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**ARDC**  
**PRODUCTION DESIGN**  
**HANDBOOK**

John L. Thompson & Company  
1112 - 22nd Street, N. W.  
Washington, D. C.

Contract No. AF 18(600)-1789

DECEMBER 1958

Materials and Equipment Division  
RESEARCH AND DEVELOPMENT COMMAND  
UNITED STATES AIR FORCE  
ANDREWS AIR FORCE BASE  
Washington 25, D. C.

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## FOREWORD

This Handbook was prepared by the John I. Thompson and Company, Washington, D. C., under Contract No. AF 18(600)-1789.

The contract required a review and extraction of pertinent information from source material furnished by the Materials Branch, Materials and Equipment Division, ARDC, which included various collections of current information, AIR FORCE REPORTS and studies, illustrations, charts, graphs and tabular data.

Lt. Colonel R. W. Connors and Mr. C. W. Kniffin of the Materials and Equipment Division, ARDC, generously contributed their time and experience in providing technical guidance for the preparation of this report.

Source material assisted greatly in the utilization of authentic and reliable material. Recognition is given to these sources at the end of each chapter.

All users of this handbook are invited to submit recommendations, correct any inaccuracies, provide additional information, or to otherwise improve this report to: Commander, Air Research and Development Command, USAF, Andrews Air Force Base, Washington 25, D. C., Attention: RDRAEF.

## ABSTRACT

The purpose of this handbook is to assist aircraft designers with the various production processes available for their use and as well, to acquaint them with the problems arising from the use of these processes. It is the aim of this report to give the designer a greater feeling for the difficulties that may arise when the part he has designed is sent to the shop for production.

The information contained herein represents contributions from a great many authoritative sources. It was gathered through an extensive search of both commercial and military literature. At the end of each chapter, references are given from which the designer may gather a wider scope of the subject than was feasible to include in the chapter itself.

Basically, the most important hot and cold forming processes are discussed as well as treatment and inspection techniques. The chapters are mainly divided into three sections consisting of: description of process, advantages and limitations, and design considerations. By use of the expanded table of contents, the index, and the glossary, the designer should be able to locate information on almost every production technique currently used in aircraft manufacture.

## PUBLICATION REVIEW

This report has been reviewed and is approved,

FOR THE COMMANDER:



R. W. CONNERS  
Lt. Col., USAF  
Chief, Materials Branch  
Materials and Equipment Division

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## INTRODUCTION

This handbook on the complex subject of production design has been undertaken with the hope that it will be of some help to the designer of present and future air and space vehicles and associated equipment. Attempt has been made to cover the present state of the art in production techniques. Even as the book is being printed, however, new methods and procedures are being developed to cope with the wider use of new materials. It is anticipated that this new information will be added to the handbook in future supplements.

The objective of this effort is to provide a designer's reference manual. It is not a requirements manual such as HIAD, HIGED and similar ARDC publications. The information and data has been compiled particularly for the aircraft, missile, and ground support equipment designer. It is intended that this handbook will enhance the designer's ability to inject producibility into the design of Air Force weapons.

Each metal forming process is covered in a separate chapter which describes the following points:

- (1) basic process
- (2) various production methods
- (3) production equipment
- (4) advantages and limitations
- (5) suitability of various metals
- (6) production quantities and economics involved
- (7) design considerations
- (8) usual dimensional tolerances
- (9) surface finishes obtainable

Each process is complete within itself and the handbook does not necessarily have to be read in sequence.

It should be noted that this handbook concerns manufacturing processes by which metals hot or cold, are formed into finished parts requiring little or no subsequent machining. To the designer this is but one facet in his critical assignment, for he must deal with problems of selection of materials, strength of materials, part configuration and space limitations, design functions, and environmental stresses to list but a few.

