confined weld locations, a small flange dimension may restrict access, and thereby prevent a successful spot weld. Such is the case with C-shaped parts or U-shaped channels with short flanges (Figure 7). For instance, specifying a ¼ in. (6 mm) diameter weld on a ⅜ in. (10 mm) flange not only violates spacing considerations, but also makes it very difficult for the operator to access the weld location.

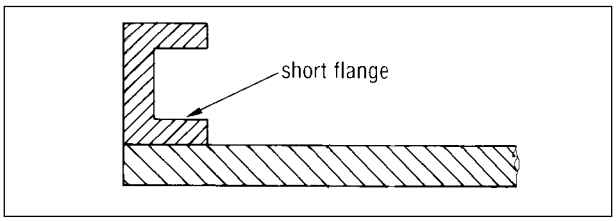


Figure 7. Specifying spot welds on short flanges could make access nearly impossible.

Cosmetics

Good design practices attempt to limit spot welding on appearance or cosmetic surfaces. While textured paints can be used to hide small electrode marks on finished surfaces, grinding, or filling and grinding, is often required and can double the cost of the welding operation.

Often, structural elements such as stiffeners are required to reinforce large cosmetic surfaces. For these applications, designers should select material which is thinner than the material from which the appearance part is fabricated. This assures that weld shrinkage will occur on

the noncosmetic part which helps to control the cost of filling and abrasive finishing.

Plating Spot Welded Parts

Spot welding creates overlapping seams which, when immersed in electroplating solutions, trap solution residues through capillary action. This creates two problems. First, the residue often leaves plating salt deposits which are unsightly and which, in extreme cases, may require touch up or manual removal at increased cost. Second, the metal in the seam is unprotected and can corrode severely in harsh environments.

When designing spot welded assemblies for electroplating, consideration must be given to plating drainage, enclosed seams and pockets, overlapping seams and other areas where solutions may be trapped or where special cleaning or processing techniques may be required. When these operations are combined, early consultation with an experienced supplier is crucial.

Spot Welded Fasteners

Weld nuts and weld studs are commonly used to provide a means for subsequent fastening of additional components and assemblies, or for periodic removal of service parts for maintenance and repair. When specifying welded fasteners, care should be taken not to tightly tolerance concentricity or perpendicularity to a datum plane, since this drastically increases cost. Weld fasteners located by holes punched by prior stamping operations are an accurate and generally preferred location method.

For maximum cost-effectiveness, select weld nuts and studs of one size that will be used throughout the assembly. This helps to keep set-ups to a minimum and increases manufacturing throughput.

Nuts located by holes are typically within ±0.006 in. (0.15 mm) of the original hole location. Studs can be located to ±0.020 in. (0.51 mm) with simple fixturing. Closer tolerances require more sophisticated and costly fixtures.

Positive Location of Workpieces

Precise locations of spot welded parts is a cost-related process and should be considered during the design. Part positioning involves either extensive fixturing or, preferably, self-alignment through built-in stamped features like holes and tabs. With the latter method, the location is predetermined by the accuracy of alignment features.

The preferred and most easily achieved method for accurately self-fixturing parts is the half sheared or extruded cylindrical button and matching hole in the mating part. (Figure 8). One mating hole should be 0.003 in. (0.08 mm) larger in diameter than the extrusion and the second hole should be slotted by 0.040 in. (1.02 mm) minimum to allow for normal fabrication tolerances as shown in the drawing. Another alternative is to produce a lanced tab in a punching process. Mating parts can then be brought up to it and located in position.

Knowledgeable designers recognize such cost-saving and quality-improvement methods and specify them in the manufacturing process. The consistency attainable with such methods surpasses that of sophisticated jigs and fixtures but the greatest value is the cost efficiency. Additionally, these techniques can be used for fillet welding applications, and mechanical assemblies.

Projection Welding

A refinement of resistance spot welding is resistance projection welding (RPW). It makes use of projections previously formed on the workpiece to reduce the power required to make a resistance weld. Consequently, multiple welds can be made more easily at the same time, and thicker sections can be joined more readily than in RSW. Other advantages include reduced shunting effects, closer weld-to-weld spacing and welding of workpieces with smaller flanges.

Projection welding can be used on low-carbon, low-alloy and stainless steels, as well as on aluminum. Typically, thicknesses up to 0.125 in.

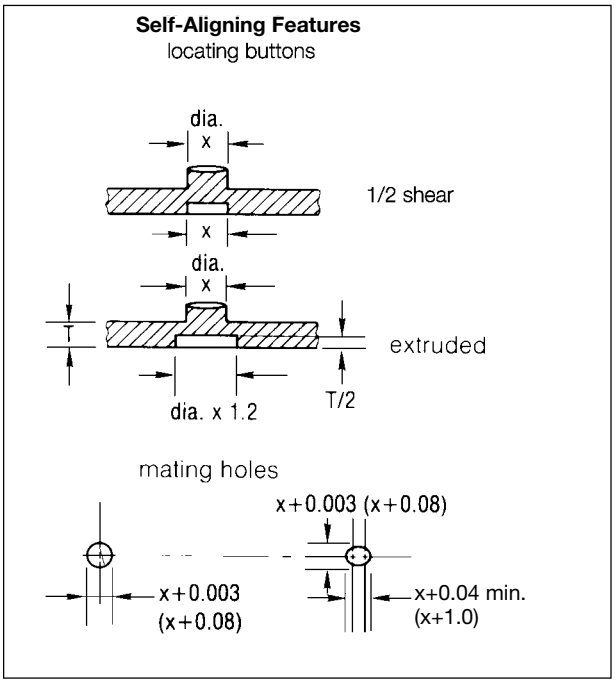
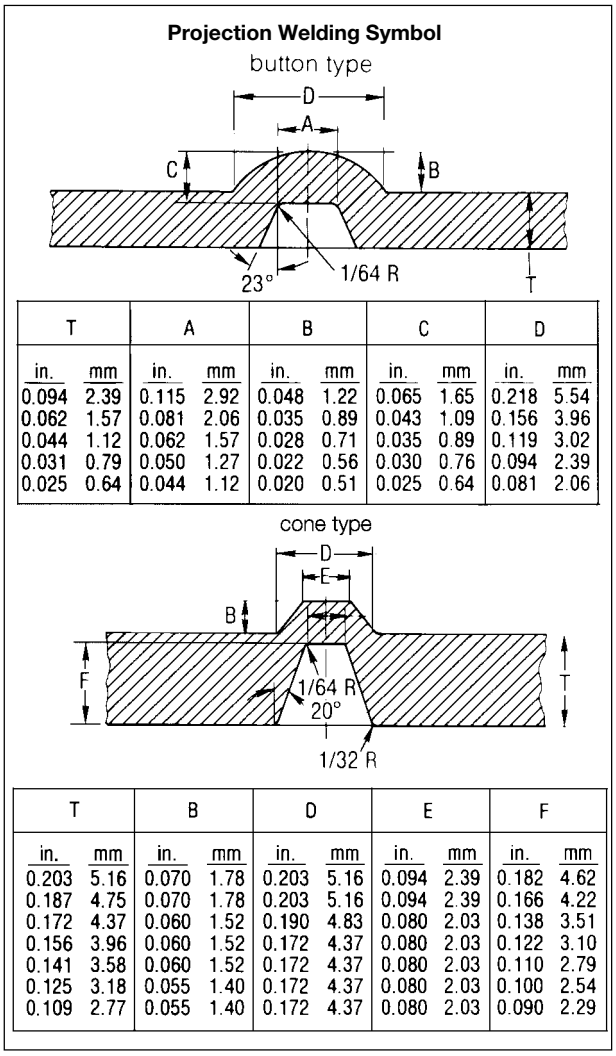


Figure 8. Half shear or extruded button, with their mating holes, can accurately align components for spot welds where tolerances are important.

(3.18 mm) can be joined. Thin workpieces—from 0.010 in. (0.25 mm) up to 0.022 in. (0.56 mm)—may require special equipment. Below 0.010 in. (0.25 mm), RPW is not recommended, because on this thin material the projections would collapse before the fusion temperature is reached.

The two major types of welding projections appear in Figure 9, along with commonly used projection sizes, which are normally based on the thickness of the thinner material to be welded. In general, projections should be positioned as shown in Figure 10 to optimize strength and accessibility.

While RPW can be less expensive than RSW, workpiece alignment is more critical, and heights of projections with simultaneous welds need to be closely controlled—typically, within 0.003 in. (0.08 mm) of each other.



T		A		B		C		D	
in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
0.094	2.39	0.115	2.92	0.048	1.22	0.065	1.65	0.218	5.54
0.062	1.57	0.081	2.06	0.035	0.89	0.043	1.09	0.156	3.96
0.044	1.12	0.062	1.57	0.028	0.71	0.035	0.89	0.119	3.02
0.031	0.79	0.050	1.27	0.022	0.56	0.030	0.76	0.094	2.39
0.025	0.64	0.044	1.12	0.020	0.51	0.025	0.64	0.081	2.06

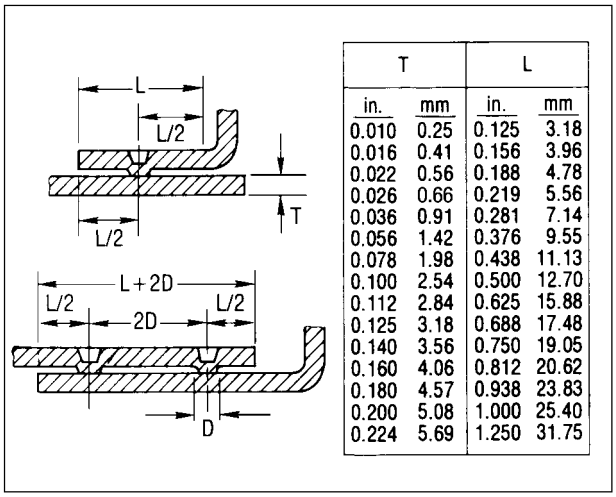
T		B		D		E		F	
in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
0.203	5.16	0.070	1.78	0.203	5.16	0.094	2.39	0.182	4.62
0.187	4.75	0.070	1.78	0.203	5.16	0.094	2.39	0.166	4.22
0.172	4.37	0.060	1.52	0.190	4.83	0.080	2.03	0.138	3.51
0.156	3.96	0.060	1.52	0.172	4.37	0.080	2.03	0.122	3.10
0.141	3.58	0.060	1.52	0.172	4.37	0.080	2.03	0.110	2.79
0.125	3.18	0.055	1.40	0.172	4.37	0.080	2.03	0.100	2.54
0.109	2.77	0.055	1.40	0.172	4.37	0.080	2.03	0.090	2.29

Figure 9. Button and cone type welding projections and typical dimensions.

Tolerance Considerations

Required restrictive tolerances should be indicated on the part drawing, while less important dimensions should be designated with appropriately relaxed tolerances. One way to do this is to expand the tolerance block on drawings by including:

English Units
.X ± 0.100 (2.54 mm)
.XX ± 0.020 (0.5l mm) (dedicated tools)
.XX ± 0.030 (0.76 mm) (universal tools)
.XXX ± 0.010 (0.25 mm)



T		L	
in.	mm	in.	mm
0.010	0.25	0.125	3.18
0.016	0.41	0.156	3.96
0.022	0.56	0.188	4.78
0.026	0.66	0.219	5.56
0.036	0.91	0.281	7.14
0.056	1.42	0.376	9.55
0.078	1.98	0.438	11.13
0.100	2.54	0.500	12.70
0.112	2.84	0.625	15.88
0.125	3.18	0.688	17.48
0.140	3.56	0.750	19.05
0.160	4.06	0.812	20.62
0.180	4.57	0.938	23.83
0.200	5.08	1.000	25.40
0.224	5.69	1.250	31.75

Figure 10. Recommended positioning for projection welds made on various thicknesses of sheet metal.

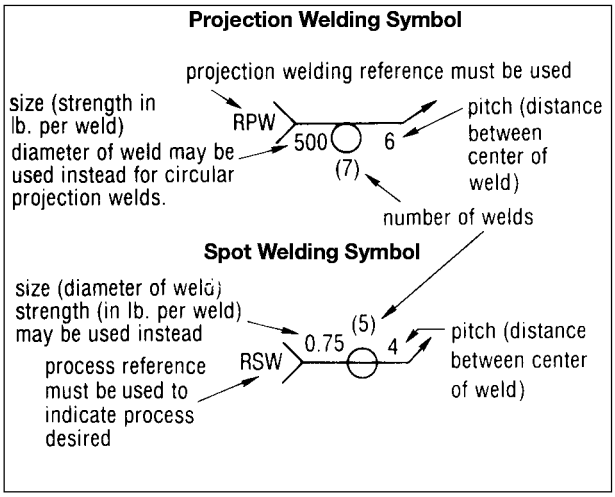


Figure 11. Recommended method for specifying spot welds and projection welds.

When specifying attachment of structural parts such as stiffeners use the most liberal tolerance (X ± 0.100), since this reduces or eliminates fixturing costs for such unimportant dimensions. Critical dimensions, for such details as hole diameters, coplanar hole-to-hole spacing, etc., should be separately toleranced.

Established by the American Welding Society (AWS), the recommended method for specifying resistance spot welds and projection welds appears in Figure 11.

14

WELDING

Apart from resistance spot welding (RSW), there are three processes most commonly used for welding metal stampings and fabrications: gas metal arc welding (GMAW) or MIG; gas tungsten arc welding (GTAW) or TIG; and gas welding.

Although a high initial investment is necessary, laser welding is being widely employed by companies requiring large quantities of multi-point welds. This method utilizes robots, at welding speeds up to 150 inches (3.8 m) per minute. Other processes—plasma arc, ultrasonic, and electron beam welding—are also available, but these methods are usually restricted to welding of particular materials with special design requirements, such as microelectronic and aerospace components. Suitability for general sheet metal applications is limited, and processing may be cost-prohibitive.

• **Gas metal arc welding** creates an arc between a continuous wire filler metal (consumable electrode) and the sheet metal workpieces. Shielding gas protects both the molten metal and the arc from the atmosphere (Figure 1). This process is suitable for most metals and alloys.

Among the most readily weldable materials are: carbon steels, low-alloy steels, stainless steel; 3000, 5000, and 6000-series aluminum alloys; and magnesium alloys. Other alloys that can also be GMA welded via special methods include 2000 and 7000-series aluminum alloys; high-zinc-content copper alloys, and high-strength steels.

• **Gas tungsten arc welding,** commonly called TIG (tungsten inert gas), produces an arc between a nonconsumable tungsten electrode and the sheet metal workpieces. Inert gas is used to shield the arc and the work; filler metal is optional (Figure 2). Like GMAW, GTAW can be used to join most metals and alloys, but produces higher quality welds because of the absence of weld spatter and higher base metal dilution. Unlike GMAW, GTAW can be used to

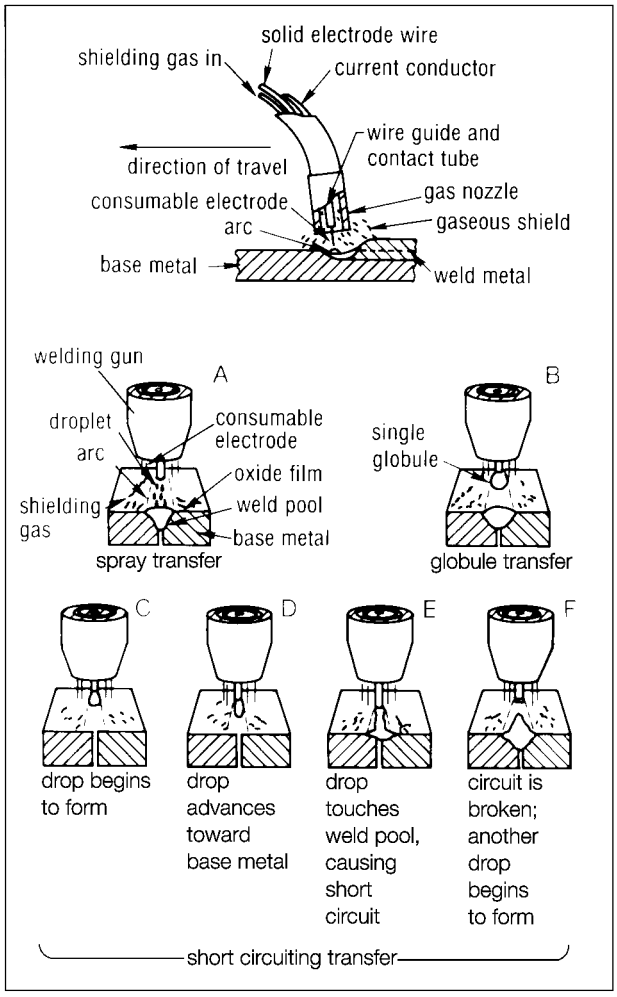


Figure 1. Schematic of basic MIG welding process and variations.

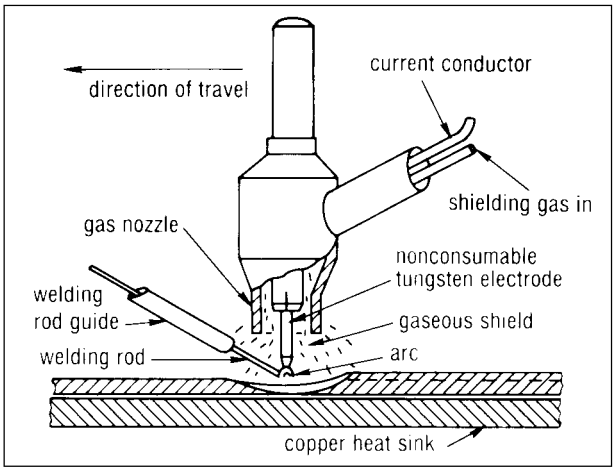


Figure 2. Schematic of TIG welding.

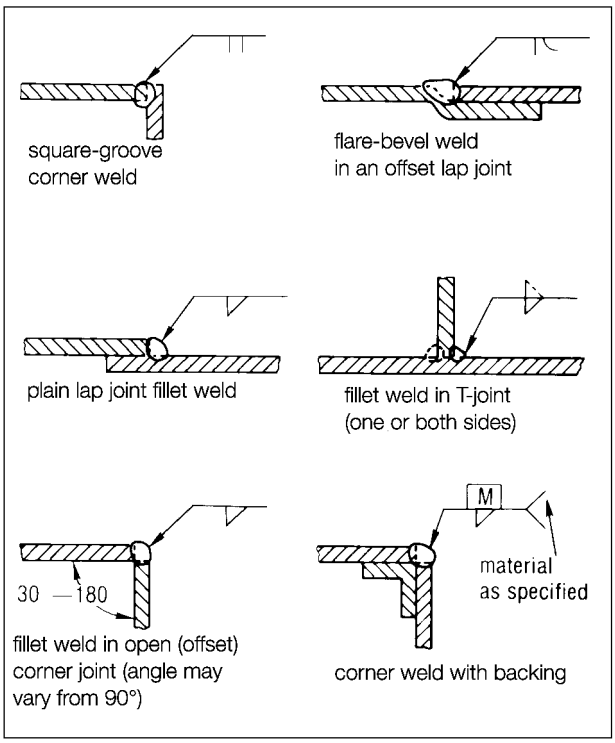


Figure 3. Common weld joints for stampings and sheet metal fabrications.

produce fuse-welded joints without filler metal, which is called autogenous, resulting in minimal smooth welds relative to the base metal on butt and corner joints.

GTA welds can be made in all positions, but the process is considerably slower than other welding processes. Compared to GMAW, GTAW typically takes at least twice as long to complete the same type of weld. Pulsed current is routinely used in GTAW to control weld pool penetration accommodating less-than-optimum fit-up of parts to be welded.

Oxyfuel gas welding (OFW) makes use of the heat generated by an oxygen and acetylene gas (or other gas) flame to weld two components together. Filler metal is manually supplied by a welding rod. The use of this process has rapidly declined in the past decade because of heat distortion, and extremely low travel speeds.

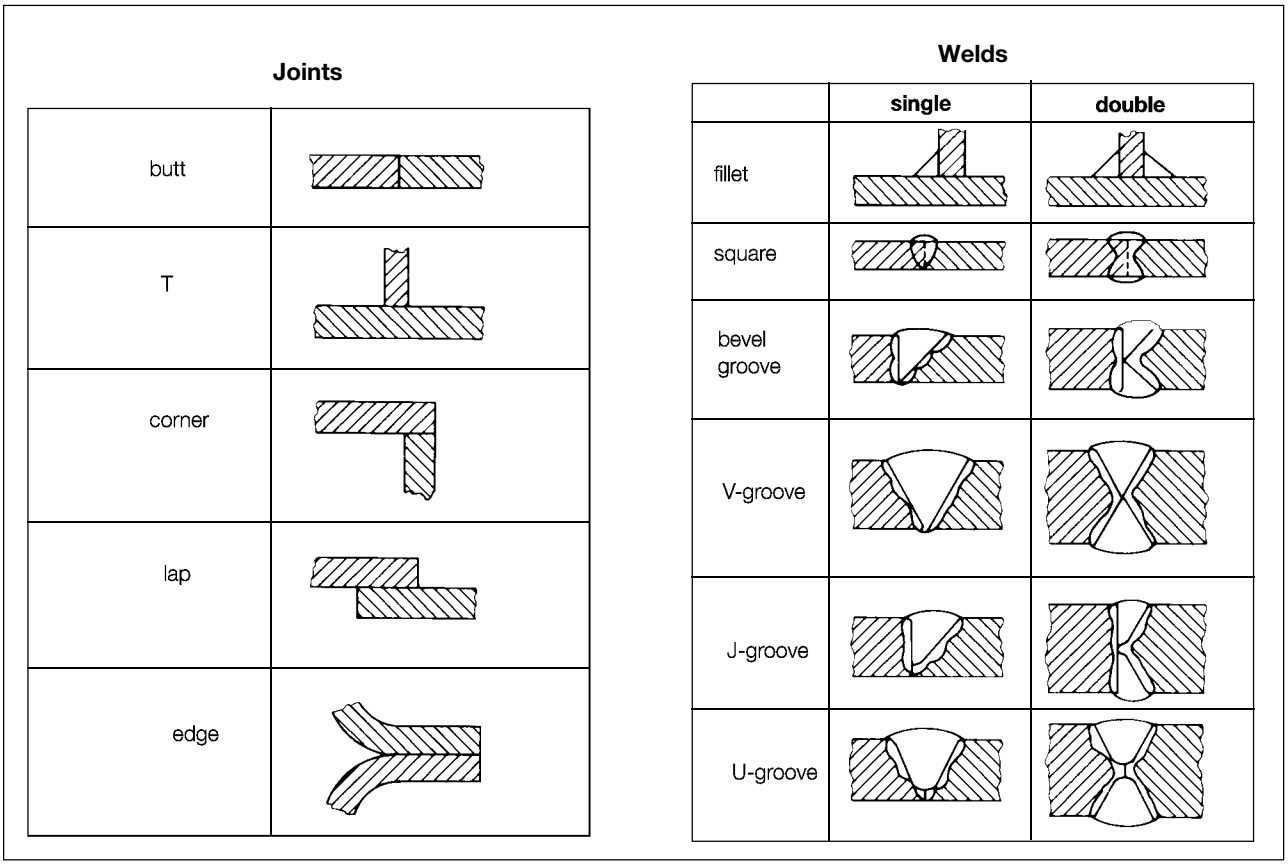


Figure 4. types of joints and welds.

Weld Joint Design

Several types of joint designs are appropriate for welding sheet metal. This includes butt, corner, edge, lap and T-joints. See Figure 3 for joints typically used for stampings and sheet metal fabrications.

In theory, types of joints do differ from types of welds. In practice, however the two terms are often confused. For clarification, see Figure 4. These welds can be further defined by the preparation of the joint pieces and resulting weld geometry. Fillet welds are used for T, corner, and lap joints. Bead welds are used on edge and butt joints, which may also have a groove preparation sometimes requiring multiple passes.

For joints made on thin sheet certain dimensional recommendations or limitations apply to single-pass fillet and groove welds. See Figures 5A-5E for details.

All types of joints—butt, corner, edge, lap and "T"—are appropriate for GMAW and GTAW welding. Corner joints, in particular, find extensive use in sheet metal cabinets and enclosures (Figure 6.)

Specifying Welds

To avoid extra cost and excessive part distortion, the knowledgeable designer should avoid over-specifying weld size and accumulative length.

In structural or dynamically loaded parts, where strength and performance are important, the welding method and size is usually specified to meet mechanical requirements. In low-stress statically loaded parts like cabinets, the method is not as critical, because service loads are relatively small. Tack welds or short intermittent welds are applied using criteria like the weld

length, size, spacing, location and frequency (number of welds). Usually, the welding method is not critical on low stress sheet metal structures.

When welds are specified on an engineering drawing, they are often done "using symbols," following ANSI/AWS A2.4-79 (Figure 7). Although technically correct, following this method may generate many extra hours in part design. Usually it is sufficient to designate welds with notes on the drawing without separately calling out fillet welds, groove welds, etc. This is particularly applicable to welding sheet metal parts when the same process is used to make all welds.

Some metalforming suppliers suggest that designers not specify the exact method and type of welding. This provides increased flexibility, depending on the equipment available, and often results in the most economical choice for the customer.

For covers and decorative items, it usually suffices to specify "corners must be filled or smooth," or alternately, to reference a paint or other finishing specification, which simply may designate "no openings." Similarly, chassis design merely requires specifying weld location, leaving the welding method up to the supplier.

For welding corners on a frame or similar component, GMA welding is structurally sound and the surface can be readily ground to produce an acceptable surface for painting or other finishing. When welding covers and other cosmetic low volume parts, GTA welding with a filler wire often delivers the best economy.

Tack welds are often used to hold parts in place while more extensive, final welds are made. For sheet metal, tack welds often provide more than adequate strength and avoid the overdesign and expense of an "all-around" fillet weld. However, if no other welding is required on an assembly, spot welding deserves initial consideration.

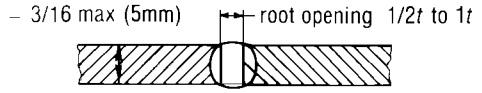


Figure 5A. Dimensional recommendations for square-groove butt joint in thin steel sheet.

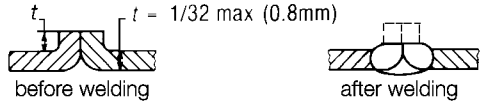


Figure 5B. Butt joint made on short-flanged edges requires no filler metal and helps control melt-through and distortion.

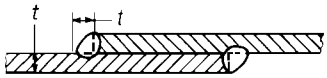


Figure 5C. Lap joint with a double fillet weld should have a 1 in. (25 mm) minimum overlap. A single fillet and shorter overlap may suffice when less strength is required.

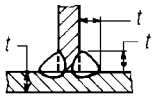


Figure 5D. Compared to a single fillet, a T-joint with a double-fillet weld produces maximum joint strength. Shortest side of the fillet should be equal to the material thickness.

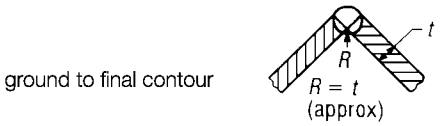


Figure 5E. Corner-edge joints in thin sheet with a V-groove weld are completed with one pass. For higher strength, a second pass (inside) or backing may be required. A simple jig may be required to minimize distortion and maintain squareness of a corner joint.

Figure 5.

Material Thickness

Because of the flexibility of arc-welding processes, thin sections can be joined to thicker sections more readily than with resistance welding. Optimum weld quality results when the workpieces being joined are approximately the same in thickness, thus allowing for equal weld penetration during fillet and tack welds.

General guidelines are helpful: GMAW with short-circuiting metal transfer is recommended for steels from about 0.250 in. (6.35 mm) thick down to about 0.020 in. (0.5 mm). The pulsed

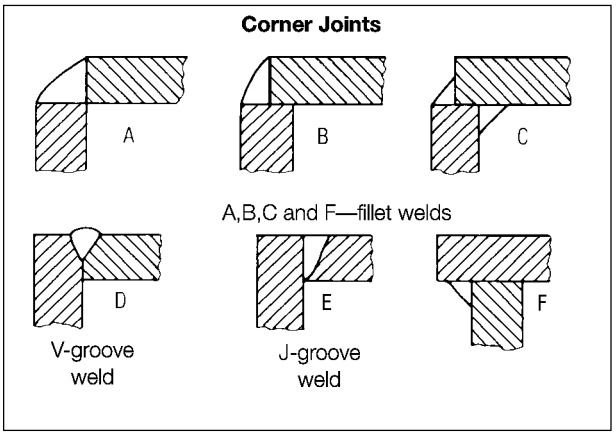
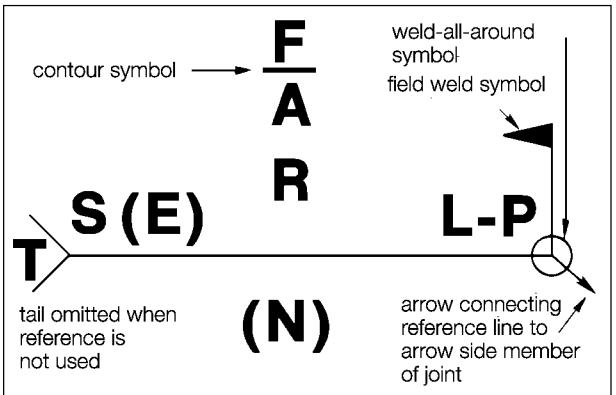


Figure 6. Various corner joints suitable for welding of sheet metal.



T	specification process or other reference
S	depth of preparation size or strength for certain welds
E	effective throat
F	finish symbol
A	groove angle included angle of countersink for plug weld
R	root opening depth of filling for plug and slot welds
N	number of spot or projection welds
L	length of welds
P	pitch (center-to-center spacing) of welds

Figure 7. How to specify welds.

GMAW method is appropriate for the thinner sheet down to 0.020 in. (0.5 mm). In contrast, TIG can be used to weld sheet as thin as 0.005 in. (0.13 mm).

Weld Strength

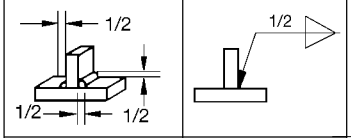
In theory, weld strength should be adequate to handle the stresses the assembly will see in service plus the desired safety factor. Yet overdesign of specified welds is common. A weld may be overdesigned to boost the strength of a thin sheet metal part (designed thin for cost saving), but final cost may surpass that of using heavier gauge metal in the first place. The metalforming supplier can often help determine the best welding option based on manufacturing capabilities and experience.

For welded butt joints, filler materials are usually selected to match the strength of the

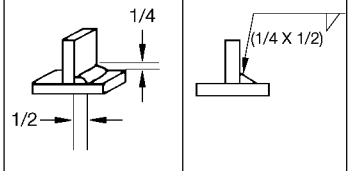
Table I. Allowable loads for fillet welds

leg size		E60 or F-60 weld metal				E70 or F-70 weld metal			
		parallel load, 10 lbf		transverse load (a), 10 lbf		parallel load, 10 lbf		transverse load (a) 10 lbf	
in	mm	in	mm	in	mm	in	mm	in	mm
1/16	1/59	0.80	3.56	0.93	4.14	0.93	4.14	1.09	4.85
1/8	3.18	1.59	7.07	1.86	8.27	1.86	8.27	2.17	9.65
3/16	4.76	2.39	10.63	2.80	12.45	2.78	12.37	3.26	14.50
1/4	6.35	3.18	14.14	3.73	16.59	3.71	16.50	4.35	19.35
5/16	7.94	3.98	17.70	4.66	20.73	4.64	20.64	5.44	24.20
3/8	9.53	4.77	21.22	5.59	24.86	5.57	24.78	6.52	29.00
7/16	11.11	5.57	24.78	6.52	29.00	6.50	28.91	7.61	33.85
1/2	12.7	6.36	28.29	7.46	33.18	7.42	33.00	8.70	38.70
5/8	15.88	7.95	35.36	9.32	41.46	9.28	41.28	10.87	48.35
3/4	19.05	9.54	42.43	11.16	49.64	11.14	49.55	13.05	58.05
7/8	22.23	11.14	49.55	13.05	58.05	13.00	57.82	15.22	67.60
1	25.4	12.73	56.62	14.91	66.32	14.85	66.05	17.40	77.40

(a) non-code work



symbol indicates two fillet welds, both with 1/2 in. (12.7mm) leg dimensions



symbol indicates a fillet weld on arrow side of joint with 1/4 and 1/2 in. (6.35 and 12.7mm) legs

orientation of legs must be shown on drawing

base metal. For fillet welds, stresses are assumed to act in shear and weld strength depends on leg size, length of the weld, type of weld metal, and loading direction. See Table I for allowable loads.

Cost of Welding

Because welding is such a versatile process, it is often the best way to produce sheet metal assemblies which must meet both strength and cosmetic requirements. However, compared to other joining processes, manual welding, particularly in smaller volumes, can be relatively expensive. As the volume of the product to be assembled increases, the process becomes competitive with alternate joining methods. High volume products can be very economically produced using dedicated fixturing and laser, semiautomatic or robotic welding techniques.

The length and width of a weld can have a great effect on cost. By not specifying size, length and number of welds, and by avoiding fillets that are welded all around, the size of a weld can be limited, reducing cost. Additionally, choosing weld locations and orientations that more directly resist primary service stresses can reduce weld size. Again, this reduces labor and material costs.

Finish and Spatter

If a perfectly smooth surface is required, GMAW welding is not the method of choice because it generates spatter. Designers should be careful to specify when weld spatter is not allowed.

As an alternative, if the weld can be put on the inside of the part and spatter is acceptable there, design requirements can be met most economically with GMAW, because it is much faster than GTAW. Occasionally, both GTA and GMA welding may be used to obtain optimum cost-effectiveness and meet cosmetic requirements. If parts have to be masked for spatter, or cleaned after welding—or if anti-spatter compounds are required, GMAW costs can increase dramatically, making GTAW welding more cost-effective.

Parts that are to be painted or otherwise finished after welding may require a secondary grinding operation to smooth welds down to an acceptable level. Depending on finishing specifications, the cost of secondary grinding can easily equal or exceed the initial welding cost.

When welding is done on a "face" or cosmetic panel, small dips or undercuts may appear. If this is visually unacceptable, grinding and polishing are needed. Surface finish should always be specified to reflect cosmetic requirements. This is particularly important when welding thick to thin material.

Weldable Materials

GMAW and GTAW processes can weld practically all ferrous and nonferrous materials to themselves or to very similar alloy compositions. For welding dissimilar metals, GTAW is the process of choice, permitting carbon steels to be joined to stainless or to copper alloys. Before opting for such designs, however, consideration should be given to consequent effects, such as galvanic corrosion and differences in expansion coefficients and conductivity. Welding dissimilar metals requires special attention to electrode composition, welding technique, and other factors, and involves additional cost.

Steels coated with cadmium, lead, tin and zinc present special problems in achieving a sound, cost-effective and cosmetically acceptable weld. In all cases, toxic gases are produced. Even aluminum-coated steel presents difficulty and requires special methods. Further, when coatings are removed to facilitate welding, they usually must be reapplied afterward at additional cost.

Weld Distortion

Distortion can be a major factor in sheet metal welding. Whenever sheet metal is heated, some distortion will occur. See Figure 8 for typical distortion in a T and butt joint. In general, distortion can be controlled to varying degrees

by clamping or fixturing, use of heat sinks (see Figure 2) and special welding techniques. Proper joint design and correct welding procedures limit distortion.

Certain welding configurations are more likely to distort. For example, welding four corners on a cover or enclosure usually produces distortion. The more welding done, the more distortion will occur. Even tack welds create distortion, which can be minimized by careful spacing. The American Welding Society (AWS) recommends 2 in. (51 mm) as a minimum between tack welds.

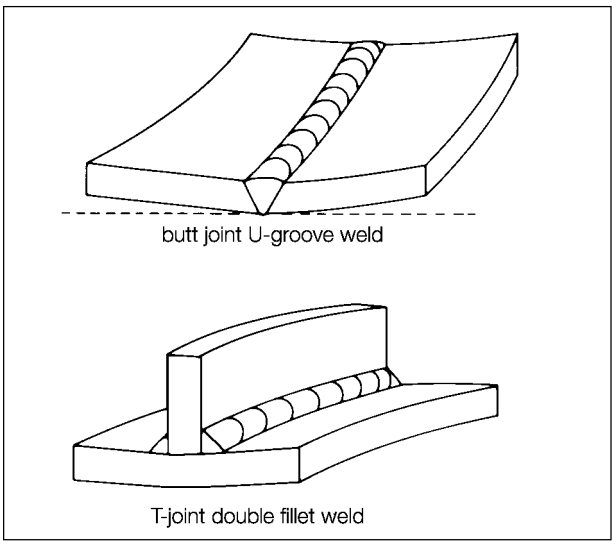


Figure 8. Distortion of welded sheet metal parts.

While special weld techniques and welding sequences can be used to minimize distortion, avoiding distortion completely can be very costly and very difficult to ensure. The cost-effective approach is to permit a certain amount of distortion and allow for it in part design.

Distortion of local features can also be a problem. In a flat plane, local distortion is likely if other design features are too close to the weld. For instance, holes located 1/4 in. (6 mm) from the weld will change shape. Consequently, secondary operations like reaming, drilling or punching after welding, may be required to restore function. Prediction of heat zone distortion usually requires trial and error experimentation before completing a design.

Good Fit-Up for Quality Welds

Fit-up, or how well components line up, can have a dramatic effect on weld quality and generally depends on the material thickness and how parts are welded. A large gap between parts will cause shrinkage upon cooling and produce excessive distortion or result in burn-through. Tight fit-up is a prerequisite for quality TIG welding. This is most important when fuse welding without filler metal.

Fixtures and Tooling Holes

Tooling holes or other self-locating features on parts being welded into an assembly are of utmost importance and should therefore be part of the original design whenever possible. The significance of these features is the economical and quality impact they have on the finished product. This is especially true for smaller, close tolerance assemblies.

The use of welding fixtures is sometimes unavoidable and even dictated by circumstances, but do add an initial tooling cost to the project. Fixtured assemblies are also slower to work with than self-fixturing features because of added bulk weight, which adds to the per-part-cost. Since fixtures have tolerances of their own, and gauging contacts, clamping pressures and deflections can vary from part to part, the tolerances of the welded assembly will reflect these variables.

The great variety in size and accuracy requirements of welded assemblies dictate different methods of fitting and fixturing. Exacting electronic housings, for example, need a different approach than a heavy wall and angle iron structure. With this in mind, the design tolerances should be based on material thickness, structure size and welding process. For a guide on locating parts to each other during welding, also see the “Positive Location of Workpieces” with details and illustrations in the preceding chapter on spot welding.

Weld Location and Accessibility

Welds must be located with operator accessibility in mind. While it's very simple to indicate a weld on a drawing, accessibility requires careful planning. Most welding processes are limited by the torch size and the angle at which the electrode is applied to the work.

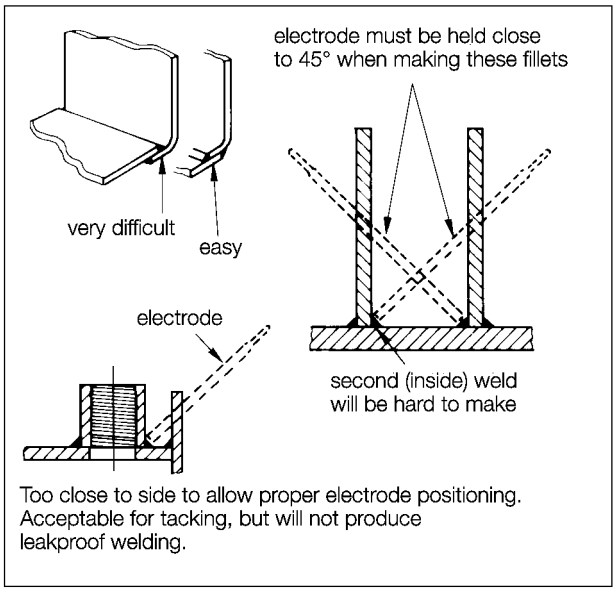


Figure 9. Weld joint designs with poor accessibility.

In practice, GMAW torches take up more space than GTAW torches, but in either case, the operator needs room to access the joint. If accessibility is doubtful, check clearances with the metalforming supplier before the design is finalized. See Figure 9 for various design geometries that should be avoided.

The Cleaner, the Better

To achieve optimum quality welds, workpieces should be free of foreign contaminants, oil, grease, etc. In general, cold-rolled steel parts do not require the cleaning that hot-rolled steels require. Aluminum alloys require wire brushing or etching before welding to remove oxidation and produce the highest quality welds, at added costs.

Defects That Can Affect Quality

Rejections most frequently occur because of distortion caused by the cooling of the weld metal and resultant pulling on adjacent parts. In applications where all the special techniques available to a welder are used, the part still may not be flat after welding without use of a secondary straightening operation. Such extra-cost secondary operations should be weighed against more liberal flatness requirements, such as 0.008 in. (0.20 mm) per linear inch of surface.

Finishing Considerations

It is extremely important that the designer consider the effect of any welding on subsequent finishing operations. Welded assemblies to be painted should preferably be designed with hidden welds. If this is not possible, locate the welds for easy and economical grinding access. Grinding should be avoided in inside corners or on internal surfaces, as it requires special equipment and costly hand operations.

Parts which are to be electroplated should be designed to eliminate overlapping seams, hidden corners and other areas where plating solutions can be trapped and create subsequent corrosion and bleed-out. Good welding design for finishing can be confirmed by consulting with the metalforming supplier early in product development.

Tolerancing Considerations

Generally, weld length, height and spacing are not rigidly toleranced. These dimensions are usually toleranced very generously, and where possible, specified only by nominal dimensions. While elaborate fixtures can be used to control the length of a weld, this approach is expensive and slows down the welding process, further increasing manufacturing costs. Tolerancing the height of a weld within 0.030 in. (0.76 mm) will usually require a secondary grinding operation.

For economy, squareness also should not be overspecified. When very accurate squareness is required, self-locating features should be incor-

porated, since this is much more cost-effective than building, using and maintaining a fixture. Self-fixturing assemblies can reduce the cost to fixture the components by as much as 60%.

Welding Automation

When part geometries, sizes, quantities, fit-up and fixturing are appropriate, processes like GMAW, GTAW and laser lend themselves to various degrees of automation, from semi-automatic to robotic welding. It should be noted that automated welding requires precise dimensional control of components and may dictate special tooling. If fixturing requirements permit, several parts can be ganged together, so that the robot can make identical welds on each part. The result is greater economy.

15

INSERTED FASTENERS

Nut and stud inserts can provide wide design flexibility for fastening stampings and sheet metal fabrications together (Figure 1). All of these fasteners can be installed economically—except concealed head studs, which require expensive machining operations.

Inserts are special nut or stud fasteners that are designed to be pressed into prepared holes in sheet metal parts. Inserts provide captive male or female threads in materials too thin to tap, when higher strength fastening is required, or when repeated access after assembly is anticipated. They are routinely less expensive than the conventional nut and bolt alternative.