Several processes closely associated with metal forming processes are included in the manual. They furnish the designer with additional and helpful information during, and particularly subsequent to, his process selection. The following processes are found in the latter chapters:

- (1) Heat Treatment
- (2) Soldering
- (3) Brazing
- (4) Welding
- (5) Surface Finishes
- (6) Surface Cleaning
- (7) Surface Treatment
- (8) Non-Destructive Inspection

To make reading easier and eliminate the need for additional references, a glossary has been included clearly defining terms peculiar to the various manufacturing processes.

## CHAPTER 1

### FORGING

#### GENERAL

Forging is a shaping process that involves plastic flow of a metal under pressure at some predetermined temperature range. If the shaping is performed at elevated temperatures, the process is known as hot forging; if done at room temperature, the process is known as cold forging.

Some of the advantages of forging are:

- (1) high ultimate strength.
- (2) controlled grain flow.
- (3) uniform density of grain structure.
- (4) low machining costs.
- (5) weight saving due to elimination of bolts, rivets, and other fasteners.
- (6) wide range of shapes, sizes, and materials.

Some of the disadvantages of forging are:

- (1) high die cost when only a small quantity is desired.
- (2) difficulty in meeting requirements such as draft, radii, thickness, etc., on unmachined surfaces.

#### HOT FORGING

Hot forging is a process that involves shaping of a metal at some predetermined elevated temperature range which renders the metal into a workable plastic state. This shaping is caused by impact (striking) or pressing (squeezing) forces. When hot metal is forged, displacement usually occurs at temperatures above those required for recrystallization, thus forming the part with less internal stress.

There are several methods of hot forging commonly in use, namely:

- (1) Smith (flat die) forging
- (2) Drop (impact) forging
- (3) Press forging
- (4) Machine (upset) forging

#### Smith Forging

Smith, or flat die, forging is done with flat dies and simple hand tools, using either press or impact pressure to form the metal while it is in the plastic state. This is usually done with steam hammers, but small forgings are sometimes produced using motor-driven helve hammers or pneumatic hammers.

This type of forging is used principally when the quantity desired is too small to justify the expense of making impression dies or when the work is needed quickly as for prototypes to alleviate the time required in die-making. Smith forging is adaptable to all forging materials and the equipment cost is low. This is the best method to use for low production runs.

### Drop Forging

Drop, or impact, forgings are formed by impact pressure from either gravity drop hammers or direct-powered drop hammers. The parts are formed from pressure between impression dies, one of which is on the hammer face and the other on the anvil. The pressure is applied intermittently and the plastic metal is gradually formed into shape.

This is the most common of the forging processes. It is a high production process adaptable to all materials except high strength magnesium alloys. The equipment cost is low but the die maintenance required is great. Parts produced by this method have wide tolerances.

### Press Forging

Press forging is similar to drop forging, the main distinction being that press forging employs squeezing pressure rather than impact pressure. This process is usually done on mechanical or hydraulic presses with impression dies which contain mechanical ejectors to knock the work out of the press after the stroke is completed.

Press forging can produce a part by a single blow rather than by repeated blows as in drop forging. Although this process is adaptable to all materials, it is most commonly used in producing large aluminum or magnesium parts. The part produced can have close tolerances as well as thin webs and low draft angles. The presses for this process are expensive and require large amounts of space because of their excessive size.

### Machine Forging

Machine or upset forging is limited to producing symmetrical parts, but any variety of sizes and materials can be produced by this method. Upsetting increases the cross sectional area of the part by squeezing the metal between the dies and striking it with a heading tool. Machine forging is done on a horizontal, double acting press known as an upsetter. This produces a part with no flash and thus eliminates machining.

This process is particularly adaptable to mass production of identical parts. It can handle all materials and is probably the best forging operation for high production rates.

### Materials

The materials applicable to forging include titanium alloys, aluminum alloys, magnesium alloys, brasses and bronzes, corrosion and heat resistant alloys, carbon steel, alloy steel, and stainless steel. Table 1.1 shows a number of specific materials that can be hot forged as well as the temperature range at which the forging is normally done.

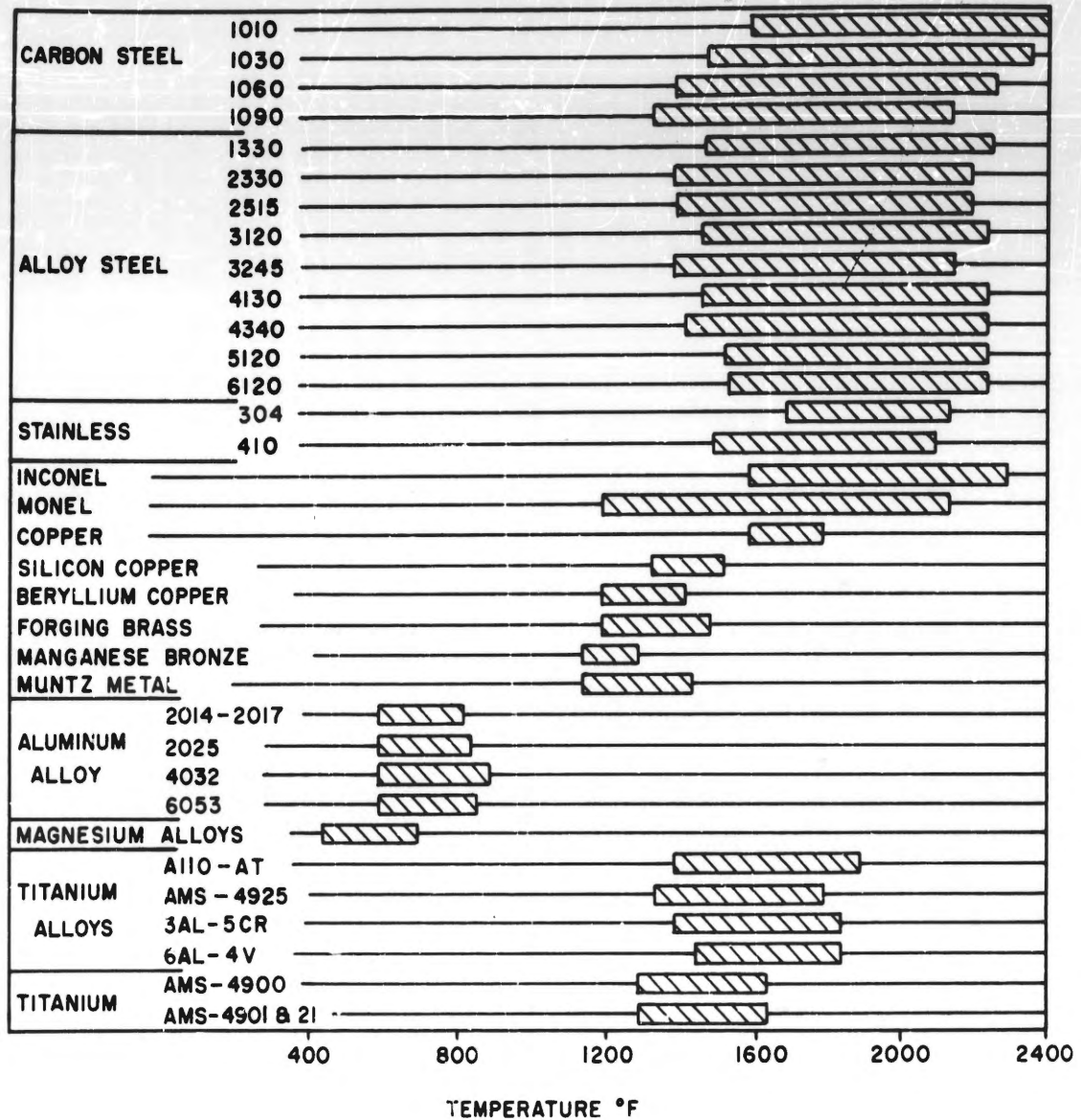


Table 1.1 Forging Temperature Ranges for Various Materials

Equipment

Forging equipment can be classified according to the kind of pressure used. The types are -