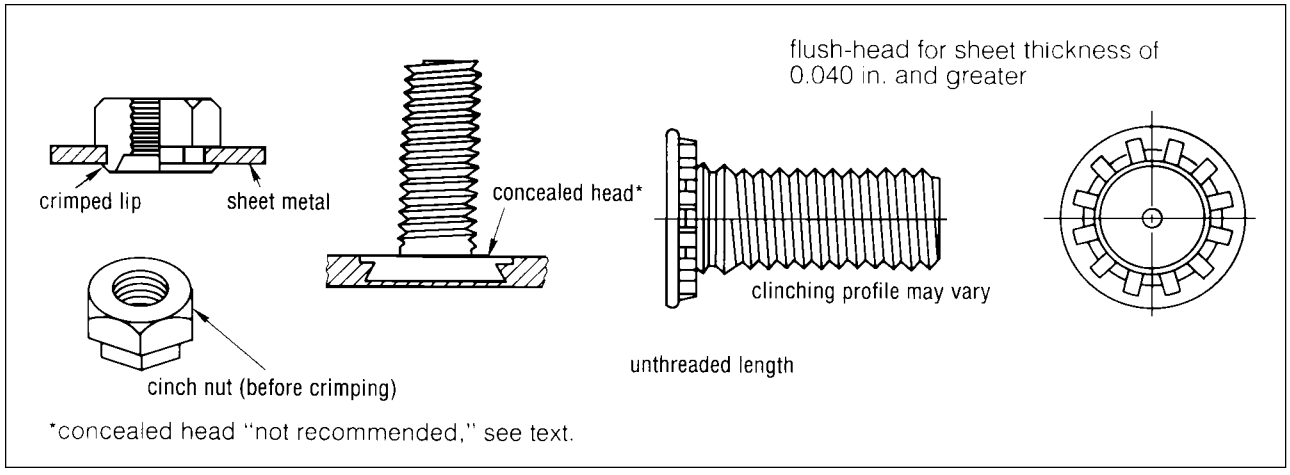


Figure 1. Examples of "clinch" nuts and studs.

A great number of inserts are available in various thread sizes, lengths, classes of fit, materials and finishes to fit most design requirements. When quantities justify, custom-made inserts may prove economically advantageous over standard types.

An important initial consideration in insert selection is access to the prepared hole. If both sides of the sheet are accessible, a wider range of manufacturers' products is applicable. However, when access is available to only one side of the sheet, rivet nut inserts (Figure 2) should be considered. These inserts can be installed, usually with special tools, like blind rivets. Alternatively, lack of access to the reverse side may also be solved by inserting fasteners designed for two-side installation, prior to bending or other forming operations. When such considerations arise, metalforming suppliers can offer practical advice.

Insert Installation

Nut or stud inserts are inserted into punched or drilled holes, then clinched or crimped into the sheet metal. Depending on the type of insert selected, it is clinched against the metal surrounding the prepared hole, typically deforming and flowing the substrate metal to lock the fastener into position. Knurled flanges and similar features are often incorporated in the insert design to aid in anchoring the fastener to the sheet.

Inserts can be installed by standard presses with a punch and anvil set-up (Figure 3) and by hydraulic and pneumatic tools. With automatic feeding capabilities, specially designed presses

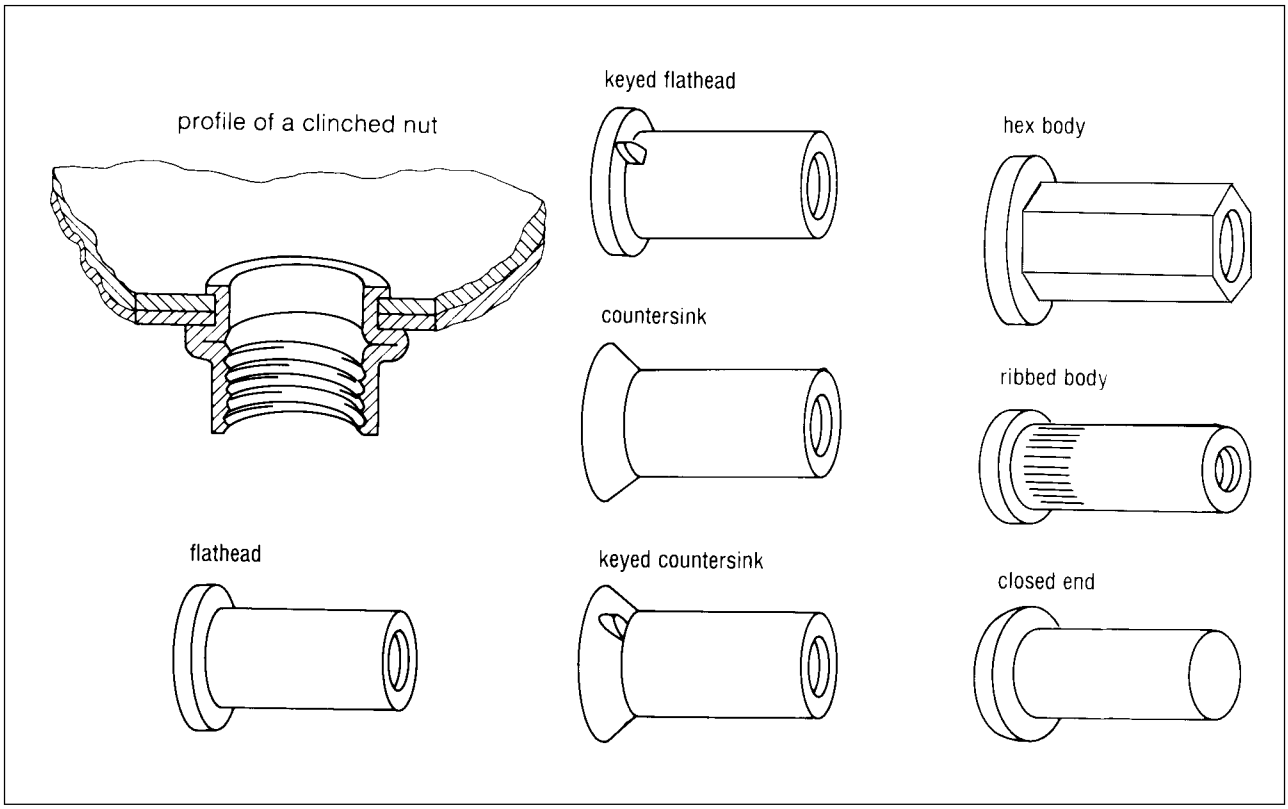


Figure 2. Typical of rivet nut inserts.

can install inserts rapidly.

Some types of inserts, like rivet nut inserts, undergo most of the deformation via clinching, while the workpiece undergoes minimal deformation. Here, keyed or ribbed fastener heads are sometimes used to prevent rotation of the insert in the workpiece, and to resist vibration in service.

These types of inserts are usually installed via special pneumatic or hydraulic tools. For high-volume production, fully automated systems including auto feeders and robotics can be utilized.

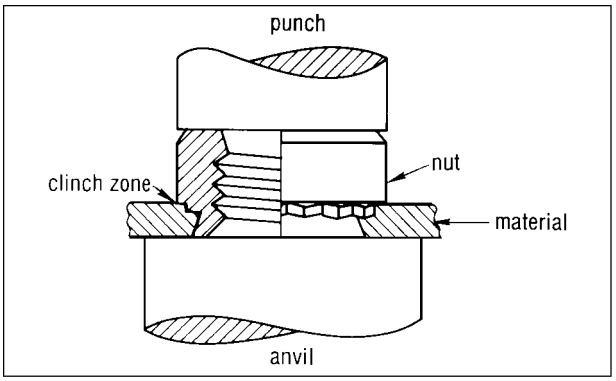


Figure 3. Inserts can be installed by standard presses with a punch and anvil set-up.

Cost Considerations

Generally, the more functions an insert performs and the more exotic the material and finish, the higher the cost. Beyond that, the cost of nut inserts vs. extruded-and tapped holes is always a controversial issue. Often the choice depends on the designer's preference and experience. The economy of one system vs. the other should be discussed with the supplier.

Extruded holes are ideal in stampings when the part will be tumbled and finished, then assembled with self-tapping screws. Because extruded holes are created in a punching operation, many stamping companies advise using this option when additional holes and other features will also be punched and formed to create the final stamping. For higher production volumes this approach can be the most economical choice.

Other means of installing threads—weld nuts and studs, self-locating projection weld nuts, extruded-and-tapped holes—should also be evaluated on a cost/performance basis. Metalforming companies can advise which alternative is most suited for a particular design.

Types of Inserts

To facilitate a particular part design, inserts can be installed flush (Figure 4) into one side of the sheet, or nonflush, with the head protruding. Flush installations usually require a special head on the insert and/or a countersunk or counterbored hole.

As depicted in Figure 5, additional fastening

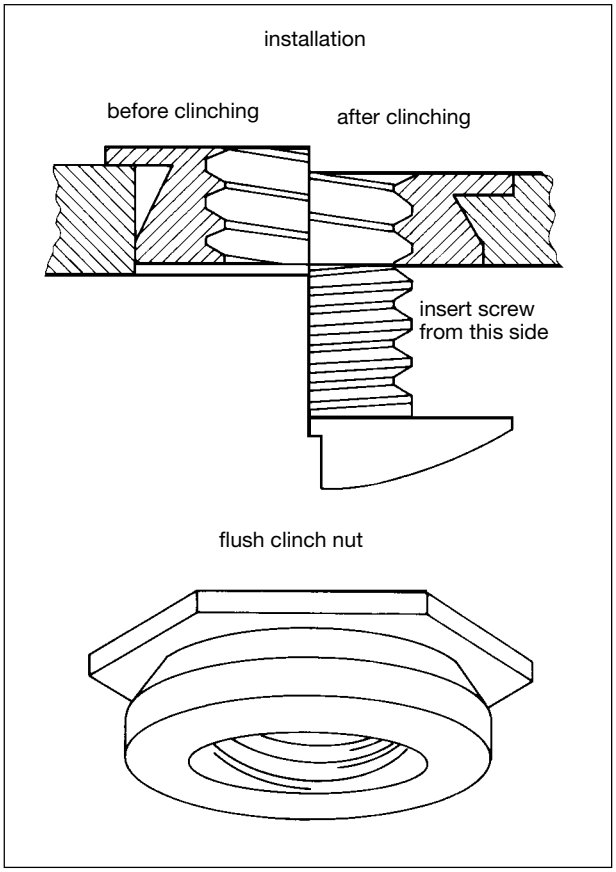


Figure 4. Example of nut inserts installed flush with the sheet.

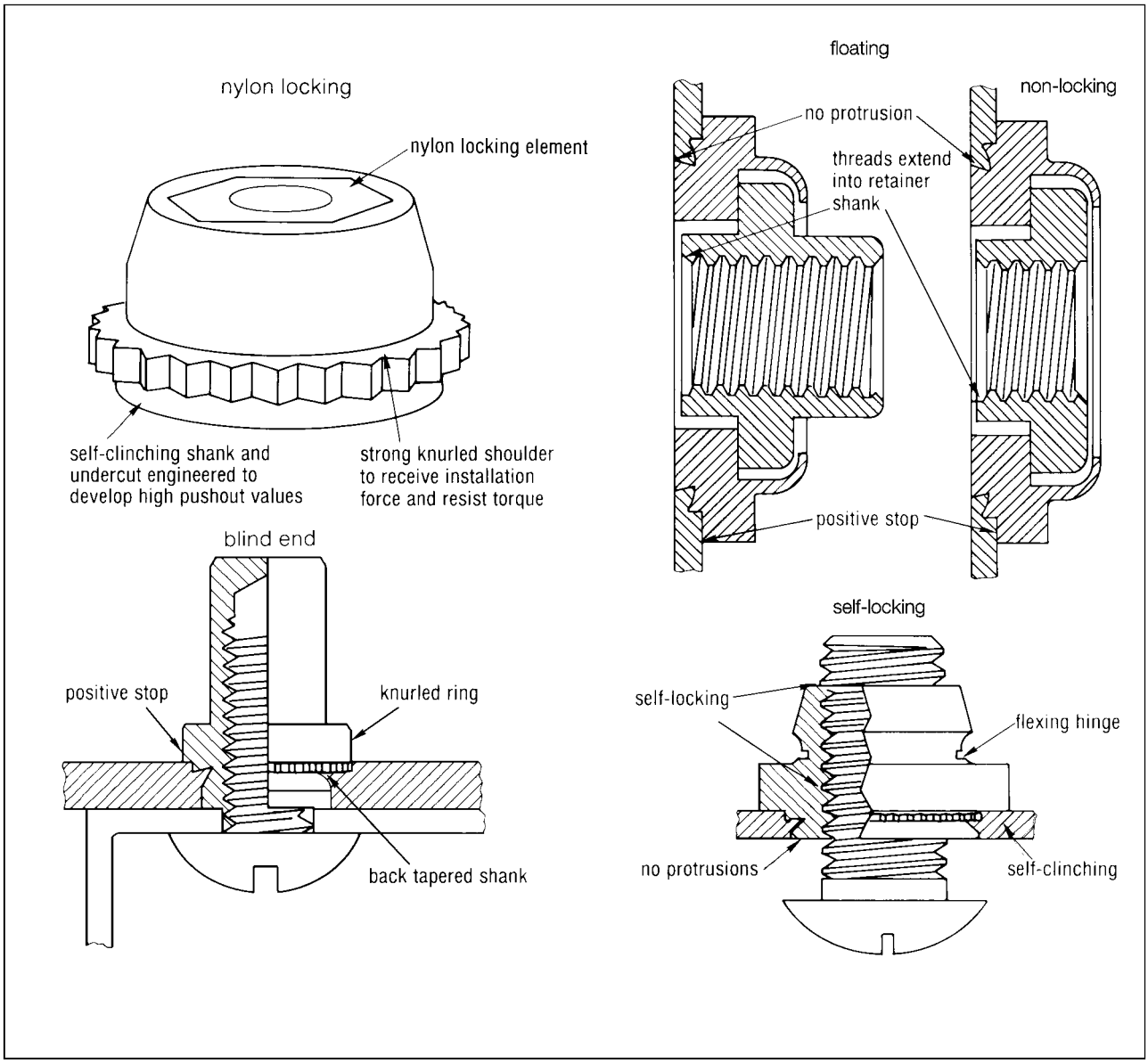


Figure 5. Nut inserts with self-locking features are another method of fastening.

functions are achieved by nut inserts with self-locking features (accomplished by interrupted threads, coatings, and special nut designs, etc.). "Floating" fasteners provide for mismatch (e.g., ±0.015 in. (±0.38 mm)) between mating fasteners or holes. Blind-end types form a seal against liquids and foreign contaminants; and, special spring-loaded panel fasteners can be flush-mounted as a single unit.

Depending on the type selected (and the manufacturer), inserts can be used to join more than two components together. For example, rivet nut inserts can join or "rivet" two sheets and also provide threads to mount a third component (Figure 6).

Key Design Parameters

The insert type is chosen based on functional and aesthetic requirements such as flush mount, self-locking nut or concealed head stud.

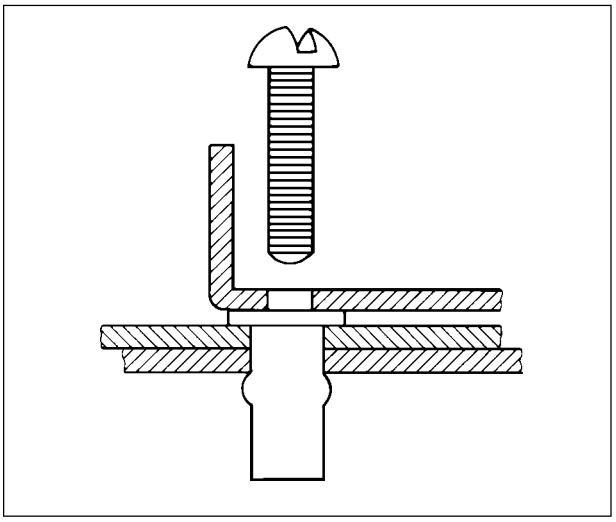


Figure 6. Here a rivet nut insert is used to join or "rivet" two sheets and also provide threads to mount a third component, an angle bracket.

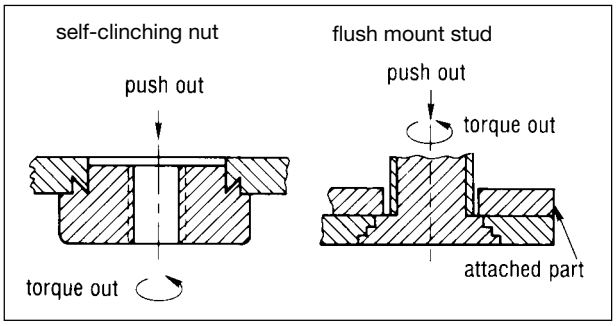


Figure 7. Strength of inserts is measured by push-out and torque-out values.

Other important factors for consideration in selection are strength, workpiece hardness and thickness, material compatibility, finish, distortion, clearance and tolerances.

• **Retention strength** of inserts, as measured by push-out and torque-out values (Figure 7), is a direct result of the metal flow and interlocking that occurs during installation. Consequently, the design of the insert and the material into which it is being installed can have a significant effect on strength. As may be expected, strengths increase with larger diameter inserts and thicker sheets.

Aluminum inserts in aluminum exhibit lower push-out and torque-out values than steel inserts in steel. When higher strength is needed, both carbon steel and stainless steel inserts can be used in aluminum workpieces. For applications that require optimum strength—such as when replacing weld studs—high-torque-resistant studs with heavy heads can be specified to boost pull-through values.

For rivet nut inserts, tensile strength, thread strength and shear strength, as well as torque-out values can be used in determining what insert type will resist design stresses. Highest thread strength is provided by stainless steel inserts, followed by steel, then aluminum. However, most steel self-clinching fasteners are heat treated and will then prove the strongest threads.

• **Hardness** of the workpiece is also an important criterion. In general, inserts are recommended for use in workpieces up to a specific maximum hardness according to the insert's material type. For self-clinching fasteners the fastener must always be significantly harder than the workpieces.

• **Thicknesses** from as low as 0.020 in. (.5 mm) up to about ½ in. (12.7 mm) are suitable for inserts depending on the manufacturer and insert type. For nut inserts in sheet metal, typical workpiece thicknesses range from 0.030 in. (0.75 mm) to 0.125 in. (3 mm), corresponding to thread sizes from #2-56 to 5/16-18.

For best performance, insert size (diameter and threads/in.) and shank length for a given type of insert should correspond to the minimum thickness recommended by the manufacturer. However, shank lengths recommended for a specific minimum thickness can usually be used in thicker workpieces so that one "standard" size can be used throughout an assembly and for similar parts.

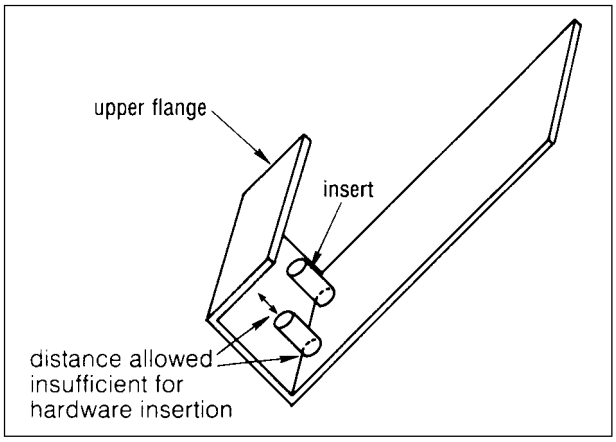


Figure 8. Illustration of insufficient clearance.

• **Compatible Materials** should be used to avoid galavanic corrosion in the insert and workpiece. Inserts are available in a wide variety of materials, including aluminum alloys, carbon steel, stainless steel and brass.

In service environments where this is not a problem, steel and stainless steel inserts can be used in aluminum to achieve higher strengths. Steel and stainless steel inserts are installed in aluminum after anodizing or other finishing operations. Stainless hardware is installed in steel after plating.

• **Finish.** Various corrosion-resistant finishes to meet commercial and military specs may be specified. Typical for steel are black oxide and zinc plating, to which a clear or other chromate can be applied for additional corrosion protection.

For aluminum, anodizing or color anodizing are the two options. Stainless steel inserts are usually passivated to enhance corrosion resistance. Standard finishes vary among manufacturers; custom and unique finishes usually command a premium cost and require extended lead times.

• **Edge distortion** is hardly ever a problem if the insert manufacturer's recommendations are followed. Closer proximity to the edge leads to edge distortion, which may interfere with subsequent assembly and/or part function. While smaller than minimum edge distances can be used, they usually require special fixtures to restrain the sheet during installation. This extra expense is usually cost-prohibitive and often distortion cannot be prevented.

• **Clearance** must be adequate. While hole locations and their distances from other features are usually dictated by design analysis and the methods that create them (see punched holes and slots in Stamping Production Chapter), these should be tempered by such factors as additional clearance for the insert installation equipment, the subsequent assembly tool, and the length of the insert (Figure 8).

• **Accessibility** should be considered in the design stage. Particularly important is the closeness of inserts to bends and formed features. Even if the insert is installed prior to bending to accommodate a difficult manufacturing sequence, subsequent access to the insert is a must so that the mating fastener can be installed.

Tolerance Considerations

Generally, hole diameters for clinch nuts and studs should not be toleranced by the designer since the supplier implements nut/stud manufacturing tolerances to maintain insert locations. Usually only the diameter of the hole should be specified with a reference indicating the insert type, length, etc.

Typically, the supplier can advise whether the holes need deburring. Many manufacturers recommend no deburring, since this extra metal can result in a better clinch. In contrast, manufacturers of rivet-nut inserts ordinarily recommend burr-free holes.