- (1) Impact pressure
- (2) Push pressure
- (3) Combination impact and push pressure

Impact pressure is a high velocity pressure imparted by any of several types of power hammers and drop hammers. In open flat-die forging, all power hammers are operated under the same principle of gravity, that is the energy of a falling weight displacing the metal. For

repeated blows, the hammer may be raised mechanically or pneumatically. Some hammers (double acting) use mechanical or pneumatic forces to increase the velocity of the falling hammer. Helve hammers and trip hammers are small power hammers and are used mostly in preforming or pilot production operations. The weights for each type swing on a lever or helve.

Push pressure is a low velocity pressure imparted by a hydraulic or mechanical press. Sizes of these presses can run from 250 tons pressure up to 50,000 tons pressure.

A combination of impact and push pressure is pressure imparted by a upsetter, which is a high-speed mechanical forging press. These pressures are obtained by use of closed dies, the metal being upset or pierced, or both, to fill the die cavity.

A variation in impact forging is the double ended or mid-air forging process. In this operation both the upper and lower dies move and the piece is formed between these moving dies, thus eliminating the foundation shocks from the forging impact pressures and reducing the size requirements of the base of the machine.

### COLD FORGING

Forming of a cold (room temperature) piece of metal is normally restricted to thread and form rolling operations, to cold heading operations, and to coining and swaging, staking, and sizing operations on preformed pieces. In general, all the processes involve plastic flow of metal; however, because the operation is done at room temperatures, the degree of deformation and size of parts that can be handled is much more limited than in the hot forming process.

#### Cold Heading

Other than forging temperature, the basic distinction of cold heading is a working of the metal on the end of the piece, upsetting or flowing metal along the axis of the piece rather than on the side as in a press. Some flattening can be done but again, only on the end of the piece. Typical products include bolts, nuts, rivets, and similar items.

Heading machines are high speed and automatic and fall into the two general classes of open die and solid die headers. The former clamps the piece between die halves, while the latter confines the metal in a one-piece die.

There are a group of various cold forming processes used mostly as finishing and secondary operations on fabricated pieces or small parts. Each of these processes will be discussed briefly.

#### Staking

Staking is a press or hand operation used for mechanical assembly of component parts. It consists of deforming the metal of assembled parts in a manner which prevents their loosening and separating under operating conditions. A typical staking operation is illustrated in Figure 1.1. A hollow punch, the rim of which is ground to a sharp edge like that on a cold chisel, is forced into the metal adjacent to the hole, thus peening it against the shaft or stud placed in the hole. The staking punch creates compressive stresses generally near the surface of the work while at the same time causing very high tensile stresses locally at the sharp edge. This causes permanent set in the region of the tensile stress, leaving residual compression when the punch is removed. The stud or shaft can be serrated or knurled to increase its torque capacity. This method is used extensively for fastening brass, aluminum, and zinc parts to other parts which can be made of any metal.

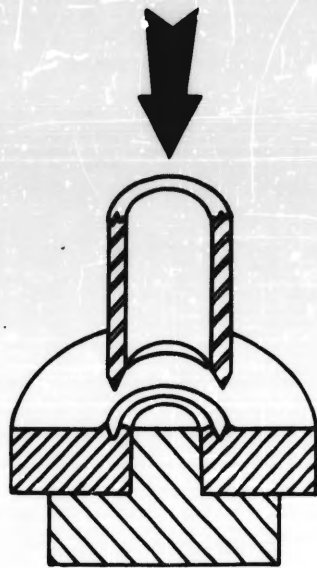


Figure 1.1 Typical Staking Operation

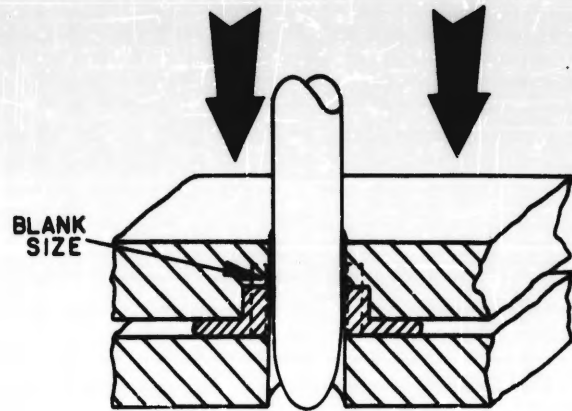


Figure 1.2 Typical Swaging Operation

### Swaging

Swaging begins with a relatively thick blank which is squeezed in compression between a punch and die causing the metal to flow outward through the diminishing volume between the punch and die. Figure 1.2 shows a typical arrangement of tools for producing a small wheel or gear blank with an integral hub by this method. Almost any metal can be swaged although it is obvious that the extent of the change in shape can be greater with metal possessing a high ductility. Brass, aluminum, or zinc are usually selected for this purpose. The metal will not flow out through the orifice in a uniform wave front; therefore, it is necessary to use an excess of material so that trimming and shaving can produce a final size and shape of the perimeter. The shape and size of the blank should be such that the metal on the perimeter of the part will be stretched no more than the corresponding per cent elongation obtained from standard tensile tests, and the reduction in thickness should be kept within the working range of the material.

Another method of swaging is rotary swaging, or rotary reducing as it is sometimes called. In this process the length of the part is increased by reducing the cross sectional area. The metal blank is fed, either mechanically or manually, into the dies where a series of hammer blows, applied in a circular fashion, form the blank to the desired configuration. The number of times the part is struck is 3000 - 5000 blows per minute.

Parts may be swaged hot or cold. Cold swaging is more desirable since it is more economical and it produces a better surface finish. There are some materials that are highly work-hardenable and there are some reductions that are so severe, that hot working is necessary before swaging.

The different swaging processes can be classified as:

- (1) pointing (spouts, shell noses, bayonets, etc.)
- (2) forming (bearings, bushings, struts, axles, etc.)
- (3) attaching (cable, wire, and hose fittings)

Hammering is a variation of swaging in which two vertical dies are employed. The work is fed through the lower die while the upper die continually strikes the workpiece. Hammering

can sometimes produce parts that swaging cannot, such as round parts.

### Sizing

Sizing is literally a cold forging operation used to produce the desired size of a forging or sheet metal assembly by squeezing it between constraining punch and die elements. It is necessary that the metal be stressed thoroughly in compression so that it will hold its shape through permanent set. Application of the operation is restricted to relatively simple shapes for which rigid die elements can be made to apply considerable force over the entire areas concerned. A typical application of this operation is in the production of the desired contour of an automotive brake shoe which has been assembled by riveting and spot welding from several sheet metal components. This operation is occasionally referred to erroneously as "coining," an operation in which the metal is constrained against flow in all directions.

### Coining

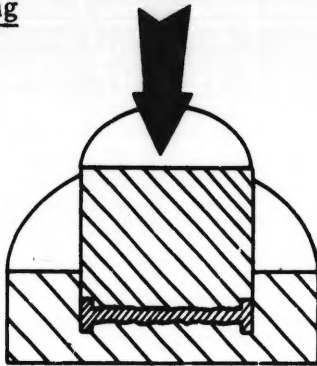


Figure 1.3 Typical Coining Operation

Coining is very similar to embossing in that it is used to produce shallow configurations, but in addition the metal is constrained against lateral flow through the use of a positive punch and die arrangement as illustrated in Figure 1.3. Thus serrations can be produced on the perimeter of the coin. Normally only relatively soft materials or alloys are selected for processing by this method; such alloys are copper, aluminum, brass, and others.