When accuracy of hole location is important, holes should be dimensioned from a datum (not chain dimensioned) to avoid accumulation of tolerances (Figure 9) and resulting misunder-

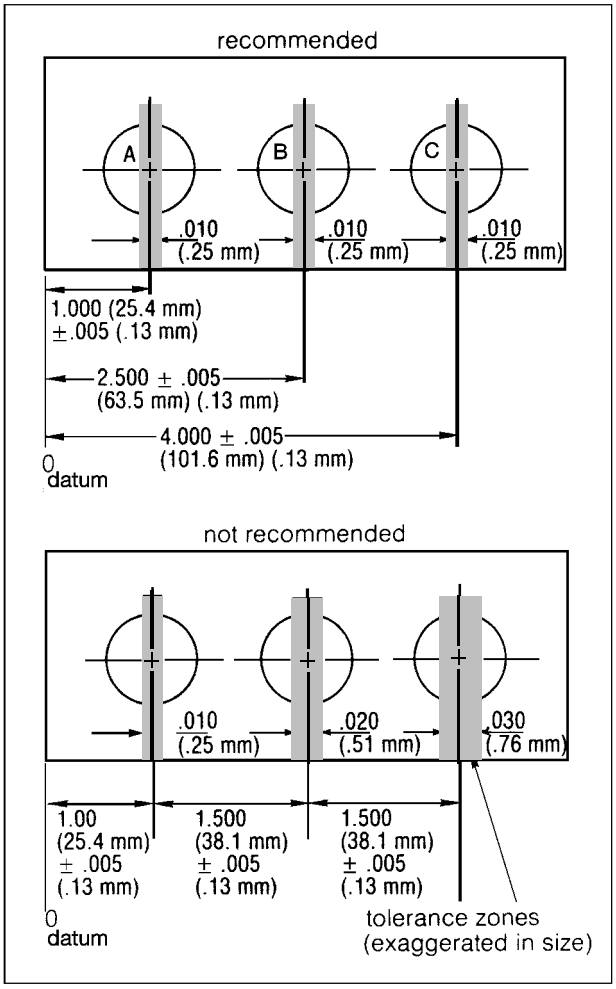


Figure 9. "Recommended" and "not recommended" dimensioning for accurate positioning of holes.

standings. If tolerances achievable with inserts and punched holes are not acceptable for the design, then another method of fastening should be considered.

During insert installation, even with the anvil and punch on center, some movement occurs as the insert is put into the hole and clinched. As a result of this variable, as well as variations in concentricity of hardware, and hole location, the accumulative tolerances can range as much as 0.015 in. (0.38 mm) from the design centerline.

If tighter tolerances are required, use of a fixture can provide more accurate hole location. Perpendicularity of inserts to the sheet is usually quite consistent as a result of proper installation.

16
HEAT TREATING

Heat treatment is a thermal process designed to obtain specific metallurgical and mechanical properties in ferrous and non-ferrous materials. During heat treatment the crystal structure and/or surface chemistry of the material being treated is altered. The final properties after thermal processing can include combinations of increased material strength, wear resistance, formability, fracture toughness and/or corrosion resistance.

Choosing the proper heat treatment process for a specific part design can be difficult. Fortunately, the heat treating requirements are usually established when the design engineer decides what mechanical properties are required for the part. Then it is up to the part manufacturer to determine how to best perform that process with optimum quality, shape stability, and economy in mind. The treatments of greatest importance in sheet metal processing include:

1. Surface treatments.
2. Hardening of carbon and alloy steels through quenching and tempering.
3. Vacuum heat treating of stainless and tool steels.
4. Slow cooling processes.

Surface Treatments for Ferrous Alloys

Stampings are often made from low carbon cold rolled steel that permits forming to be done while the steel is soft and easily shaped. For many types of applications it is desirable to produce a chemical change on the surface of the material which can increase strength and wear resistance or improve resistance to corrosion. These inexpensive low carbon steels can be given wear-resistant properties that would normally be associated with highly alloyed, more expensive steels.

Materials with less than 0.70% manganese may require a more severe quench to obtain adequate wear resistance at the sacrifice of distortion. For parts that require higher core strength material with a carbon level of 0.30-0.50% can be used for case hardening. Caution must be exercised with any material

greater than 0.30% carbon to assure adequate ductility for the final application.

Three different processes are commonly used to develop surface hardness on steel: carburizing, carbonitriding and ferritic nitro carburizing.

• **Carburizing** is a process that introduces carbon to the surface to form a hard wear-resistant final surface layer, known as the "case," on a low carbon steel. Normal depths of case range from 0.005 in. (0.127 mm) to 0.060 in. (1.524 mm) deep. By using a low carbon steel, only the surface is changed while the core remains soft and ductile. The depth to which the carbon is added to the steel is determined by time and temperature.

• **Carbonitriding** introduces carbon and nitrogen to the surface. The addition of ammonia to the atmosphere provides a source for nitrogen which increases hardenability and forms hard microscopic nitrides. These cases can be harder than carburized cases and they maintain hardness better in higher service temperatures. Carbonitrided cases are less resistant to impact. Due to nitrogen's increase in hardenability, carbonitriding can be used on lower grades of carbon or hot rolled steel. Normal depths of case are 0.020 in. (0.508 mm)

• **Ferritic Nitrocarburizing** is a process in which nitrogen and carbon are diffused into the surface of ferrous metals to form a thin complex layer of hard carbide-containing nitrides. This process is performed at lower temperatures and does not rely on transformation, or quenching. Because of these lower processing temperatures very little distortion takes place. This can be an excellent application for thin precision stampings that distort during traditional heat treating operations. Thin gage materials <0.030 in. (0.762 mm) can also show a marked increase in overall strength.

Hardening of Carbon Steels

Through heat treating, components can be made harder, stronger and more wear resistant. The hardening procedure consists of three essential steps: austenitizing, quenching and tempering.

• **Austenitizing** is achieved through heating the part to an elevated temperature where a structure of austenite can form. This should be done in a uniform manner with a minimum of temperature differentiation from piece to piece. The part should be held long enough to ensure that the temperature is uniform throughout its cross section.

• **Quenching** provides the transformation of soft austenite into a harder microstructure. This is normally accomplished by immersion into a liquid such as water, oil or salt. To minimize distortion the quenching media selected should only cool the part as fast as required to harden the particular steel.

Water–Water based quenches are the most severe. Lower carbon and lower alloy materials may require this medium to create desired strength levels. Brine or caustic soda quenching can create hardness values of up to HRC 45 for 1018 material. Water based quenches will also result in the greatest level of distortion and can cause cracking in complex parts over 0.35% carbon.

Oil—Oil quenching is the most common. Oil is commonly used for medium carbon materials (1045-1050), engineering alloys (4140, 4340, 6150), or spring steels over ⅛ in.(3.175 mm) in thickness. Distortion and danger of cracking are lower than that for water based quenches.

Salt–Salt quenches are less severe than oil quenches and provide for greater distortion control. Higher hardenability materials are needed for salt quenches since they remove heat slower. Austempering and martempering are two types of salt quenches.

• **Tempering** is performed to impart a given

level of toughness to the material after quenching. Tempering temperatures can range from 250 to 1200°F. As a general rule, materials over 0.40% carbon should have a minimum of a 300°F temper.

Austempering consists of austenitizing the steel in a suitable medium and quenching in molten salt that is between 450 to 700°F to produce a structure called bainite. Austempering is usually limited to parts with a thickness of less than ⅛ in. (3.175 mm). Parts that are austempered will distort less than parts quenched in oil and the bainite structure has greater ductility and toughness than tempered martensite. However, bainitic structures also have lower yield strengths than a conventionally hardened material of the same hardness level. Because of the size limitations and increased expense austempering is not widely used. The ability to add toughness and reduce warpage makes the procedure useful in the heat treatment of scraper blades, springs and lawn mower blades.

Martempering is also known as marquenching. The primary reason for martempering in the stamping industry is to offer greater dimensional control than traditional quenching. In many cases, martempering has eliminated the need for quenching fixtures that were needed to control distortion in conventional quenching. In addition, some stampings can be marquenchened and straightened before any substantial hardening takes place. Marquenching usually has a greater heat treating expense but can be justified by the reduction in distortion on thin or critical parts.

Vacuum Heat Treating

One of the requirements for processing tool and die materials, stainless steels, copper and brass is that the surface of the alloy remains clean. Vacuum furnaces are used to protect these and other exotic materials. The typical vacuum furnace consists of a chamber in which the work is heated and cooled by a blast of inert gas such as argon or nitrogen.

• **Non-Ferrous Alloys** are materials in which iron is not the major element present. These alloys respond to stress-relieving, annealing solution and aging treatments. Principal non-ferrous alloys that are used as metal stampings are copper, aluminum, brass and beryllium copper.

• **Aluminum Alloys.** Heat treating of aluminum is designated by a series of numbers ranging from 0 to 8. The alloys that have been annealed are designated by T-0. (2024-0) Alloys that have been solution treated are designated T-4. (2024-4) Alloys that have been aged are said to be in the T-6 condition. (2024-6) See Table I.

Table I. The various heat treatments and mechanical properties associated with precipitation hardened aluminum alloys.

Alloy	Solution Heat Treatment	Precipitation (Aging) Heat Treatment
2024	920F Water Quench	375F for 11-13 Hours
6061	970F Water Quench	320F for 16-20 Hours
7075	880F Water Quench	250F for 24-28 Hours

Mechanical Properties

Alloy	Temper	Yield PSI	Tensile PSI	Elongation in 2"%
2024	0	11,000	27,000	22
2024	T-6	52,000	69,000	10
6061	0	8,000	18,000	30
6061	T-6	40,000	45,000	17
7075	0	15,000	33,000	16
7075	T-6	73,000	83,000	11

The steps for heat treating are very simple, but important. Solution treated parts are quenched in water and the aging is processed in a recirculation air furnace. Work that becomes distorted during heat treatment must be straightened soon after the quench when the yield strength is lowest.

• **Beryllium Copper** alloys possess excellent electrical, mechanical and physical properties and

are easily blanked stamped and formed. Once the desired shape and dimensions have been achieved the alloy can be age-hardened by suitable heat treatment. See Table II. For a bright finish after heat treatment the parts should be processed in an atmosphere or a vacuum furnace. Thin parts that must hold tight dimensions can be fixture hardened to reduce warpage and springback. This material is supplied in the solution treated A or solution treated and cold worked 1/4 H, 1/2 H and H tempers.

Table II. Beryllium Copper Strip Properties After Age Hardening

Temper	Age Hardening Treatment F	Tensile Strength PSI	Yield Strength PSI .2% Offset	Rockwell Hardness B or C Scale
Berylco 25 (CA 172)				
AT	3 hr 600	165-190	140-170	C 36-41
1/4 HT	2 hr 600	175-200	150-180	C 38-42
1/2 HT	2 hr 600	185-210	160-190	C 39-42
HT	2 hr 600	190-215	165-195	C 40-45
Berylco 10 (CA 175)				
AT	3 hr 900	100-120	80-100	B 92-100
1/2 HT	2 hr 900	110-130	95-120	B 95-102
HT	2 hr 900	110-130	100-120	B 95-102
Berylco 165 (CA 170)				
AT	3 hr 600	150-180	85-115	C 33-38
1/4 HT	2 hr 600	160-185	135-165	C 35-39
1/2 HT	2 hr 600	170-195	145-175	C 37-40
HT	2 hr 600	180-200	155-185	C 39-41

Specifying Material and Heat Treating Processes

All material designations and processing information should be clearly called out on the drawings. The SAE or AISI material designation should be specified whenever possible. The material trade name is sometimes a satisfactory substitute. However, the use of general terms such as "spring steel" is seldom adequate.

Hardness requirements should note the type of test such as Rockwell or Brinell and the hardness range. For spring steel a 4 to 5 point range is desirable. Case hardening treatments should specify the method of reading case depth (total or effective) and the range allowed. For case depths below 0.015 in. (0.381 mm) a 5 point range is desirable. For case depths over 0.015 in. (0.381 mm) a 10 point range should be specified.

Parts that have areas where hardness testing is not allowed should be clearly noted.

Hardness Measurement

The hardness of a part is the universal measure of heat treat performance. Fatigue strength, toughness or tensile strength are examples of properties that are correlated with the hardness value. Even though hardness itself may not be the important characteristic the correlation is consistent. In summary, hardness is specified because it is easy to measure. The most common procedures for hardness testing are the Brinell, Rockwell and Vickers methods.

• **Brinell Method.** This test is quick, accurate and reproducible. A hard carbide ball is pressed into the steel. When the ball is removed it leaves a small depression. The diameter is measured by a small portable microscope and the hardness value is determined by referring to Table III. The Brinell system is usually used on softer materials, while the Rockwell system is used on harder materials.

Table III. The Brinell Hardness Test

Diameter 3000 k9 load 10 mm ball	Hardness number
2.25	745
2.30	712
2.35	682
2.40	653
2.45	627
2.50	601
2.56	578
2.60	555
2.65	534
2.70	514
2.75	495
2.80	477

• **Rockwell Method.** While the Brinell system measures the *diameter* of the hole, the Rockwell method measures the *depth* of the hole.

The Rockwell unit of measure is divided into the superficial and standard scales. See Table

IV. The superficial scale employs very light loads and is used on material that has a light case depth. The standard scale is used on the majority of work. The most common and universal measurement is the Rockwell C scale.

Table IV. Rockwell Hardness

Scale Designation	Penetrator	Load
	Standard Scales	
A	Diamond	60 kg
C	Diamond	150 kg
B	1/16" ball	100 kg
	Superficial Scales	
15N	Diamond	15 kg
45N	Diamond	30 kg
15T	1/16" ball	15 kg

• **Vickers Method.** The same globalization of manufacturing that has promoted the increased use of metric dimensioning favors the Vickers hardness testing method. This method uses a diamond as the penetrator similar to the Rockwell method but requires measurement of the impression area rather than the impression depth. An advantage of the Vickers method is that one continuous hardness scale can be used to describe all classifications of metals. The Vickers hardness numbers are denoted a DPH (Diamond Pyramid Hardness).

Hardness Conversion—There may be times when it isn't possible to measure the part by the method specified. It is often acceptable to convert to the desired reading by using Table V.

Table V. Hardness Conversion Table

C	A	D	15N	30N	45N	DPH	Brinell
150 kg Brale®	60 kg Brale	100 kg Brale	15 kg N Brale	30 kg N Brale	45 kg N Brale	10 kg 136° Dia.	3000 kg 10mm Ball
Rockwell	Rockwell	Rockwell	Rockwell Superficial	Rockwell Superficial	Rockwell Superficial	136° Diamond Pyramid	Brinell (Hultgren Ball)
70	86.5	78.5	94.0	86.0	77.5	1076	—
69	86.0	78.0	93.5	85.0	76.5	1004	—
68	85.5	77.0	—	84.5	75.5	942	—
67	85.0	76.0	93.0	83.5	74.5	894	—
66	84.5	75.5	92.5	83.0	73.0	854	—
65	84.0	74.5	92.0	82.0	72.0	820	—
64	83.5	74.0	—	81.0	71.0	789	—
63	83.0	73.0	91.5	80.0	70.0	763	—
62	82.5	72.5	91.0	79.0	69.0	739	—
61	81.5	71.5	90.5	78.5	67.5	716	—
60	81.0	71.0	90.0	77.5	66.5	695	614
59	80.5	70.0	89.5	76.5	65.5	675	600
58	80.0	69.0	—	75.5	64.0	655	587
57	79.5	68.5	89.0	75.0	63.0	636	573
56	79.0	67.5	88.5	74.0	62.0	617	560
55	78.5	67.0	88.0	73.0	61.0	598	547
54	78.0	66.0	87.5	72.0	59.5	580	534
53	77.5	65.5	87.0	71.0	58.5	562	522
52	77.0	64.5	86.5	70.5	57.5	545	509
51	76.5	64.0	86.0	69.5	56.0	528	496
50	76.0	63.0	85.5	68.5	55.0	513	484
49	75.5	62.0	85.0	67.5	54.0	498	472
48	74.5	61.5	84.5	66.5	52.5	485	460
47	74.0	60.5	84.0	86.0	51.5	471	448
46	73.5	60.0	83.5	65.0	50.0	458	437
45	73.0	59.0	83.0	64.0	49.0	446	426
44	72.5	58.5	82.5	63.0	48.0	435	415
42	71.5	57.0	81.5	61.5	45.5	413	393
40	70.5	55.5	80.5	59.5	43.0	393	372
38	69.5	54.0	79.5	57.5	41.0	373	352
36	68.5	52.5	78.5	56.0	38.5	353	332
34	67.5	50.5	77.0	54.0	36.0	334	313
32	66.5	49.0	76.0	52.0	33.5	317	297
30	65.5	47.5	75.0	50.5	31.5	301	283
28	64.5	46.0	74.0	48.5	29.0	285	270
26	63.5	44.5	72.5	47.0	26.5	271	260
24	62.5	43.0	71.5	45.0	24.0	257	250
22	61.5	41.5	70.5	43.0	22.0	246	240
20	60.5	40.0	69.5	41.5	19.5	236	230

Slow Cooling Processes

Treatments that require slow cooling include annealing, normalizing and stress relieving. These processes make the steel softer, more ductile and relieve stresses that can cause distortion or fracturing.

• **Normalizing** is a process in which the steel is heated above the critical temperature and cooled in still air. The term normalizing means to return the steel to its normal condition—as it was before cold working or other processing. Medium carbon steels are normalized to give them better machining qualities.

• **Stress Relieving.** Steels are subject to residual stresses caused by machining, cold drawing and rolling. Stresses are internal forces that can cause extensive distortion or even fracturing if they are not released. The normal temperature range for stress relief is 1000 to 1200°F. In addition, welding assemblies are stress relieved before heat treating to prevent cracking. Stress relieving, unlike normalizing or annealing, does not affect hardness if the temperature is 50°F or more below the final tempering temperature.

Annealing

The process for annealing includes: full anneal; spheroidize anneal; and process anneal. In annealing the cooling rate is slower than normalizing, which results in a softer more ductile part.

• **Full Anneal.** In full annealing, the steel is heated to a temperature that is normally 50°F above the upper transformation temperature. The steel is than held (soaked) at one hour and then slow cooled, usually at 100°F per hour.

• **Spheroidizing.** The term spheroidizing comes from the tiny spherical or global shaped carbide grain structure produced in the material. This provides for improved machinability and formability in high carbon (0.7 to 1.9 percent carbon) steels. Maximum ductility is obtained by this method, which is beneficial in some forming operations.

• **Process Annealing.** This annealing cycle is performed between a series of cold working operations—usually in cold rolling, wire-forming or drawing operations. Process annealing is sometimes called bright annealing and is carried out in atmosphere or vacuum furnaces.

17
PLATING

Plating is a process that extends the versatility of stampings and sheet metal fabrications by adding a decorative and/or protective layer of another metal to the base metal or substrate. On steel, electroplating is a process commonly used to deposit another metal. On aluminum, anodizing is routinely used to create a stable oxide layer which is insulating in nature. To enhance the electrical conductivity of aluminum, a chromate conversion coating may be applied to prevent surface corrosion. Copper and its alloys are often coated with tin for solderability, and with nickel for wear properties.

Whenever plating is being considered, alternative processes that can produce similar results should be evaluated. Among these are painting and use of prefinished material.

Electroplating on Steel

Electroplating deposits a protective metal (anode) from solution onto a steel substrate (cathode) via an electrochemical reaction driven by DC current. Zinc, cadmium, tin, nickel, and chrome, as well as copper, brass, silver and gold are suitable for plating steel.

The two main reasons for electroplating steel alloys are corrosion protection and enhanced appearance. Other benefits include improved wear or abrasion resistance, better paint adhesion, and electrical conductivity.

Zinc plating is routinely used to prevent steel substrates from rusting. Cadmium plating provides protection equivalent to that of zinc. Today the number of cad-plating facilities is limited due to environmental concerns.

In practice, adding a chromate conversion coating to zinc plate boosts corrosion resistance significantly. However, a thin coating of zinc is adequate for many sheet metal parts. Chrome plating is usually reserved for wear-resistant and cosmetic applications. See Table I for a comparison of metal-coating properties.

• **Plating Thickness.** Depending on the application, thickness of the electroplate varies. Typically, a light coating (approx. 0.2 mils or

Table I. Properties of Metal Coatings

Coating Type	Normal Thickness Range, Mils	Approximate Hardness, kg/mm^2	Characteristics
Electrodeposits			
brass	0.1–0.3	200	used for thin decorative deposits
cadmium	0.1–0.5 flash 0.6–1.0 avg 1.5–5.0 heavy	100	will prevent rusting in humidities to 80% covers well has lubricating properties
chromium	0.05–0.1 flash 0.1–0.1 avg 0.5-2.5 heavy	900	excellent wear resistance resistance to most chemicals difficult to grind poor throwing power
copper	0.1–0.3 flash 0.5–1.0 avg 2–50 heavy	150	good conductivity plates over most metal surfaces
gold	0.02–0.1 flash	80	expensive does not oxidize
decorative nickel (soft)	0.1–0.5	250	good throwing power good underdeposit for other platings
hard nickel	0.1–0.5 flash 0.7–1.5 avg 2–50 heavy	500	good corrosion resistance satisfactory wear properties can be plated with low stress
silver	0.1–0.3 avg 1–30 heavy	100	exceptional lubricative properties expensive
tin	0.3–1 avg	50	corrosion resistant
zinc	0.2–0.5 avg	100	excellent for rust protection
Immersion platings			
electroless nickel	0.1–0.3 flash 0.5–0.75 avg 2 heavy	450 as plated 650 heat treated	will plate in holes and recesses fair wear resistance cannot use for heavy deposits (>0.002 in.)
Chemical conversion coatings			
anodizing of aluminum (clear and dyed)	0.1–0.3 decorative 0.4–0.6 light industrial 0.7–1 industrial	1100	excellent corrosion protection when sealed covers well can be permanently colored
hard anodizing of aluminum	1–3	1100	good wear resistance good resistance to atmospheric corrosion
black oxide	0.01–0.1	150	atmospheric corrosion protection (should be oiled)
chromating	~0.001	not measurable	improves corrosion resistance of some metals
phosphating	0.02–0.4	not measurable	porous, can be impregnated with oil for lubrication and rust protection improves paint adhesion zinc phosphates protect from rusting

0.005 mm) is used for decorative purposes, providing adequate corrosion resistance for many stampings and sheet metal fabrications. Heavier coatings can be selected for increased corrosion protection in more aggressive environments.

• **Surface Finish.** Plating accurately replicates the existing surface finish, including scratches and other defects. For cold-rolled steel, No. 3 Bright finish is best.

Anodizing of Aluminum

Most commonly used to protect or decorate aluminum, the anodizing process is different but comparable to electroplating of steel. The aluminum substrate (the anode) is immersed in an anodizing (acid) solution with a cathode; with a current driving the reaction. But rather than depositing a layer of metal, anodizing chemically converts the surface of the base metal into an integral, hard, oxide coating. Unlike plating, the thickness of the specified anodized layer grows 50% above the surface of the substrate and 50% penetrates into the substrate surface.