## DESIGN CONSIDERATIONS

### Materials (Titanium)

Since titanium is an extremely active element, it combines readily with other elements when heated to the forging range. A hard oxide coating forms on the exposed surfaces during the forging operation and, since this coating must be removed either by cleaning or machining, it is impossible to design for precision forgings in titanium.

### Draft Angle

The most important of the shape problems to be considered in designing a piece to be forged is draft angle. Tables 1.2 and 1.3 list some of the recommended draft angles in use. Since the actual draft angle will be basically a function of the location of the die parting line and, since it is not the object of the handbook to advise die-designing methods, only general considerations which may be used in designing any piece for forging are illustrated in Figures 1.4 through 1.6.

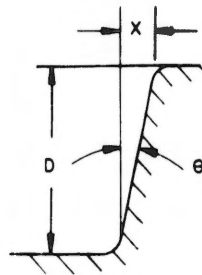
The types of forgings listed in Table 1.2 are described as follows:

- |                   |   |
|-------------------|---|
| Precision -       | Practically no machining required.  |
| Close Tolerance - | Ribs and projections used as forged, machining limited generally to facing surfaces. Weight of primary importance.                      |
| Conventional -    | Ribs and projections machined on one side only. Other machining generally limited to external surfaces. Weight of secondary importance. |
| Blocker -         | Forgings machined overall, including both sides of ribs and projections.  |

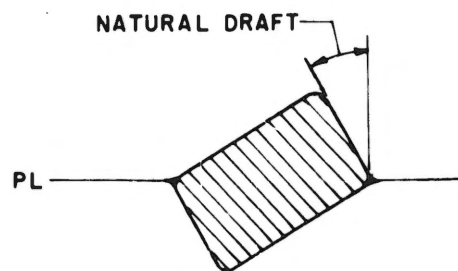
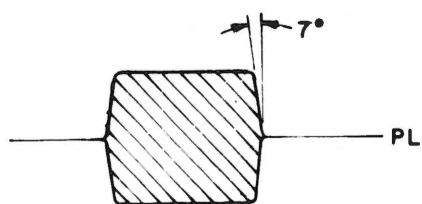
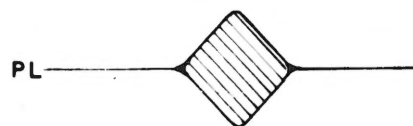
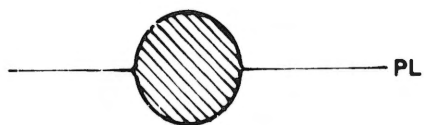
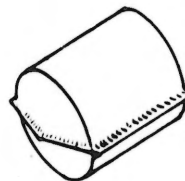
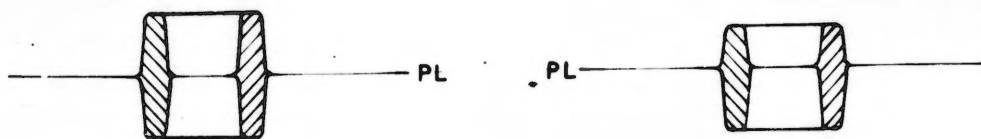
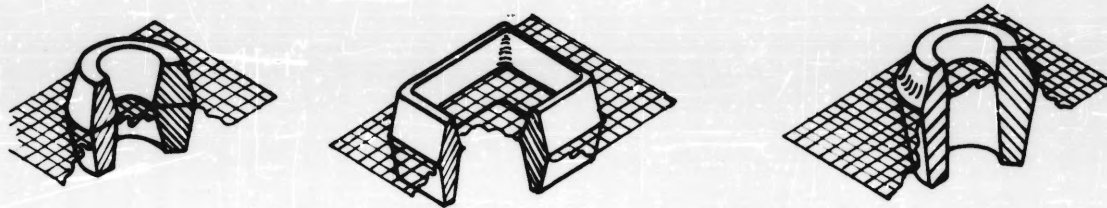
Table 1.2 Recommended Draft Angles for Closed Die Forging

Material Forged	Precision	Close Tolerance	Conventional	Blocker
Aluminum	0° - 1°	1° - 3°	3° - 5°	5° - 10°
Magnesium	0° - 1°	1° - 3°	3° - 5°	5° - 10°
Steel	---	3° - 5°	7° - 10°	10° - 15°
Titanium	---	3° - 5°	7° - 10°	10° - 15°

Table 1.3 Conversion Chart for Draft Dimensions (X) For Standard Draft Angles (θ)

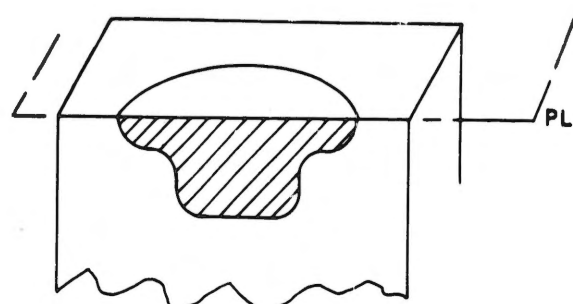
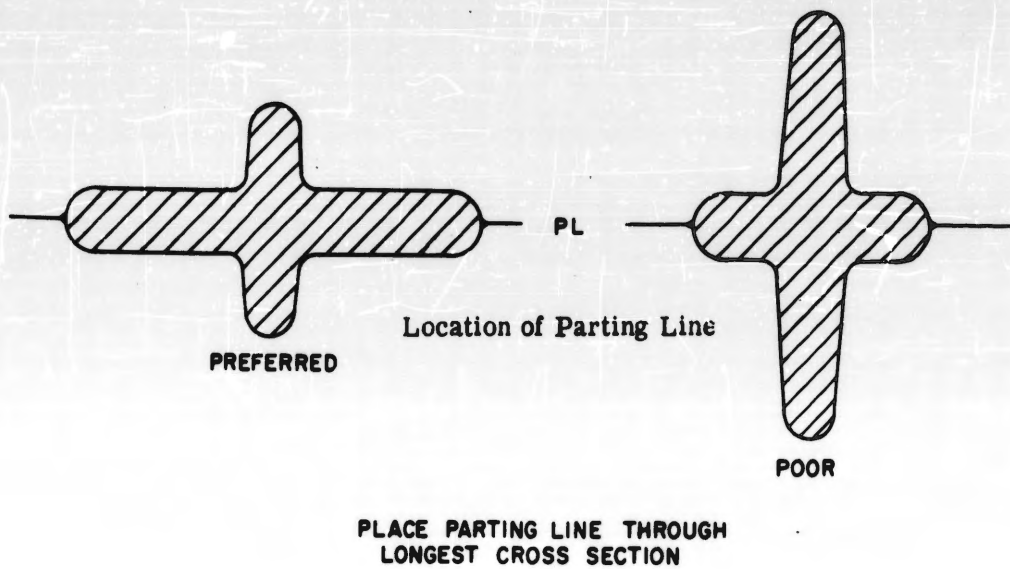