The resultant coating is slightly rougher than the substrate, and more porous, possibly indicating the need for a special sealing process when optimum corrosion resistance is required. Also, some aluminum alloys anodize better than others. See Table II.

Table II. Alloy Suitability for Anodizing.

5052
5086*
6061
1100
3003
7075

*specifically suited for anodizing critical cosmetic parts (available in heavier thicknesses only)

While most aluminums accept a thin anodized coating—0.0001 to 0.00l in. (0.002 to 0.025 mm)—not all are suitable for thick coatings. Thicker coatings—from about 0.001 to 0.003 in. (0.025 to 0.076 mm)—are normally referred to as "hard" or "hard coat" anodizing, which is actually a different process than conventional anodizing. Typically, these thicker coatings are more wear- and abrasion-resistant.

Decorative (thin) anodizing is routinely used by itself to provide adequate corrosion and wear-resistant surfaces on aluminum.

Anodizing is ordinarily selected to increase corrosion resistance, change or enhance appearance, improve wear resistance, improve paint adhesion, or even impart a color change to aluminum substrates. While clear and black are readily available, a limited number of other colors are available from suppliers who specialize in color anodizing for decorative hardware.

• **Conversion Coating.** Aluminum chromate is probably the most commonly used single-coat protection for aluminum parts when no hard surface is required. It is known by trade names Alodine and Irridite. It is the specified coating used to provide adhesion for organic topcoats and for good electrical conductivity.

Design Considerations for Plating

Electroplating thickness varies according to the part configuration. During design, special attention must be given to corners, enclosed features, recesses, holes and threaded parts.

• **Outside sharp corners** typically receive about twice as much plating as flat surfaces. This factor may need to be taken into account for critical dimensions.

• **Hole and slot dimensions** of a critical nature should be sized to compensate for the amount of plating called out, to avoid difficult and costly masking.

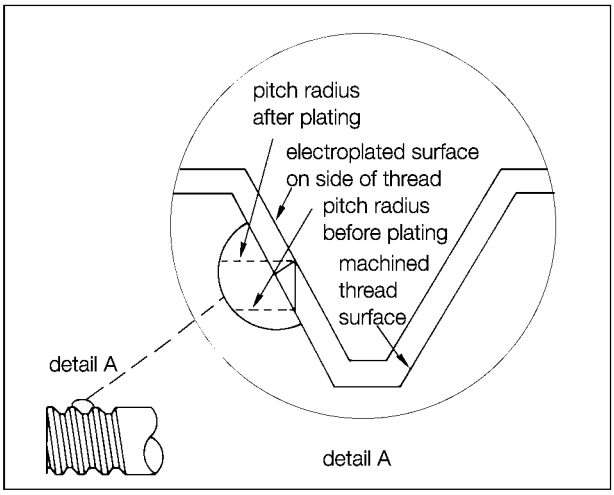


Figure 1. Pitch diameter for an American Standard thread increases by 4 times the electroplate thickness. (Increase in pitch diameter is measured at 30° to the surface.)

• **Threaded features** can also be troublesome if not planned for in the design stage. Allowance should be made for pitch diameters of screw threads, which can increase by a factor of four times the plating thickness (see Figure 1).

• **Tapped holes** may require re-tapping after plating to ensure dimensional accuracy. Specifying "check with standard hardware" or the use of thread forming screws are probably the most economical options. Most metalforming suppliers are able to control thread tolerances by using specific oversized taps.

• **Threaded studs** (and other projections like pins) accumulate more plating than other areas. Specifying "must accept standard hardware" instead of inspection with go/no-go gauges often eliminates masking.

• **Recessed areas,** such as internal isolated corners, channels, etc., may be very difficult to plate, resulting in little to no coverage inside of parts. Although special electrodes help, they don't entirely correct the problem and always create additional expense. In some cases, this can be avoided by plating individual parts before assembly; in others, a redesign or different coating method may be warranted. A good rule of thumb is to avoid plating of overly complex assemblies.

• **Lap-Welded joints** will trap plating solutions through capillary action between the two surfaces. The resulting salt bleed-out is not only a cosmetic defect, but leads to severe corrosion problems.

A compromise solution is to place the welds on embossed areas raised a minimum of 0.015 (0.3 mm) height to allow for flushing and blow drying between the surfaces. Other alternatives are riveting or the use of threaded fasteners for post-plating assembly. Fabrication from preplated material is another compromise approach, resulting in the plating being discolored and damaged in the electrode contact area during spot welding. (See Spot Welding, Chapter 13)

• **Masking** of stampings and fabrications to selectively anodize only certain areas is usually not recommended because of occasional processing problems and associated costs. Although the process is technically feasible, anodizing solutions sometimes penetrate the masking, producing a part that must be reworked. (The part has to be unmasked, stripped, cleaned, remasked and then reanodized.) In addition to being less than completely reliable, masking is time-consuming and costly.

Easing Processing

For most types of plating, designs should incorporate two practical features to facilitate processing: (1) drain holes and vent holes for plating solutions and rinsing, and (2) a tab or hole to allow easy attachment of parts to racks.

Painting over Plating

Coatings—both organic paints and chemical conversion types—can be applied over plating to increase corrosion protection, or to obtain a desired texture or color. With steel, for example, a chromate or phosphate conversion coating may

be applied after zinc plating primarily to increase adhesion for an organic topcoat. Lacquer can also be used over conversion coatings.

How to Specify

The type of plating, thickness range, hardness (if applicable), special treatments such as surface preparation, baking, etc., and any post-plating processes (including additional coatings) should be specified. Notations on critical dimensions should specify whether the dimensions apply *before or after* plating.

Plating thickness should be specified as a range, not a minimum, because thick deposits may result in poor adhesion, cracking or dimensional problems. Special requirements (for properties like conductivity, salt-spray resistance, etc.,) should, of course, be referenced, along with the appropriate test method.

If a standard plating spec (ASTM, Federal, Military, etc.,) is referenced, any deviations from it should be noted. To avoid the possibility of error—since specs are periodically changed and updated—submitting a copy of the pertinent specification to the supplier is generally helpful.

18
PAINTED PARTS

A variety of organic coating systems are available for use on metalformed parts. When a finish is selected which meets a customer's cost and cosmetic criteria it is essential that mutually accepted standards be negotiated with the supplier prior to actual production. These should define: color, gloss, texture, thickness, imperfections, inspection methods, target specification ranges, and any other unique requirements.

Types of Organic Coatings

Organic coatings for sheet metal parts cover the entire spectrum—from water-borne to solvent-based to powder coatings, with selection based on the service and application environments. See Table I for paint grades recommended for specific environments.

While environmental regulations limit use of solvent-based coatings in many areas, water-based systems are available in virtually all systems and provide substantially equivalent performance. This is possible through the use of water-soluble binders that rely on the same resins (acrylic, epoxy, alkyd, etc.) as their solvent-based counterparts.

Ultimate performance for a particular environment includes proper cleaning and pretreatment prior to topcoating with an organic system. More demanding service conditions typically make use of a basecoat or primer to further enhance corrosion resistance and adhesion.

In severe environments such as exposure to elevated temperatures, abrasion, chemicals and high intensity UV radiation, organic systems are often not the best choice since they eventually degrade. In these circumstances, the designer must select another material or finish such as hard chrome, electroless nickel, porcelain enamel or stainless steel.

Coverage

As with plating, paint coverage behind stiffeners, under deep return flanges, in hidden corners and deep pockets is often limited. Although conversion coatings such as phos-

Table I. Properties of Selected Organic Coating System

Resin	Forms available	Drying method	Favorable characteristics	Unfavorable characteristics	Cost	Uses
Acrylic	Solvent, water-borne, powder	Air dry, bake	Outdoor durability, chemical, heat resistance	Poor-fair adhesion, tendency to be brittle	Moderate high	Automotive topcoats, appliances, coil coatings, aluminum siding, general industrial use
Alkyd	Solvent, water-borne	Air dry, bake	High gloss, flexibility, good durability, versatility	Poor alkali resistance, generally not hard, tendency to yellow, depending on resin	Low, moderate	Trade sales enamels, trim paints, exterior enamel, general metal finishing
Chlorinated rubber	Solvent	Air dry	Water, alkali, acid resistance	Abrasion resistance, hardness, gloss sensitivity to solvents	Moderate	Maintenance coatings, ship bottom paints, swimming pool paints, chemical process equipment
Epoxy	Solvent, water-borne, powder	Air dry, bake	Excellent adhesion, chemical resistance, flexibility, abrasion resistance, hardness	Rapid chalking on exterior exposure, poor resistance to oxidizing acids, yellows in clears	Moderate, high	Maintenance paints, automotive primers, appliances, metal products
Fluorocarbon	Solvent, powder	Bake	Highest exterior durability, chemical resistance	Adhesion, recoatability, high baking temperatures	High	Coil coatings, siding
Nitrocellulose (a)	Solvent	Air dry, bake	Extremely fast drying, good hardness, abrasion resistance	Low solids content, fair to good exterior durability, low flash point solvents	Low moderate	Furniture finishes, touch-up lacquers, general-purpose product finishes, aerosol lacquers
Phenolic	Solvent, water-borne	Air dry, bake	Hardness, adhesion, resistance to chemicals, corrosion	Darkens, can only be used in dark-colored coatings	High	Can linings, tank linings, maintenance paint on metals
Polyester	Solvent, water-borne, powder	Air dry, bake	High gloss, hardness, chemical resistance, high film build	Fair adhesion, may hydrolize under certain conditions	High	Wood finishes, coil coatings, specialty bake coats
Polyurethane	Solvent, water-borne, powder	Air dry, bake	Chemical resistance, abrasion resistance, hardness, exterior durability	Some types yellow and chalk readily on exterior exposure	Moderate, high	Aircraft finishes, metal and plastic coatings
Silicone	Solvent, water-borne	Air dry, bake	High heat resistance, exterior durability, gloss and color retention	Tendency toward brittleness, unmodified types require high baking temperatures	High	Any finish for high heat resistance, exterior metal coatings
Vinyl	Solvent, powder	Air dry, bake	Chemical resistance, flexibility, fast air dry, formability, resistance to acid, alkali, abrasion	Generally low solids, low flash points	Moderate	Can, tank linings, maintenance paints, metal decorating paints

(a) Must be modified with other resins

phates and chromates give limited short term protection against rust and corrosion, rust prevention in these areas cannot be guaranteed. Designers must consider metal protection in their basic design and, where necessary, specify pre-plated materials or finishing with immersion techniques which include fluidized bed powder applications, electro-deposition and electroless nickel.

Surface Preparation

Surface preparation is critical for adequate adhesion. Without proper cleaning for removal of oil, grease, dirt, lubricants, scale and oxides, paints will not adhere properly to the substrate.

With sheet metal parts, the proper surface condition is often obtained by using a conversion coating prior to applying an organic topcoat, providing cleaning as part of the process sequence. These so-called "conversion" coatings react with the metal substrate to form a corrosion-resistant layer. Typically, iron phosphate is used for steel parts, and a special chrome-phosphate or aluminum-chromate treatment (irridite and alodine) for aluminum.

In general, water- and solvent-borne organic finishes are not recommended over zinc and chromate conversion coatings. Clear and yellow chromates, as well as aluminum chromates, may degrade at temperatures above 150°F, which is well below the 250° to 350°F bake-temperature range of most paints. While these systems are routinely specified, bond and abrasion resistance may be questionable.

Class Designations

Coatings are categorized according to requirements for cosmetic or appearance criteria. Non-appearance parts like internal components usually need painting only for basic protection, electrical shielding or nonreflectivity. As a result, requirements in these areas may be less stringent.

Classes basically reflect appearance requirements. While this is a good way to differentiate between degrees of cosmetic characteristics, no universal standard has been adopted. A useful general guideline is to break down appearance parts into three categories: Classes A, B and C.

- **Class A** surfaces, are most critical in terms of appearance including number and size of allowable defects. Parts in this class may have a smooth or textured surface and are the primary cosmetic surfaces in direct view. Front panels on business-machine housings, instrument cabinets or other enclosures are examples.

- **Class B** refers to parts that are not in direct view, such as the back panel of an enclosure. Here, appearance is not as critical, and the number and size of allowable defects is greater than in Class A.

- **Class C** ordinarily applies to internal or hidden parts, whose surfaces need only coating. These parts are likely to be viewed only by service personnel. More and larger imperfections are allowed. Scratches and other surface flaws like weld marks may be painted, without need for grinding or other finishing to enhance the surface quality prior to painting.

Other systems for classifying surfaces may differ in the type of coating (smooth, textured, etc.) and may provide additional details. Even if no surface-quality classification is used, expectations regarding texture and number and size of defects should be clearly detailed for the metalforming supplier.

Key Coating Characteristics

To ensure that a coating performs its intended function (e.g., matching the color of mating components and protecting the metal component in its end-use environment), certain basic requirements should be met. Beyond selection of the correct coating system, the most important film characteristics include hue, gloss, texture and thickness.

- **Hue** denotes the color to be matched.

Many factors influence this characteristic, among them: the substrate and surface finish, primer coat, if any, thickness of the coating, and how it is applied. In addition, critical color matching may require specifying the pigments used to achieve a particular hue.

Otherwise, a conditional match may result. This can occur because various combinations of pigments may produce essentially the same color. If exactly the same pigments are not used, the color appears different under various light sources.

Inspecting for color match can be done by a "trained eye" or more accurately via a spectrophotometer or other instrument. The latter method, which yields a spectral curve (Figure 1), is often preferred because it is less subjective.

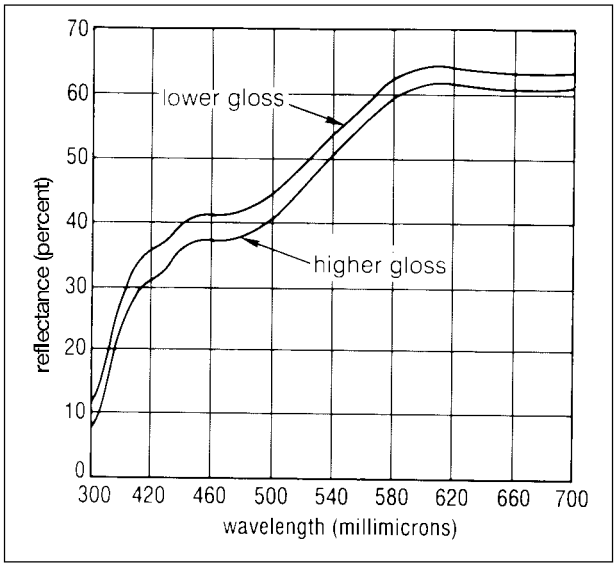


Figure 1. Spectral curves show how light reflectance of a paint varies throughout the visible spectrum and the effect of gloss on the same color.

How close a color match is required should be discussed between customer and supplier, and both should use the same method of inspection. To that end, color samples or "chips" provide a standard for comparison. Sets of identical chips should be made available to both the customer for inspection and the metal-forming supplier for production. The chips should be at least 4 in. x 6 in. (l00 mm x l50 mm) or larger. As a rule, the color sample should define the permissible range of gloss, texture and depth of color. If a painting subcontractor does the actual painting, a third set of chips should be provided.

• **Gloss** is the sheen or luster of a coating and is typically specified by a gloss range. In general, a higher gloss makes a particular color look deeper or more saturated. Because gloss can affect the apparent color and vice versa, the same paint chip or standard should be used to check both gloss and hue.

Although visual comparisons are possible, a more accurate and less subjective method is the gloss meter. Commonly used to check specular gloss (ratio of incident to reflected light), gloss meters measure gloss within a 100-point scale at typical angles of 45°, 60° or 85°. Here, both supplier and customer should utilize the same angle of incidence and, if possible, the same instrument.

Flat or matte paints typically exhibit a gloss reading of less than 15 on an 85° gloss meter. Semi-gloss is normally in the range of 15 up to about 80; full or high gloss, 80 and above (both measured on a 60° gloss meter). Even though instrumental gloss readings can be very accurate, spec ranges should not exceed that achievable in production painting. For the most critical applications, a range of ±5 is typically acceptable.

• **Texture** indicates the relative roughness of a coating and is normally classified as heavy, moderate (or medium) and light. Unfortunately, there is no absolute standard for texture, which can differ widely between various manufacturers. In fact, one company's medium texture may approach another company's heavy texture and, at the same time, be close to a third company's light designation.

Texture can drastically affect the perceived color of a painted part, especially when heavy. To avoid potential conflicts, two sets of stan-

dards or paint chips should be utilized. The first set, without texture, should be used for color and gloss only. The second set—to be used solely for comparisons of texture—should contain two differently textured chips, representing minimum and maximum limits.

Pre-approved standards prior to production painting of sheet metal parts offer a workable method for agreeing on finish requirements. Since paint chips tend to change with time from oxidation and wear, some metalforming suppliers prepare paint chips just before components are painted. Upon submission to the customer, one set is approved and signed, then returned to the supplier for use in painting production. This approach helps to reduce defective parts, avoids misinterpretation of standards and accommodates any recent changes the customer may have made in terms of texture, color or gloss.

• **Thickness** is critical in achieving the required properties of a coating. Too thin a coating can decrease corrosion protection gloss and hiding power, as well as affect color. Too thick a coating may lead to insufficient adhesion, orange peel, runs, wrinkling and other problems.

Many organic coatings are applied at thicknesses ranging from just less than 1 mil (0.25 mm) up to about 3.5 mils (0.09 mm). Primers for metals are applied from about 0.3 to 0.7 mils (0.007 to 0.02 mm). This dry film thickness is adequate for covering the substrate, but it does not hide all defects in the base metal. While a textured paint does cover more imperfections, it is not a universal remedy for improperly designed parts and poorly specified base metal, nor a substitute for required mechanical finishing operations like grinding.

To keep costs down, dry-film thickness should be specified by a range, whose lower value provides the minimum performance desired. In practice, the spec range should not be so restrictive that it cannot be achieved by the application method to be employed. Spray techniques, for instance, usually involve a 50% overlap on successive passes, which in itself may introduce some variation in the dry-film thickness.

In production, the thickness of sprayed coatings is checked "wet" with a wet-film thickness gauge. The desired dry-film thickness is then estimated from the percentage of solids in the paint. Although fairly accurate, this method cannot absolutely control thickness.

If coating thickness is deemed a critical issue, the same method should be used for measurement by both supplier and customer. Short of microscopic and destructive methods, thickness can easily be checked on steel substrates with a magnetic thickness gauge or by very accurate electronic instruments, which can be used on practically all substrate materials. Inductance instruments deliver accuracy of 10% for thicknesses up to 1.5 mils (0.04 mm) and higher accuracy for thicker films.

Overly restrictive thickness ranges are costly and wasteful, particularly for a non-critical, non-appearance part which requires only minimal protection. Minimum dry-film thickness of an organic coating can be held to approximately ½ mil (0.01 mm), when required.

• **Good adhesion** is the basis for coating performance. Proper cleaning and surface preparation, selection of a suitable primer or basecoat for the substrate in question, and application as recommended by the paint manufacturer are all necessary for optimum adhesion.

If special primers, cleaning procedures, or chemical conversion treatments are required to maximize adhesion and overall performance, they should be indicated on the engineering drawing. Reference to a particular standard, such as ASTM, may be helpful when no internal specifications exist.

If required, testing for adhesion is usually performed by a cross-cut/tape test (e.g., ASTM D3359), where vertical and horizontal cuts are made through the coating. Tape is applied, then stripped off. Adhesion is evaluated by the paint remaining (Figure 2). Sometimes, special

scrape-adhesion or parallel-groove adhesion test instruments are used.

• **Special requirements** for painted parts can include abrasion resistance, pencil hardness, impact resistance, environmental testing, and a host of others. If such special requirements are necessary, they and the appropriate test methods should be discussed with the metalforming supplier. As with adhesion, gloss and other key characteristics, many standard test procedures are detailed in the appropriate ASTM specifications (Table II).

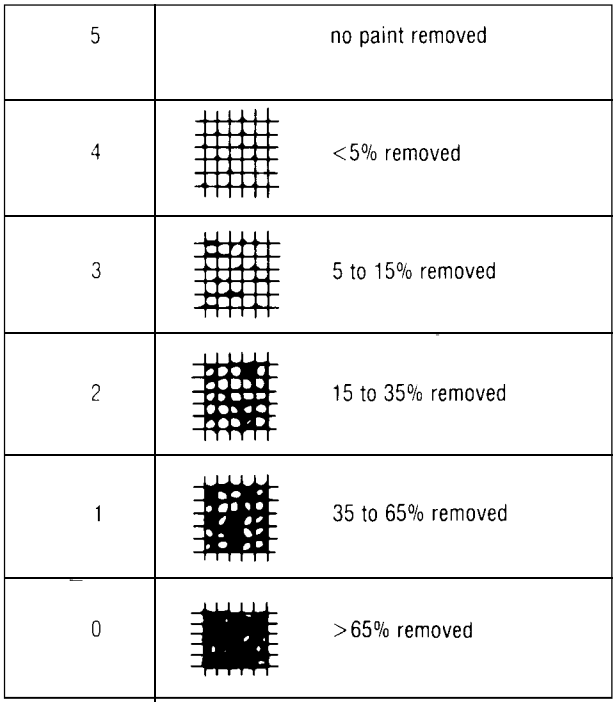


Figure 2. Relative adhesion of paint to metal as determined by the cross-cut tape test. Higher numbers indicate better adhesion. As shown, coating is white; substrate black.

Practical Considerations

Numerous practical aspects of painting—masking overspray, silkscreening, etc. should be closely scrutinized to minimize finishing cost and avoid costly rework or preparation prior to painting. When properly designed and specified, painted parts can be surprisingly cost-effective.

Table II. ASTM Test Methods for Organic Coatings

Property		ASTM Method
abrasion resistance:	air blast abrasion tester falling sand method	D658 D968
adhesion:	scrape adhesion parallel-groove adhesion tape adhesion	D2197 D2197 D3359
chemical resistance:	household chemical resistance detergent resistance hydrocarbon resistance	D1308 D2248 —
chip resistance		D3170
color difference:	visual evaluation instrument evaluation	D1729 D2244
cracking resistance		D2246
elongation:	conical mandrel cylindrical mandrel	D522 D1737
filiform corrosion		D2803
gloss		D523
hardness		D1474
holdout		C540
mildew resistance		—
outdoor exposure:	blistering cracking rusting checking	D714 D661 D610 D660
print resistance		D2091
salt spray resistance		B117
sanding properties		—
water resistance:	high humidity water immersion	D1735 D870
weldability		—

• **Masking** to keep an area or part feature paint-free introduces significant costs because it is a time-consuming hand operation. Tape or other masking material (rubber stoppers, plastic tubes, etc.) must not only be applied before painting, but also must be removed afterward. Masking is sometimes difficult to remove, particularly after baking, and may require rework,

which involves further expense for sanding and repainting. On difficult jobs, it is not uncommon for masking/unmasking to comprise 50% of the painting cost.

When paint-free features are required for a design, the best option may be to redesign the part to avoid masking. Painting a sheet metal component with two different colors and textures is an example. If two colors are required the more economical solution may be a two-piece design which is then mechanically assembled after painting.

Since steel rusts, aluminum or other non-ferrous materials should be considered for parts that absolutely require paint-free features (such as holes). In applications where conductivity is the main concern, paint that incorporates nickel, aluminum, carbon or other conductive fillers is another alternative to paint-free features. However, these coatings are usually reserved for internal, non-cosmetic, parts.

There are also alternatives to designating "paint-free threaded hardware" that requires expensive masking: (1) specifying "threads to be checked with standard hardware;" (2) specifying "threads to be checked prior to the application of finish," which is adequate for 6-32 thread diameters or larger with air-operated assembly equipment; and (3) evaluating pop rivets, thread-cutting or thread-rolling fasteners as alternatives, to reduce hardware, painting and installation costs.

When masking cannot be avoided, masked areas should be toleranced generously. Masking tolerances are generally no tighter than ±0.1 in. (2.5 mm).

• **Overspray** is a consideration that should not be ignored. Total elimination of overspray can be expensive, requiring masking or special application techniques. In fact, if masking is required to avoid overspray, it is usually less expensive to paint the entire part, if acceptable.

Except when it may affect other cosmetic surfaces or when overspray may interfere with the function of a part (e.g., a grounding connection), knowledgeable designers specify "overspray permissible," then designate areas that must be paint-free on the drawing. For most internal parts, overspray presents little problem.

• **Silk-screening** is routinely used for labeling, logos and decorative painted surfaces. As with cosmetic parts, silkscreening can also be classified. For example, Class A silkscreening may include very fine details. Silkscreening should be applied to smooth, painted surfaces.

Although application over lightly textured surfaces is possible, this should be reserved for such applications as bold graphics or part identification on non-cosmetic components. Detailed screen printing develops irregular edges when applied over medium or heavy textured surfaces.

Silk-screening of internal-part surfaces like the inside of a cover panel may drive up cost, since fixturing is so difficult that manual operations (dropping the screen into place, then removing it) may be the only option.

For decorative silk-screening, all requirements should be specified: for example, no interrupted lines, broken letters, etc., with locations indicated on the part drawing. To avoid additional cost and reduce uncertainties, customer-supplied artwork is best.

Potential Defects

Perfection is often approached but never achieved in a painted part. For cosmetic surfaces, allowable flaws or defects are often related to the class of a part, as previously discussed. Typical of such cosmetic standards are limitations on the size and the number of flaws allowed per surface. (Table III.)

• **Inspection criteria** should be carefully detailed so that both the customer and the metalforming supplier use the same inspection process. The product should be viewed under 100 footcandles of uniform, non-directional light.

Viewing should occur without a direct reflection of the light source with the product

Table III. Chart of Allowable Defects Per Class of Coated Parts.

	# of flaws allowable per surface		
Types of flaws	**class A**	**B**	**C**
discoloration glossiness specks	two max. dimension: 0.5 mm (.02 in)	four max. dimension: 1.5 mm (.06 in)	six max. dimension: 3.2 mm (.13 in.)
lint and scratches	two max. dimension: 0.3 mm x 0.8 mm (.01 in. x .03 in.)	four max. dimension: 0.5 mm x 2.3 mm (.02 in. x .09 in.)	four max. dimension: 0.5 mm x 6.4 mm (.02 in. x .25 in.)
marks and runs	none	two max. dimension: 1.5 mm (.06 in)	four max. dimension: 3.2 mm (.13 in.)
nonadhesion and nonuniform coverage	none	two max. dimension: 2.3 mm (.09 in.)	four max. dimension: 3.2 mm (.13 in.)

Table IV. Viewing Time and Distance for Cosmetic Parts.

surface viewing type, as defined*	class A prime view external parts	class B secondary external or internal parts	class C coverage only internal parts
	viewing time		
	7 sec.	5 sec.	3 sec.
	viewing distance		
I	12 in. (300 mm)	24 in. (600 mm)	36 in. (900 mm)
II	18 in. (450 mm)	30 in. (750 mm)	48 in. (1200 mm)
III	24 in. (600 mm)	48 in. (1200 mm)	60 in. (1500 mm)

** "surface" definitions*

I — all surfaces of a small object, combined not exceeding 24 in. sq., (600 mm2) or a single surface 12 in. sq. (300 mm2)

II — a surface larger than 12 in. sq. (300 mm2) but smaller than 30 in. sq. (750 mm2)

III — a surface exceeding 30 in. sq. (750 mm2)

note: several adjacent surfaces of >90° to each other may be viewed as one surface from one view point, using the size and viewing time limitations for the combined areas.

oriented as nearly as possible to the position in which it is to be used in service. Magnification should not be used.

The product should be scanned for the time period shown in Table IV. In the absence of specific product orientation and viewing specification information, the product should be scanned at the indicated distances for the part sizes given in Table IV.

Basic Design Tips for Painted Parts

Obtaining an acceptable cost/performance balance for painted sheet metal components can often be a design challenge. Here is a summary of practical tips for optimum performance and minimum cost.

• Design built-in drain holes into parts like covers with return flanges, so that phosphating solution and paint do not get trapped.

• Design for open hems rather than closed hems so that the surface is better protected.

• Evaluate accessibility to the inside of parts. If deep recesses and internal corners are inaccessible, consider a redesign or select another alternative to organic paints.

• Avoid masking whenever possible; consider design alternatives.

• Design a hole or other alternative for hanging the part during painting, if an existing feature cannot be used for the purpose.

• Allow for nominal paint thickness on critical dimensions.

• Avoid paint-free areas on steel parts because of rust.

• Consider alternatives for threaded features, since threads may require extensive masking.

• If using multiple suppliers for the same color-matched part, supply paint from the same manufacturer and batch, and provide for approval, if possible.

19
PACKAGING

Packaging can become a major part of a successful manufacturing plan. Cost considerations are another reason to give packaging the close scrutiny it deserves. Packaging requirements should be discussed with your supplier. Many issues may need to be addressed such as part configuration, fragility, shipping, intended future storage and processing.

To avoid misunderstanding, it is recommended that packaging type and related specs appear on the purchase order, request for quotation, and engineering drawing.

'Delicate' Parts and Features

Certain part features require more protective packaging to ensure that components are received in usable condition. These include:

- **Aesthetic surfaces** of external appearance parts that have been painted, plated, etc., as well as parts that will be finished or painted at the customer's facility.

- **Extended tabs** and other protruding design features like flanges, which may bend or scratch and gouge adjacent parts.

- **Thin-sheet components** that may distort, bend and otherwise become damaged in transit.

The net result is nonfunctional parts, which cannot meet dimensional requirements nor become part of a final assembly.

Common Packaging Types

Different types of packaging offer varying degrees of protection. Transit damage occurs most commonly when vibration causes parts to abrade each other or when parts are bent or crushed because of carton failure.

To protect individual parts, several different types of packaging are routinely used. These include:

- **Individual wrapping**, where each part is

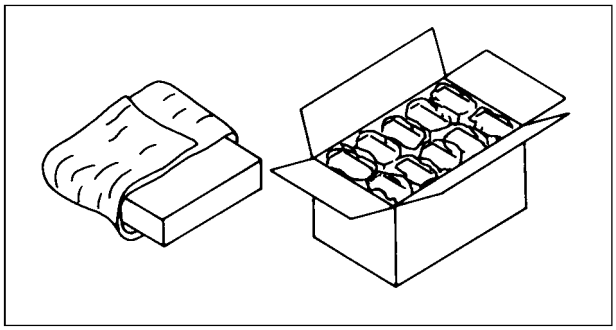


Figure 1. Individual wrapping for part protection.

wrapped in soft paper, cellulose-type or expanded (foamed-plastic) sheeting (Figure 1).

• **Cellular dividers**, where parts are separated using cardboard dividers (Figure 2). Depending on part size, multiple layers can be used within a carton; sometimes referred to as egg-crate type packaging or divider packs.

• **Skin packaging**, using skin or shrinkwrap to hold parts in place and separate them (Figure 3). Additional protection may be needed between multiple layers.

• **Die-cut inserts** or molded trays for damage-prone, delicate parts are custom tailored to fit individual shapes (Figure 4). A more expensive option than most packaging, it's usually reserved for high-cost components.

• **Nesting** involves inserting the protective material between stacked or closely packed components. This method minimizes bulk, allowing more pieces per carton.

Packaging selection often changes with part configuration, size, surface quality, etc., so optimum cost effectiveness dictates evaluating each factor for different components. "Blanket" packaging specifications for all parts are rarely cost effective.

Because availability and prices vary, alternate packaging that affords equivalent protection should be allowed, permitting the stamper or fabricator to choose the least costly and most effective option. Some packaging concepts are highly labor-intensive, and associated labor costs are passed on to the customer.

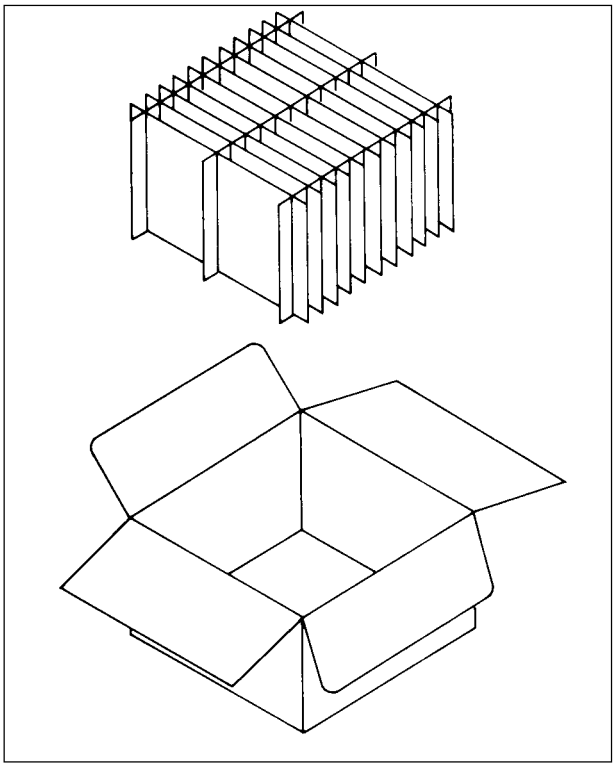


Figure 2. Cellular dividers for separating metal components.

Customer Receiving Requirements

To eliminate potential receiving problems at a customer's facility, suppliers need to know the weight and size of containers (both pallets and individual boxes) that can be handled effectively. Unnecessarily restrictive dimensional tolerances on length, width and height of packaging, drive up costs and should be avoided.

• **Individual Packages.** Typically, weight limitations apply to manual handling (e.g., a 35-50 lb. limit on what one person can carry) as well as to palletized loads. Shipments which exceed the manual handling limit must be palletized at additional cost.

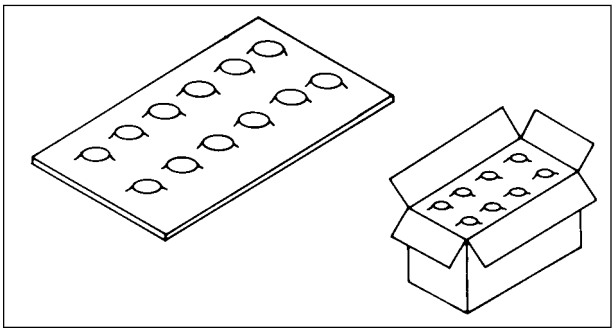


Figure 3. Skin packaging.

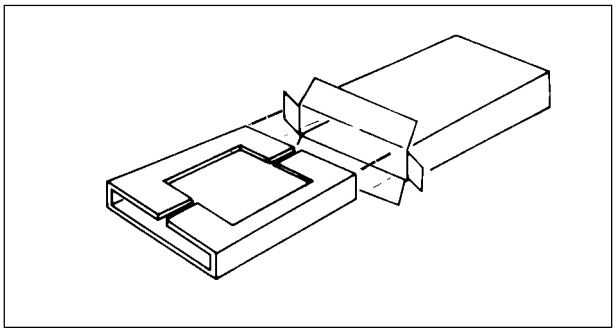


Figure 4. Die-cut inserts.

Shape and bulk of individual cartons must be sized for safe handling by one person. These should be adequately sealed with packaging tape, hot-melt adhesive, metal fasteners, staples, etc., as specified by the customer. When required, resealable carton closures should be specified.

Specialized and automated material handling systems sometimes dictate custom packaging and containers. If so, all details should be provided by the customer, including who is to provide special reusable containers for JIT deliveries.

• **Palletized Loads.** In general, palletized loads are required to resist normal hazards related to the shipping mode without exceeding the maximum specified weight. Typically, individual cartons that make up the pallet load are expendable corrugated boxes, unless reusable special containers are specified. Alternates—such as wooden crates, wooden boxes or wire-bound boxes—are commonly permitted when required to meet a particular carrier's requirements or shipping regulations.

Either metallic or nonmetallic banding or stretch wrap are standard methods for stabilizing pallet loads to avoid shifting or damage. Good shipping practice avoids positioning cartons and installing strapping, etc. beyond pallet dimensions.

Dimensions and configuration of the pallet should be detailed. A widely used standard pallet is 42 x 48 in. (1.1 x 1.2 m) with a minimum of three 48 in. (1.2 m) long runners per pallet and a minimum of three bottom slats (1 x 6 in. nominal size) (25.4 x 152.4 mm). Alternately, pallets can be specified to National Wood Pallet and Container specifications.

To match customer receiving capabilities, pallet load weights, 2000 lb. (4400 kg) max. and load heights, 44 in. (1.1 m) recommended 60 in. max. (1.5 m) should also be indicated. Restrictive tolerances, such as ±¼ in. (6 mm) on skid length and width, or ±2 in. (51 mm) on height, are inappropriate— except when necessary to accommodate specific uses such as automated handling equipment. Such tight tolerances are not common in the industry and, of course, increase unit cost.

Finally, consolidation of more than one part number on a pallet may reduce shipping cost and should receive consideration, where appropriate.

Labeling

Labeling preferences vary widely throughout industry; no universal standards exist. From an inventory viewpoint, labeling of all cartons is usually preferred. However, several available approaches to labeling dictate that customers contact suppliers to ensure that existing practice is compatible with their receiving departments.

Bar coding for computerized inventory shipping, receiving, etc. is increasingly common. If bar coding is required, customer specifications must be timely, complete and exact.

Reusable Packaging and Special Handling Containers

On large fabricated parts and assemblies—and on fragile components—packaging costs are often greater than 10% of the product value. Knowledgeable designers consider packaging during the design phase of a project to limit this cost and the associated customer expenses of unpackaging and detrashing (disposing of the used packaging materials).

Two methods are being widely adopted to accomplish these goals. The first, reusable packaging, requires design of boxes, cartons or foam protection which is collapsible or can be nested for return to the supplier. Properly designed reusable packaging can be used a minimum of eight times and is usually more sturdy and hence provides more protection because it is designed for multiple uses.

The second method—specially designed transport containers—is gaining acceptance with the movement to just-in-time product deliveries and the consequent limited process inventories. In this application, special containers are designed to match the customer's parts handling system and assembly line requirements.

The units are made from durable materials such as metal, hardwood or molded plastics. They are designed to provide complete transit protection, to go right to the assembly line and to be collapsed or nested for return and reuse. The initial investment is substantial but the containers are usually justified on the basis of reduced damage, easier handling, elimination of disposable packaging costs and reduced line labor in unwrapping and detrashing.

Fabricators and stampers can provide advice and design assistance when reusable or special packaging is under consideration.

GLOSSARY

2-D—Having two dimensions, possesses length and width, but no depth.
3-D—Having three dimensions, possesses length, width and depth.
ASCII—Acronym for "American Standard Code for Information Interchange."
Abrasion Resistance—Ability of a coating to withstand rubbing, scraping and eroding forces.
Abrasive—Sharp mineral particles, used for metal removal.
Abrasive Media—Matrix used to carry the mineral particles for the purpose of material removal.
Acidic Etching—Removal of surface contamination by acid treatment.
Adaptor—A block used to mount a form tool to a slide.
Air Bending—Forming operation in which a metal part is formed without the punch and die closing completely on the part. (See Press Brake Chapter.)
Air Hardening Steel—An alloy steel which will form martensite with high hardness when cooled in air from its proper hardening temperature.
Alloy—A substance that is a mixture of two or more metals, or of a metal with a non-metallic material.
Alodine–Commercial trade name for a chromate conversion coating over aluminum.
Aluminum Alloy—Pure aluminum which has been melted together with other constituents to achieve specific physical and mechanical properties.
Aluminum Oxide—Hard mineral of aluminum and oxygen ($Al0_3$) used as an abrasive.
Annealed—The softest possible state of any material.
Annealing—Full heat treating process whereby metal is heated to a temperature above its critical range, held at that temperature long enough to allow full recrystallization, then slowly cooled through the critical range. Annealing removes working strains, reduces hardness, and increases ductility.
Anode—The positive electrode in an electrolytic cell.
Anodizing—Process of applying a controlled oxide layer to the surface of aluminum.
Archive—The storage of files for long periods of time.
Arcs—Partial circles used to describe rounded corners of material and show bends in material.
Artificially Aged—Hardening process of material by temperature.

Austempering—A heat treating operation in which austenite is quenched to and held at a constant temperature (usually between 450°F and 800°F) until transformation to bainite is complete. In some steels at certain hardness levels, bainite is tougher than quenched and tempered structures.
Austenite—The solid solution in which gamma iron is the solvent. Austenite is a structure and does not refer to composition. Austenite is the structure from which all quenching heat treatments must start.
Austenitic Stainless Steel—Non-magnetic stainless steel. Not hardenable through heat treatment; good corrosion resistance.
Automatic Spinning—The process of forming metal over a mold using an automatic (Computer Controlled or Template) spinning lathe.
Auxiliary Slide—A bed mounted, cam operated slide typically used for forming on a slide forming machine.
bis — Acronym for "bits into sound."
bps—Acronym for "bits per second." Refers to the rate at which a data communications line can transfer information.
Back Gauge—A stop located in the rear of a metal forming or fabricating machine which is used to position the workpiece during an operation.
Banding, Metallic or Non-Metallic—Strong, lightweight ribbons, generally of steel or nylon, applied under tension to strap packages on a pallet.
Bar Coding—Machine readable alphabetic and/or numeric information used for identification.
Bark—An older term used to describe the decarburized skin that develops on steel bars heated in a non-protective atmosphere.
Barrel Tumbling—Process in which parts to be deburred are put together with abrasive material into a many-sided barrel and slowly rotated for prolonged periods for the purpose of burr removal.
Basecoat—See "Primer."
Bed—Bottom transverse structural member on a metalforming machine.
Belt Sanding—Metal removing process in which an abrasive impregnated continuous cloth belt does the cutting.
Bend Radius—Inside radius of a formed feature.
Bend Relief—A clearance notch at an end of a flange to allow bending without distorting or tearing adjacent material.
Bending—Generally applied to forming. Creation of a formed feature by angular displacement of a sheet metal workpiece. See also "Drawing" and "Forming."
Bi-Planar—Refers to surfaces which meet at an angle in different planes.
Blank—(1) Sheet metal stock from which a product is to be made. (2) Workpiece resulting from blanking operation.
Blanking—Die cutting of the outside shape of a part.
Bleed-Out—Leaching of entrapped plating solutions, causing surface discoloration and corrosion.
Blind End Fastener—Internally threaded fastener which is manufactured with one end closed such that, when installed, it forms a gas and moisture resistant seal.
Blind Fastener—Fastener which is capable of being permanently installed and used in a workpiece with access from only one side.
Blind Rivet—Rivet which is capable of being installed and used in a workpiece or assembly with access from only one side.
Bottoming—Forming operation in which the punch and the die is closed completely on the workpiece. See Press Brake Chapter.
Bow Distortion—See "Oil Canning."
Brass—Alloy of copper and zinc.
Break-Off—See "Breakout."
Breakout—Fractured portion of the cross section of a cut edge of stock. A condition naturally occurring during shearing, blanking, punching and other cutting operations.
Bridges—See "Micro Ties."
Bright Annealing—Annealing work in a protective atmosphere to prevent discoloration as the result of heating. In some atmospheres oxides may be reduced.

Brinnell Hardness Testing–A method of testing the hardness of material. This test is usually used on softer materials and castings in which a carbide ball is pressed into the material for a given period of time and then removed. The resulting impression is measured for the width along with a value determines hardness of the material.
Brushing—Mechanical or cleaning of parts before further processing.
Buffing—Polishing method employing soft cloth to carry very fine polishing compounds.
Burn Mark—Heat discoloration created in the contact area of a welding electrode.
Burnish—Smooth or shiny area above the breakout on a sheared edge. Also called shear or cut band.
Burr—Raised, sharp edge inherent in cutting operations such as shearing, blanking, punching and drilling.
Burr Direction—Side of the stock on which burrs appear.
Burr-Free—Edge without sharp protrusions.
Burr Height—Height to which burr is raised beyond the surface of the material.
Burr Rollover—Condition of burr displacement resulting from mechanical deburring operation.
Bus Bar Copper—Copper with minor alloying constituents with high conductivity used for electrical applications.
Butt—End to end.
CAD—Acronym for "Computer Aided Design." See CAD chapter.
CAM—Acronym for "Computer Aided Manufacturing."
CNC—Industry acronym for "Computer Numerical Control."
CNC Turret Press—Automatic punch press indexing the material and selecting the intended tool out of the rotary tool holding device (turret) totally by computer control for piercing, blanking and forming workpieces as programmed.
Cadmium Plating—Electrolytic process for metal coating in which commercially pure cadmium is the anode.
Cam—A machine component used to control the motion of slide forming slides and attach.
Camber—Gradual deviation from straightness of the edge of sheet or coil stock caused during the slitting operation.
Cam Chart—A chart created by the tool designer assuring that the sequence of operations of a complicated part fall within the 360 degree slide forming machine cycle.
Cam Trim—Removing excess material after the part has been drawn or formed. This is done with a cam activated operation, usually as a secondary operation.
Capillary Action—Liquid trapping action caused by the closeness of two surfaces and the surface tension of the liquid.
Carbon Steel—Steel which owes its properties chiefly to various percentages of carbon without substantial amounts of other alloying elements.
Carbonitriding—A heat treatment for steel which adds carbon and nitrogen from an atmosphere rich in such elements.
Carburizing–Adding carbon to the surface of steel by heating it in contact with carbon rich gases.
Case—The surface layer of a steel whose composition has been changed by the addition of carbon, nitrogen, or other material at high temperature.
Case Hardening—A heat treatment in which the surface layer of a steel is made substantially harder than the interior by altering its composition.
Cathode—A negatively charged electrode.
Cellular Dividers—Slotted cardboard sheets designed to be interleaved in a master carton producing individual pockets to separate parts.
Center—The point which lies midway between the extents of a feature in both the X and Y direction.
Center Tool—See mandrel.
Chain Dimensioning—Drafting practice which dimensions repetitive features from each other rather than a common datum.
Checks—Surface ripples and cracks induced by forming.
Chemical Etching—Removal of metal through

chemical erosion process.
Chromate—Post-treatment wash (non electrolytic) coating which is used over zinc, cadmium, treated aluminum and other plating operations to seal the surface of the coating, prevent oxidation and, in certain cases, improve the electrical characteristics of the coating. May be clear, yellow or blue to visually indicate that the product has been coated.
Chromate Conversion—Application of a salt or ester of chromic acid to a metal workpiece by dipping or spraying. The coating is generally used to seal the surface of the workpiece to enhance electrical properties or reduce corrosion.
Circles—A continuous arc starting and ending at the same point.
Clad Shape—A roll formed shape made up of two materials simultaneously fed into the roll forming mill to produce a composite section.
Clamp Marks—Slight indentations at the edge of one side of stock caused by pressure from turret press holding devices. See also "Workholder Mark."
Clinch Fastener—See "Inserted Fastener."
Clock Spring Material—Alloy steel available in a pre-hardened condition between Rockwell Hardness 45 and 52.
Co-Engineering—Process in which the customer and the supplier review and modify a design to simplify manufacturability of a part.
Co-Planar—Having all elements, features, dimensions or functions existing in one geometric plane.
Coating System—Consists of a number of coats separately applied in a predetermined order at suitable intervals to allow for drying or curing.
Coat—Paint, varnish or lacquer applied to a surface in a single application (one layer) to form a properly distributed film when dry.
Coil Breaks (Crossbreak)—Defective condition of ridges or marks across the width of sheet or coil caused by improper coiling or leveling.
Coining—Compressive metal flowing action. See also, "Bottoming."
Cold Rolled Steel—Steel which was reduced to final thickness in the cold state by a rolling mill. Creates a smooth surface with slight skin hardness.
Cold Weld—Defective weld due to improper contact or inadequate heat during welding.
Cold Worked—Material hardened naturally through forming at ambient temperatures.
Cold Working—Plastic deformation of a metal at a temperature low enough so that recrystallization does not occur during cooling.
Collapsible Tool (Segmented)—A "mold" having a removable center core which keeps the perimeter pieces in place during spinning.
Color—One aspect of appearance; a stimulus based on visual response to light, and consisting of the three dimensions of hue, saturation, and lightness.
Color Chips—Paint samples.
Color Match—Pair of colors exhibiting no perceptible difference when observed under specified conditions.
Commercial Grade—Standard materials commonly available through supply houses.
Communications Software—A computer program that enables one computer to connect with another computer.
Compound Die—Tool used to pierce, form and blank a part at the same time, with one stroke of the press.
Compress—To condense electronic files for ease of transfer and storage.
Concealed Head Fastener—Fastener installed in a blind hole.
Concentricity—Dimensional relationship of 2 or more items sharing a common center line.
Conditional Match—Perceived identity of color exhibited by a pair of colors, each with different spectral distribution curves.
Conductive Paint—Organic coating that conducts electrical current.
Conductivity—Ability of a material to conduct electricity or heat.
Connecting Lines—Two lines on a part drawing tangent.
Continuous Radius—A roll formed shape with a continuous curve or sweep in one or more planes.
Continuous Wave—Power output mode of

lasers using a constant discharge.
Conventional Spinning—The process of forming metal over a mold using multiple passes and hand pressure.
Conversion Coating—Treatment, either chemical or electrochemical, of the metal surface to convert it to another chemical form which provides an insulating barrier of exceedingly low solubility between the metal and environment, but which is an integral part of the metallic substrate. It provides greater corrosion resistance to the metal and increased adhesion of coatings applied to the metal.
Core—The interior part of a steel whose composition has not been changed in a case hardening operation.
Core Hole—Hole diameter required before cutting or forming internal threads.
Corner—Three surfaces meeting at one point.
Corner Radius—Outside radius.
Corrosion Resistance—The ability of a substance to resist deterioration due to a reaction with its environment.
Counterboring—Machining or coining operation to generate a cylindrical flatbottomed hole.
Countersinking–Machining or coining operation to generate a conical angle on a hole.
Critical-to-Function (CTF) Dimensions—In the absence of dimensional drawings, a means of communicating by CAD dimensions critical to success of the design, tolerance and other non-geometrical information. Generally, simpler than a complete fabrication drawing because of fewer dimensions.
Cross-Hatch Pattern—Repetitive lines crossing each other at an angle, such as a coarsely woven cloth.
Cross-Sections—Sectional views.
Crystalline Structure—Arrangement of molecules in geometric patterns in a solidified material.
Cumulative Tolerance—Progressive accumulation of tolerances resulting from multiple operations or assembly of multiple parts.
Curvature—The tendency for material to retain some of the coil set of the wound coil when it is uncoiled. Also called "coil set."
Cut Band—See "Burnish."
Cut Lengths—Standard sheet sizes of material received from service centers, such as 3' x 8' or 4' x 12'.
Cut-Off—Process by which strips of material or finished parts are cut from a coil or strip of raw material.
Cut-Tape Test–A paint adhesion test consisting of the application of an adhesive tape to a dried coating and rapidly removing the tape with a swift, jerking motion.
Cutoff Press—Any one of several types of cut-off methods in a roll forming line.
DOS—Acronym for "Disk Operating System." A computer operating system.
D-Size—A common drawing size, 22" x 34".
DXF—Acronym for "Drawing Interchange File."
Datum—Theoretically exact planes, lines or points from which other features are located on design drawings.
Debur—To remove the sharp, knife-like edge from parts.
Dedicated Tooling–Commonly referred to as "hard tooling"—is tooling made to produce a specific part.
Delamination—Defective surface condition where scale, slag or other impurities not removed during mill processing affect the surface of the sheet.
Die—Tool with a void or cavity which is precisely fitted to a "Punch" used to shear or form sheet metal parts.
Die Angle—Forming term used to denote the inside angle of a matched punch and die set.
Die Clearance—Amount of space between the punch and die opening (per side).
Die Cushion—Large pressurized cylinder, generally housed beneath the bed of a press which is used to apply upward pressure to the lower die.
Die Cut Inserts—Packaging elements, generally of cardboard, which are machine blanked to a specific shape in order to precisely fit a part contour.
Die Marks—Scratches, scrub marks, indentations, galling or burnishing of sheet metal workpieces by tooling.

Dimension—A measurement describing size and/or appearance of a part feature.
Dip Brazing—Metal bonding of parts by molten bath immersion.
Discoloration—(l) Staining. (2) Changing or darkening in color from the standard or original.
Diskette—A flexible plastic disk coated with magnetic oxide and used for storing electronic data.
Double Action—Press utilizing two moving elements.
Double Burned—A condition that may occur on a laser wherein the laser essentially produces a feature twice destroying the part's edge and causing out of dimension condition.
Download—To receive data from another computer.
Drain Holes—Holes placed in the part that are nonfunctional except to allow for drainage.
Draw—A term used interchangeably with tempering in the heat treating process.
Drawing—(1) Engineering document depicting a part or assembly. (2) In metalforming, the stretching or compressing of a sheet metal part into a die by a punch to create a 3-dimensional part.
Draw Ring—Holding device in a die to control material flow and wrinkling during forming.
Dry Film Thickness—Thickness of an applied coating after drying or curing.
Dry Spray—See "Oversprays."
Ductility—Ability of a material to be bent or otherwise formed without fracture.
Dutch Bend—See "Hem."
.Exe—An executable suffix to a computer file denoting it as an execution file.
Early Supplier Involvement—Involvement of a supplier during the conceptual development stage of a product.
Edge—A transition between surfaces.
Edge Bulge—Condition resulting from any forming, piercing, hardware insertion or spot welding operation too close to an edge.
Edge Deckle (Mill Edge)—Waviness of an unslit coil edge, as received from the material supplier.
Edge Pucker—Material extrusion beyond an outside edge through metalforming.
Edge-to-Feature—A dimension between the edge of the part and a feature.
Effective Case Depth—The perpendicular distance from the surface of a hardened case to the deepest point at which a specified level of hardness is attained.
Electrodes—(1) In welding, a tungsten rod, (TIG) or consumable metal wire (MIG) which is used as an electrical conductor and arc point between the welding torch and the workpiece. (2) In spot welding, the upper and lower shaped, conductive elements between which, two or more sheet metal parts are squeezed and through which, current flows during resistance welding.
Electrolytically Deposited—Depositing of one material on another (commonly known as plating).
Electron Beam Welding (EBW)—Melting and fusing of metals by use of a collimated stream of electrons traveling at close to the speed of light. The kinetic energy from the electrons converts to heat on impact.
Electroplating—Deposition of a thin layer of metal to a workpiece using an electrolytic process.
Electrostatic Spraying—Method of spray painting in which an electrostatic potential is created between the article and atomized paint particles. The charged particles of paint are attracted to and deposited on the articles being painted. The electrostatic potential is used in some processes to aid the atomization of the paint.
Enclosed Seam and Pocket—Formed, spot welded or welded area that can entrap plating solutions.
End Flare—Seen after cut off, caused by the release of residual forming stresses in material being roll formed, where one longitudinal end springs open and the other springs closed.
Entity—A predefined element that you place in a drawing by means of a single command. A single piece of geometry or text.
Environmental Testing—Testing of a product or finish for resistance to attack by specific elements.

Etching—Chemical cleaning of parts.
Extruded Hole—Pierced and formed hole in sheet metal in which the metal has been stretched creating a tubular shape.
Feather Edge—Material thinning toward an edge, creating an irregular knife-edge, "tattered" appearance.
Feature-to-Feature—Dimension between two features on a part.
Feed Eccentric—A screw-adjusted device used to set the feed length on a slide forming machine.
Feed Unit—An integral part of the forming machine that advances either wire or strip in accurate increments.
Female Tool—A "mold" duplicating the exterior dimensions of the part.
Ferritic—Referring to iron content.
Ferro Magnetic—Various alloys that exhibit magnetic qualities.
Ferrous—Metals containing iron as a major alloying constituent.
File Names—A name assigned to a computer file.
File Transfer Protocol (FTP)—The mutually agreed upon setting used by two computers in data transmission.
Fillet Weld—Joining method of filling an inside edge with welding metal.
First Article—A part produced using production tooling via the final production process. The part is inspected and documented as proof of conformance to print.
Fit-Up—Degree of physical match between two or more components.
Fixture—Tooling designed to locate and hold components in position.
Flame Hardening—A process consisting of heating a desired area, usually localized, with an oxyacetylene torch or other type of high temperature flame and then quenched to produce a desired hardness.
Flange—Formed projection or rim of a part generally used for stiffness or assembly.
Flat or Matte—Coating surface which displays no gloss when observed at any angle; a perfectly diffused reflecting surface.
Flat Pattern—A two dimensional development that represents the part before it is formed into a three dimensional shape.
Flat Wire—Round wire which has been reduced to a flat state with rounded edges.
Floating Fastener—Hardware which allows the threaded portion to move within its particular confines without rotating, to compensate for misalignment.
Floppy Disk— See "Diskette."
Flower Diagram—A drawing which superimposes the cross section contour of a roll formed part at each roll station, starting with the flat incoming material and ending with the desired profile. It depicts the anticipated flow of material in the forming process.
Flying Die Cutoff—The system used in roll forming to cut the formed shape to length in a continuous operation. Similar in action to a punch press, but designed to allow the die to move in line with the roll formed shape during the cutoff cycle, and to make a cut on the fly based on a signal from a trigger mechanism.
Follower Block (Tail Block)—This serves to clamp the work piece to the tool.
Foreign Matter—Anything visually unrelated to the true nature of the substance under examination.
Form—A bend, or the process of bending a metalformed part.
Form Lifter—A cam-operated motion used for lifting the mandrel or forming in an opposite plane.
Form-to-Form—Dimension between two forms on a part.
Formed Tab—Small flange bent at an angle from the body of a metal workpiece.
Forming—Operation converting a flat sheet metal workpiece into a three dimensional part. See, also "Bending" and "Drawing."
Forming Slides—Cam operated units acting in a single plane used to drive tools on a slide forming machine.
Forming Tool—A slide mounted tool used for bending on a slide forming machine.
Fourslide Machine—A machine, either horizontal or vertical, used to fabricate formed metal

stampings and wire forms, by the action of four or more forming slides acting upon a stationary mandrel or center tool.

Front Cut-Off—A device driven by a cam that is mounted on the front shaft on a slide forming machine used to severe the blank from the strip before forming.

Functionality—The degree to which the designed part will perform to meet its intended purpose.

Fuse Welded Joint—Welding method without addition of a filler metal, used to generate little, if any eruption above the original surface level.

Gage—See "Gauge" definition (1).

Galvanic Corrosion—Dissimilar metals in contact with each other in presence of moisture, acting as a battery and causing an electrolytic etching deteriorating effect.

Ganged—See "Nesting."

Gas Metal Arc Welding (GMAW)—See "MIG Weld."

Gas Tungsten Arc Welding (GTAW)—See "TIG Weld."

Gas Welding—Melting and fusing metals together by use of an oxygen and flammable gas mixture.

Gauge—(1) Instrument for measuring, testing, or registering. (2) Numeric scale for metal thickness.

Gaylord—See "Master Carton."

Gloss—Term used to describe the relative amount and nature of mirror-like (specular) reflection.

Glossmeter—Instrument for measuring the degree of gloss in relative terms. Such instruments measure the light reflected at a selected specular angle.

Go/No-Go Gauge—Measuring device with two registration elements which determine if a feature to be measured is between two established limits.

Gouge—Surface imperfection, deeper than a scratch, often with raised edges.

Grain Direction—(1) Crystaline orientation of material in the direction of mill rolling. (2) Orientation of a surface finish generated by abrasive method.

Grinding—Process of removing material by abrasion.

Grippers—Material clamping devices often serrated for additional holding force to restrain material during a die operation.

Grit—Mineral particles used for abrasive metal removal.

Half Shearing—Partial penetration piercing, creating a locating button with a height of about 1/2 material thickness.

Hard Tooling—Tooling made for a specific part. Also called "dedicated tooling."

Hardenability—The fundamental characteristic of a steel which determines the ease of preventing the transformation of austenite to anything else but martensite during the quench.

Hardware—(1) The physical components of a computer system. (2) Fasteners inserted into a sheet metal part.

Hardware List—Information that should be conveyed to the part supplier specifying part numbers, description and quality of fasteners.

Heat Sink—Good thermal conductor used to remove destructive heat from an area.

Hem (Dutch Bend)—Edge of material doubled over onto itself for the purpose of safe handling or to increase edge stiffness.

Hold-Down Marks—Slight indentations or scuff marks on one side of the stock which can result from the pressure of hold down devices during shearing operations.

Hole Rollover—Rounding of the top edge of a pierced feature caused by the ductility of the metal, which flows in the direction of the applied force.

Hole-to-Feature—Dimension between the center of a hole and another feature.

Hole-to-Form—Distance from the center of a hole to the edge of a formed feature.

Hole-to-Hole—Dimension between centers of holes.

Homogenizing—An annealing treatment at a fairly high temperature designed to eliminate or reduce chemical segregation.

Host Computer—An unattended computer that can be accessed by other (remote/client)

computers.

Hot Dip—Application of a metal coating on a substrate by immersion in a molten metal bath.

Hot Rolled Steel—Steel which was roller-formed from a hot plastic state into final shape; characterized by a rough, scaly surface.

Hue—(1) Attribute of a color by means of which a color is perceived to be red, yellow, green, blue, purple, etc. White, black and grays possess no hue. (2) The name of a color of a finish, as viewed subjectively.

Hydraulic Press—Machine which exerts working pressure by hydraulic means.

Hydrogen Embrittlement—Loss of ductility of a material due to absorption of hydrogen gas during an electrolytic process or during acid cleaning of heat-treated parts.

IGES—Acronym for "Initial Graphics Exchange Specification."

Impact Resistance—Ability to resist deformation from impact.

Inboard Mill—A roll forming machine with a housing only on one end of the roll tooling shaft.

Inclusions—Particles of impurities (usually oxides, sulphides, or silicates) which separate from the liquid steel and are mechanically held during solidification. In some grades of steel, inclusions are made intentionally high to aid machinability.

Indexable Tool Stations—Special tool positions in a turret press which are equipped with numerically controlled servo drives rotating the punch and die together to profile contours, nibble angles or for other special applications.

Inductance Instrument—Instrument which is used to measure thickness of applied coatings to metal substrates. Unlike magnetic thickness gauges, inductance gauges can measure either conductive or non-conductive coatings on magnetic or non-magnetic substrates.

Induction Hardening—A form of hardening in which the heating is done by induced electrical current.

Insert—See "Inserted Fastener."

Inserted Fastener—Variety of pins, nuts, studs, standoffs or special hardware which are installed in a workpiece by inserting it into a specifically punched hole. See chapter on Inserted Fasteners.

Inside Radius— See "Bend Radius."

Inspection Criteria—Characteristics by which the part will be evaluated both dimensionally and cosmetically.

Interrupted Quench—Stopping the cooling cycle at a predetermined temperature and holding at this temperature for a specific time before cooling to room temperature. Usually done to minimize the likelihood of cracking, or to produce a particular structure in the part.

ISO Drafting Standard—Regulation for the creation of technical drawings published by the International Organization of Standards.

Isothermal Treatment—A type of treatment in which a part is quenched rapidly down to given temperature, then held at that temperature until all transformation is complete.

Jig—See Fixture.

King Post—See "Mandrel."

LASER—Acronym for "Light Amplification by Stimulated Emission of Radiation."

Lanced and Formed Tab—See "Formed Tab."

Lanced Tab—See "Formed Tab."

Lap-Welded Joint—Welded seam in which the two metal pieces to be joined overlap one another.

Laser Welding—Metal melting and fusing using the energy of a concentrated coherent light beam.

Layer—A CAD file is like a layered stack of clear transparency films with design information on the different layers. They are superimposed on each other. One can look down through all of the layers at once, or only selected layers.

Lead Screw—Part of a system which converts rotary to linear motion.

Lead Time—Time required to manufacture a product from order placement until availability. It includes planning, engineering, tool design and construction, acquisition of materials, scheduling, fabrication, finishing and packaging.

Leg Size— Width and height of the filler bead of welding material.

Lever Arms—A scissors-like apparatus used to apply pressure to the spinning blank.

Linear Slide Machine—A vertical slide forming machine with the ability to place several opposing slides arranged in a linear fashion on both the front and back sides of the tooling area.
Lines—A straight line segment between two points.
Line Width—Thickness of a line in CAD drawings.
Load Up—Accumulation and compaction of metal particles between the abrasive grit of a grinding belt disc or wheel rendering it ineffective.
Lock Seam Tube—A hollow (closed) roll form shape mechanically fastened using the roll form tooling.
MIG Weld (Metal Inert Gas) or GMAW (Gas Metal Arc Weld)—Metal melting and fusing process using a continuous metal consumable electrode with an inert gas around the electrode to shield against oxidation.
Magnetic Thickness Gauge—Device, applicable only to ferrous substrates, which measures the thickness of non-conductive coatings.
Mandrel—Usually a fixed tool on a slide forming machine that metal is formed against by the action of a slide-mounted form tool.
Manganese (Mn.)—Lustrous reddish-white metal of hard, brittle and therefore non-malleable character. Element number 25 of the periodic system. Atomic weight 54.93.
Manufacturability—The degree to which a product can be efficiently and accurately produced using modern manufacturing methods.
Martempering or Marquenching—Martempering is a form of interrupted quenching in which the steel is quenched rapidly from its hardening temperature to about 450°F, held at 450°F until the temperature is uniform, then cooled in air to room temperature. Actual hardening does not occur until the air cooling starts and is accomplished with a minimum temperature differential. Martempering is indicated for low to medium alloy steels when distortion may be a problem.
Martensite—A ferritic material with distinctive needle like structure which is always present in heat treat of hardenable steel.
Martensitic Stainless Steel—Stainless-steel series which are magnetic and hardenable by heat treating.
Masking—Temporary shielding of a portion of a product to selectively prevent the application of a coating.
Master Carton—Large box, generally 42 in. wide, 48 in. long and 30 in. high, made from heavy test cardboard and designed to fit a standard pallet.
Master Die—Universal tool receptacle for holding changeable tool systems.
Master Document—An original file retained in case of subsequent errors to a copy.
Material Utilization—Extent to which optimal use of material is approached.
Mechanical Assemblies—Part combinations attached by mechanical means through the use of hardware.
Mechanical Fastener—Device clamping two or more components together by mechanical force, such as rivets, screws, etc.
Mesh—Number of holes per inch in sieves used to sort mineral abrasive particles into specific grit sizes.
Metal Thinning—Thickness reduction during any forming operation.
Micro Alloying—Specific alloy combination usually designed for special strength, ductility or flexibility.
Micro Ties—Thin bridges of metal which are left to hold parts in place during turret punch fabrication.
Mill Edge—See "Edge Deckle."
Model—(1) Pre-production sample, made with limited emphasis on tolerance, to test a design concept. See, also, "Prototype." (2) A computer graphic depicting exact geometry of a part.
Mold Lines—Lines in a drawing connecting the inner radius and outer radius of a bend and showing the extent of bend.
Multiple Level Forming–A sequence of slide forming operations at different elevations of the center form.
NC—Numerically controlled.
N/C Press—Numerically controlled press. See "CNC Turret Press."

Nesting—(1) Grouping of identical or different parts in multiples within a workpiece to conserve material. (2) In packaging, stacking of parts whose shape permits one to fit inside another.
Nibble Marks—Slight irregularities at the edge of the stock surface after progressive punching ("nibbling") operations in a turret press.
Nitriding—The process of adding nitrogen to the surface of a steel, usually from dissociated ammonia as the source. Nitriding develops a very hard case after a long time at comparatively low temperature, without quenching.
Nominal—The targeted value for a dimension that defines the size of an ideal part.
Non Ferrous Metal—Elements and their alloys without iron as a major constituent.
Non-Geometrical—Information not related to the shape of the product. (i.e. part number, notes, material lists, tolerances, etc.)
Non-uniform Coverage—Inconsistent paint thickness.
Normalizing—The process of heating steel to a temperature above its transformation range, followed by air cooling. The purpose of normalizing may be to refine grain structure prior to hardening the steel, to harden the steel slightly, or to reduce segregation.
Notching—Operation in which the punch removes material from the edge or corner of a strip or blank.
Nugget—Area melted together during resistance welding.
Obround—Contraction of the words oblong and round denoting a punched slot with semicircular ends and straight sides.
Observational Standard — See "Color Chips."
Oil Canning—Out of flatness condition in sheet material commonly known as "Oil Canning" in which, with the edges of the sheet restrained, the center of the sheet can be popped back and forth but cannot be flattened without specialized equipment. This condition is sometimes inherent in the material as received from the supplier and sometimes the result of multiple punching or forming operations.
Orange Peel—Irregular condition surface resembling an orange skin texture.
Orbital Sanding—Non-straight-line abrasive finish with irregular circular marks.
Organic Coating—Designation of any chemical finish containing carbon.
Orthographic Drawing—A drawing showing a projection of a part in which all the features are visible.
Outboard Mill—A roll forming machine with housings that support both ends of the roll tooling shafts.
Outside Radius—Formed outside radius of a bend.
Overlapping Seam—See "Enclosed Seam and Pocket."
Overspray—(1) Spray material which may be lost within the spray booth or to the atmosphere. (2) Spray material which subsequently falls on the product. (3) Areas adjacent to coating of surfaces requiring paint.
Oxidation—Chemical reaction between a material and oxygen.
Oxidation Scale—Stained, discolored and flaky surface condition.
Pallet—A platform designed to facilitate lift truck handling of parts or packages.
Pancake Die—Simple push-through die for blanking or piercing.
Parametrics—Defining a feature's size by establishing a geometric relationship between it and other features, instead of defining it with a dimension.
Pattern Direction—Orientation of features or surface patterns on sheets and coils.
PEM® Fastener—Self-clinching inserted fastener (nut, stud, standoff, pin, blind stand off, etc.) made by Penn Engineering & Manufacturing Corp.
Pencil Hardness Test—Method to measure coating hardness based on the scratching of the film with pencil leads of known hardness. The result is reported as the hardest lead which will not scratch or cut through the film to the substrate.
Penetration—(1) Depth of a cutting operation before breakout occurs. (2) In welding, the depth of material through which fusion occurs.
Periphery—The extreme outer edge of part or

drawing.

Perpendicularity—Dimensional relationship of a part or datum located at right angles (90°) to a given feature.

Phosphating—Treatment of steel or certain other metal surfaces by chemical solutions containing metal phosphates and phosphoric acid as the active ingredients, to form a thin, inert, adherent, corrosion-inhibiting chemical conversion coating which serves as a substrate for subsequent paint coats.

Phosphor Bronze—Copper base alloy with 3.5 - 10% of tin to which phosphorus has been added in a molten state in varying amounts of less than 1% for deoxidizing and strengthening purposes.

Pickled and Oiled—Hot rolled steel with the scale removed through immersion in acid and a follow up rinsing and oiling process for oxidation protection. Also referred to as "P&O" and "HRPO."

Piercing—Punching of openings such as holes and slots in material.

Pigment—Finely ground, natural or synthetic, inorganic or organic, insoluable particles which, when dispersed in a liquid vehicle to make paint, may provide, in addition to color, many of the essential properties of a paint—opacity, hardness, durability, and corrosion resistance.

Pinch Trim—Trimming excess material from a drawn part at the bottom of the stroke. Leaves drawn shell without an inside burr, but with an outside burr and a thinned edge.

Pitting (Inter-Crystalline Corrosion)—Galvanic attack under moist and acidic conditions between molecular structures of differing alloy content.

Plasma Arc Welding (PAW)—Specialized process utilizing a non-consumable electrode ionizing an inert gas and increasing temperature to melt the material being welded.

Plastic Deformation—Permanent deformation occurring in forming of metal after elastic limits have been exceeded.

Plate—Sheet steel thicker than 7 gauge 0.179 in. (4.55 mm) or sheet aluminum thicker than 3/16 in (4.76 mm).

Point—A piece of geometry at an exact location.

Polishing—Abrasive process in which the surface created takes on a bright reflective finish, scratch-free to the unaided eye.

Postcut Roll Forming—A process whereby the raw material is fed into the roll forming mill in coil form with the formed part cut to length. This is the most common roll forming material feeding process.

Powder Coating—100% solids coating applied as a dry powder and subsequently converted into a film with heat.

Power Spinning—The process of forming metal over a mold using hydraulic pressure.

Precipitation Hardenable—Alloy in which a constituent precipitates from its supersaturated solution allowing the material to gain added strength.

Precision Lead Screw—See "Lead Screw."

Precut Roll Forming, also referred to as blank-feed—A process whereby the raw material is cut to length prior to entering the roll forming mill and fed into the mill as blanks. Primarily used for low-volume applications.

Prefinished Material—Stock which has been painted or plated prior to fabrication or stamping.

Prenotch/Prepunch Press—A device used to stamp a hole or notch pattern in incoming material on a roll forming line prior to roll forming.

Press Attachment—A bed mounted device on a slide forming machine used for punching, piercing and other press operations.

Press Section—A device that is built into a slide forming machine used for punching, piercing and other press operations.

Primer—First application of a substance capable of adhering to the substrate and providing good adhesion to a subsequent coating.

Programmable Back Gauges—Stops on metal-forming machines which can be adjusted during and between cycles by computer numeric control.

Progressive Tool—Die using multiple stations or operations to produce a variety of options. Can incorporate piercing, forming, extruding

and drawing, and is usually applied to high quantity production runs.

Projection Weld Nuts (or Studs)—See "Weld Nuts" and "Weld Studs."

Projection Welding—Using protrusions on one of the two parts to be resistance welded, creating a positive conductance path.

Prototype—First part of a design which is made to test tolerance capability, tooling concepts and manufacturability. (See model)

Pull Down—Area of material next to the penetrating edge of a piercing punch, or die edge of the blanking station, where the material yields, i.e. flows in the direction of the applied force, creating a rounded edge. Also known as "roll-over."

Pulse Mode—Intermittant surging of laser cutting power action.

Punch Direction—The direction from which a tool or punch enters the workpiece.

Punch Press—Machine supplying compression force for reshaping materials.

Punch Side—Opposite side from burr side for pierced features; side on which the punch enters the material. The punch side is the burr side for blanked outside contours.

Quenching—Cooling from high temperature, usually at a fast rate.

Quick Change Inserts—Tool sections or parts which may be changed without removing the entire tool from the press.

Ram—Driven (movable) part of a metalforming machine.

Rear Cut Off—A device on a slide forming machine driven by a cam that is mounted on the rear shaft allowing the removal of a slug from the strip, thus providing the ability to produce a blank with special end shapes.

Repositioning—Operation in turret press fabrication denoting the release of the workholders, movement of the X axis to a new position on the workpiece, and the regripping of the workpiece so that a sheet larger than the X axis table travel can be fabricated, all under computer numeric control.

Reproducibility—Extent to which parts from multiple lots are identical. Also known as repeatability.

Rerolling—Final cold rolling operation, usually done to achieve specific thickness control and improved finish.

Resins—Natural or synthetic basic material for coatings and plastics.

Resistance Projection Weld (RPW)—See "Projection Weld."

Resistance Spot Welding (RSW)—Melting and joining action of two adjoining metal surfaces created by the thermal reaction of thc metal to the flow of an electrical current forming a weld nugget.

Revision—A subsequent part drawing usually denoting corrected or improved version.

Revision Description—A written notice describing the nature of changes to a drawing.

Rivet Nut—Internally threaded fastener designed to be used as a rivet from one side of a workpiece or assembly and to provide threads for a screw or bolt to be used in assembly of a mating part.

Rockwell Hardness—An indentation hardness test based on the depth of penetration.

Roll Formed Shape, Hollow—A roll formed shape which is closed by mechanically fastening or welding the two strip edges together.

Roll Formed Shape, Open—A roll formed shape with a linear or curved contour in which the two ends of the shape are not brought together.

Roll Forming—A continuous bending operation in which sheet or strip metal is plastically deformed along a linear axis by being passed through a series of roller dies and progressively shaped to the desired contour.

Roll-Over—See "Pull Down."

Roll Stations—Tandem sets of rolls used in roll forming to shape the metal stock in a series of progressive stages to form the desired cross-sectional configuration.

Rotary Slide Machine—A vertical forming machine with the ability to place several forming slides radially around the center tool and produce intricately formed stampings and wire forms.

Roundness—Extent to which a feature is circular.

Run Out Flange—Feature on a formed part

which is designated by the designer to absorb the tolerance accumulations created by multiple forming operations.

Run—Sag or accumulation in a paint or finish film prior to curing.

Scale—(1) Thick oxide coating on material normally associated with hot working. (2) Deposit formed from solution directly in place upon a confining surface.

Scallop—Edge condition resulting from nibbling a feature in a turret press.

Scrap—Leftover, unused material relegated to recycling.

Selective Perforation—Hole or slot pattern over a specific portion of a workpiece, normally used for ventilation purposes.

Self Extracting Archive File—A library file that can automatically create a group of (CAD) files without requiring the operator to have any special knowledge, or use special software.

Self Fixturing—Part designed to be self-locating into proper position to another part with the use of built-in locators.

Self Locking Fastener—Fastener which is machined with interference threads or which has a nylon insert or other locking mechanism to securely hold mating fasteners in high torque or vibration applications.

Semi-Gloss—A gloss range between high gloss and eggshell, approximately 35 to 90 on the 60 degree gloss scale.

Semi-Perfs—See "Half Shear."

Shake Aparts—Term designating a family of parts on a sheet which are held by "Micro Ties" so small that the parts can be removed from the sheet after CNC punching by simply shaking the sheet.

Shaker Parts—See shake "Aparts."

Shear Form—See "Lanced Tab."

Shear-to-Feature—Shearing of an edge of stock to an exact dimension from an already existing feature.

Shear Spinning—The process of forming metal over a mold in one pass using hand or hydraulic pressure.

Shearing—Cutting force applied perpendicular to material causing the material to yield and break.

Shielding Gas—Inert gas used for oxidation protection during welding.

Shim Steel—Steel which has been rolled thin to a hard condition and very close tolerance.

Shrink Wrap—Thin poly film which is stretched or heat shrunk over parts for protestion or display.

Shunting—Short circuiting of a (weld) current through a previously applied weld nearby.

Shut Height—Clearance in a press between ram and bed with ram down and adjustment up.

Silicon Carbide—Mineral used for abrasive metal removal.

Silkscreening—Printing process using special inks being pressed through a finemeshed fabric which has been prepared by a photo process to let the ink pass through in predetermined patterns of lettering and graphics.

Single Action—Press utilizing one moving element.

Sinkhole—In welding, a dimple on the surface of stock caused by shrinking of the weld during cooling.

Skid Marks (Roll Slip)—Polished or burnished streaks across the stock surface resulting from improperly set roller driven material processing equipment. Skid marks are transverse to the direction of rolling.

Skin-pass—Single cold rolling process on material after a heat treating process.

Slide Forming—A high-volume stamping process in which a machine with multiple slides sequentially performs various operations (i.e. - blanking, piercing, forming, etc.).

Slot-to-Form—Distance from a slot edge to the inside edge of a formed feature.

Slug—Scrap from a piercing operation.

Slug Marks—Surface defects caused by scrap being indented into the metal surface.

Soft Tooling—A term generally applied to the fabrication of metal parts using computer controlled technology incorporating CNC turret presses, laser profilers and press brakes.

Solids—The ability of the CAD software to

realize that a volume is filled with solid matter. These CAD systems can display a design so that it looks like a solid object. Includes recognition of surfaces and wireframes.

Solution Heat Treat—High temperature process in which an alloy is heated to the suitable temperature for the alloy constituents to be in a totally soluble condition for the purpose of creating a homogeneous alloy. Through rapid cooling the constituents stay in this solution state. Metal so treated is left in a super saturated unstable state and may tend to age harden at ambient temperatures.

Solvent Based—Paint type in which a volatile liquid is used to dissolve or disperse the film-forming constituents.

Spatter—In welding, droplets of matter deposited as contaminants.

Spectral—Adjective referring to spectrum. See "Spectrum."

Spectrophotometer—Device for the measurement of spectral transmittance, spectral reflectance, or relative spectral emittance.

Spectrum—Spatial arrangement of components of radiant energy in order of their wavelengths, wave number or frequency.

Specular Gloss—Relative luminous fractional light reflectance from a surface in the mirror or specular direction. Expressed as a ratio of incident to reflected light.

Spheroidizing—A heat treating process used to change all of the carbides in steel to rounded particles, or spheroids. A completely spheroidized structure is the softest and most workable structure for any composition.

Spinning Blank—A circular disk made from sheet or plate metal.

Spot Face—Circular flat surface as a bearing area for hardware.

Spring Back—Partial rebounding of formed material caused by its elasticity.

Spring Loaded Panel Fastener—Inserted fastener which is equipped with a floating captive screw, spring and retainer such that the hardware will remain in the panel, ready for use, when the panel has been disassembled from its mating component.

Squareness—Measure of perpendicularity of adjacent edges or surfaces.

Stack-Ups—Tolerance accumulations.

Stainless Steel—Various ferritic alloys exhibiting high oxidation resistance through the alloying with chromium and nickel.

Standard Vee Die—See "V Die."

Stiffening Rib—Embossed feature in a sheet metal workpiece which is added to make the part more rigid.

Stains—Discolorations on the surface of sheet metal, caused during mill processing.

Staking—Method of fastening using displaced material for retention.

Stock Check—A device used to grip the material as the feed retracts, preventing movement of the material during the forming cycle.

Stock Reel—A powered or non-powered device used to support a coil of material as it is fed into the machine.

Stock Straightener—A machine mounted device consisting of a series of adjustable rolls used to straighten wire or strip stock as it comes off the coil.

Stretcher Leveled—A flattening process in which a material is stretched to achieve a desired flatness tolerance.

Strip Edge Forming—The use of a rolling technique to edge roll slit strip with shaped edge rolls to provide an edge finish equal to the material's surface finish. Also called edge conditioning.

Stripper—Mechanical hold-down device applied to the workpiece during the punching process.

Stripper Marks—Imprints on one side of the stock around pierced holes, caused by punch strippers.

Stripping—Process of disengaging tooling from the workpiece.

Strips—Sheet material, sheared into narrow long pieces.

Stroke—RAM travel from top dead center (TDC) to bottom dead center (BDC).

Substrate—Original material surface to which a coating is applied.

Surface—The ability of the CAD software to recognize that a closed geometric shape represents a surface of a part. Includes recognition of wireframes.
Surface Inclusions—Debris rolled into the skin of material causing a depression or thinly coated pocket.
Surgical Stainless Steel Types—Any of the 300 series stainless steels with an 18% chromium and 8% nickel content. Also includes the PH type of stainless steels.
TIG Weld (Tungsten Inert Gas)—Process using a nonconsumable tungsten electrode and a shielding gas, with filler material optional.
T.I.R.—Total indicator reading. Absolute sum of all dimensional variance.
Tack Weld—Usually refers to a temporary weld used to hold parts in place while more extensive, final welds are made. In some sheet metal applications, tack welds may provide sufficient strength to eliminate the need for an "all-around" fillet weld.
Tap Drill Size—See "Core Hole."
Tape Adhesion Test—Adherence test for painted surfaces conducted by cross hatching the surface with a sharp knife in a 1/8 inch grid pattern, applying tape (usually 3M Scotch #600 or #250), allowing to sit for a specified period, and then removing with a quick pull perpendicular to the surface of the part. Adherence is measured by the percentage of paint remaining within the grid. See the Painted Parts Chapter.
Tapping—Operation to create internal threads by either cutting or forming.
Temper Designation—Identifying systems to denote the hardness of a particular material.
Tempering—Reheating quenched steel to a temperature below the critical range, followed by any desired rate of cooling. Tempering is done to relieve quenching stresses, or to develop desired strength characteristics.
Tensile Strength—The strength of a material when subjected to a stretching force.
Test File—A CAD system file used to test the compatibility of supplier and customer CAD systems.
Text Files—A file containing words, but no pictures.
Texture—Structure of a surface as it affects appearance or feel.
Thickness—Gauge or depth of material.
Thread Rolling Tap—Tool to generate internal threads by displacing and flowing metal into a thread shape.
Ties—See "Micro Ties."
Tolerance—Permissible variation from a specification for any characteristic of the product.
Tooling Holes—Openings provided in parts for location purposes during production.
Tool (mandrel, chuck)—The "mold" from which the part is made.
Torque—Turning force.
Transfer—Exchanging electronic data from one medium to another.
Transfer Die—Variation of a progressive die where the part is transferred from station to station by a mechanical system. Mainly used where the part has to be free from the strip to allow operations to be performed in a free state.
Transfer Mechanism—Apparatus used to move a part between die stations.
Triple Action—Press utilizing three moving elements.
Tungsten Electrode—Current carrier made from the metal tungsten for its high heat resistance.
Turret—Rotary tool holding device in CNC punch presses.
Turret Press—Automatic punch press, which indexes the material and selects the intended tool out of a rotary tool holding device (turret), for piercing, blanking and forming workpieces as programmed.
Twist—The rotation of two opposing edges of material in opposite directions.
Ultimate Strength—The breaking strength of a material when subjected to a stretching force.
Ultrasonic—Sound vibration above the audible range.
Undercut—Condition of the stock resulting from welding or grinding below a desired plane.
Unfolded—The act of developing a flat pattern.
V Die—Tool used in conjunction with a V punch.

V Punch—Vee shaped tool used for angle forming.
Vibratory Finishing—Burr removal process in which an appropriate number of parts, depending on part size and abrasive material, is accelerated and decelerated by mechanical means inside of a drum-like enclosure.
Viewing Angle—Inclination from which a surface is observed, i.e. looking straight at the object = 90°.
Viewing Time and Distance—Specified period to inspect a surface condition at a preset dimension from the eye.
Viscosity—Internal friction within a fluid which makes it resistant to flow.
Void—Area in a weld in which insufficient filler material is deposited.
Water-Borne—Generic designation for a variety of organic finishes which indicates that they are compounded with water as a dilutant rather than a volatile organic solvent.
Water-Soluable—Substance which dissolves in water.
Watts per square inch—Measure of speed based on power level of laser cutting machine.
Webs—(1) Material between two openings or edges. (2) See "Micro Ties." (3) In some industries, thin material to be punched.
Weldability–Ability of a material to be fused successfully without special processing.
Weld Accessibility—Ease of reaching the weld area with the torch or electrode.
Weld Distortion—Depression or bulge on surface, caused by thermal expansion.
Weld Nut—Internally threaded hardware designed to be spot or projection welded onto sheet metal parts.
Weld Stud—Externally threaded hardware in various lengths in headed and head-less version, welded in place.
Weld-To-Edge Distance—Minimum distance from a spot weld to the material edge to create an acceptable spot weld.
Weld-to-Form Distance—Minimum distance from a formed area to electrodes to avoid shorting.
Weld-to-Weld Spacing—Minimum distance between spot welds to avoid shunting through the existing weld spot.
Wet Film Thickness—Thickness of the liquid coating film immediately after application.
Wet Film Gauge—Device for measuring the film thickness of coatings prior to drying or curing.
Wipe Die—Forming tool using two opposing edges, separated by one material thickness, moving past each other to form material.
Wire Form—A formed metal part made from wire that is usually fabricated on a slide forming machine.
Wireframe—The capability of the CAD software to represent a design as a three dimensional arrangement of lines and arcs.
Wire Line—A standard dimension from the bed of the slide forming machine to the material, used in tool layout.
Work Hardening—Increase in tensile strength of material resulting from cold working process.
Workholder—Mechanical device which holds a workpiece.
Workholder Mark—Marring of material through the use of clamping device.
Work Hole—See "Tooling Hole."
Wrinkling—a: condition in a paint film appearing as ripples: (1) produced intentionally as a decorative effect or (2) defect caused by drying conditions or an excessively thick film (common in wet spraying). b: condition of excess material created during the forming process.
Wrought–Describes material which has been plastically deformed into shape as by mill rolling.
Yield Strength—Maximum stress that can be applied without permanent deformation of material.
Zinc Plating— See "Electroplating."