Depth of Draft (D) (inches)	Draft Angle (θ)				
	1°	3°	5°	7°	10°
1/32	.0005	.0015	.0027	.0038	.0066
1/16	.0011	.0033	.0055	.0077	.0110
3/32	.0016	.0048	.008	.0115	.0165
1/8	.0022	.0066	.011	.015	.0230
3/16	.0033	.010	.016	.023	.0331
1/4	.0044	.0132	.022	.031	.0441
5/16	.0055	.0165	.027	.038	.0551
3/8	.0065	.0195	.033	.046	.0661
7/16	.0076	.0228	.038	.054	.0771
1/2	.0087	.0261	.044	.061	.0882
5/8	.011	.033	.055	.077	.1102
3/4	.013	.039	.066	.092	.1322
7/8	.015	.045	.077	.107	.1543
1	.017	.051	.087	.123	.1763
2	.034	.102	.174	.246	.3526
3	.051	.153	.261	.369	.5289
4	.068	.204	.348	.492	.7052
5	.085	.255	.435	.615	.8815
6	.102	.306	.522	.738	1.0578
7	.120	.357	.609	.861	1.2341



USING NATURAL DRAFT TO OBTAIN FLAT SIDES

Figure 1.4 Die Parting Lines and Natural Draft Angles



PL LOCATION SIMPLIFIES DIE MANUFACTURE AND ELIMINATES MISMATCH. FOR USE WITH ALUMINUM ONLY; FOR STEEL FORGINGS, PL SHOULD BE WITHIN METAL TO FACILITATE FLASH TRIMMING

Figure 1.5 Special Applications of Parting Line Location

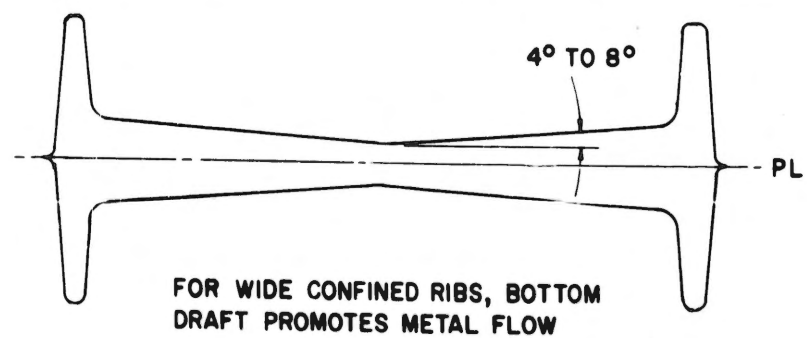


Figure 1.6 Application of Bottom Draft Angle

### Corner and Fillet Radii

Corner and fillet radii are also of prime importance in forging. Basically, dimensions are determined from height-depth ratios; in general, radii should be as large as possible. Figures 1.7 through 1.10 show some typical minimum values of corner and fillet radii.

HEIGHT INCHES FROM TO		FORGING TYPES			
		PRECISION $R_1$	CLOSE TOL. $R_1$	CONVENTIONAL $R_1$	BLOCKER $R_1$
0	$\frac{1}{2}$	.03	.06	$\frac{1}{16}$	$\frac{1}{8}$
$\frac{1}{2}$	1	.04	.08	$\frac{3}{32}$	$\frac{3}{16}$
1	$1\frac{1}{2}$	.05	.10	$\frac{1}{8}$	$\frac{1}{4}$
$1\frac{1}{2}$	2	.06	.12	$\frac{3}{16}$	$\frac{3}{8}$
2	$2\frac{1}{2}$	.07	.14	$\frac{1}{4}$	$\frac{1}{2}$
$2\frac{1}{2}$	3	.08	.16	$\frac{5}{16}$	$\frac{5}{8}$
3	$3\frac{1}{2}$	.09	.18	$\frac{3}{8}$	$\frac{3}{4}$
$3\frac{1}{2}$	4	.10	.20	$\frac{7}{16}$	$\frac{7}{8}$
4	$4\frac{1}{2}$	.11	.22	$\frac{1}{2}$	1
$4\frac{1}{2}$	5	.12	.24	$\frac{9}{16}$	$1\frac{1}{8}$
5	$5\frac{1}{2}$	.13	.26	$\frac{5}{8}$	$1\frac{1}{4}$
$5\frac{1}{2}$	6	.14	.28	$\frac{11}{16}$	$1\frac{3}{8}$

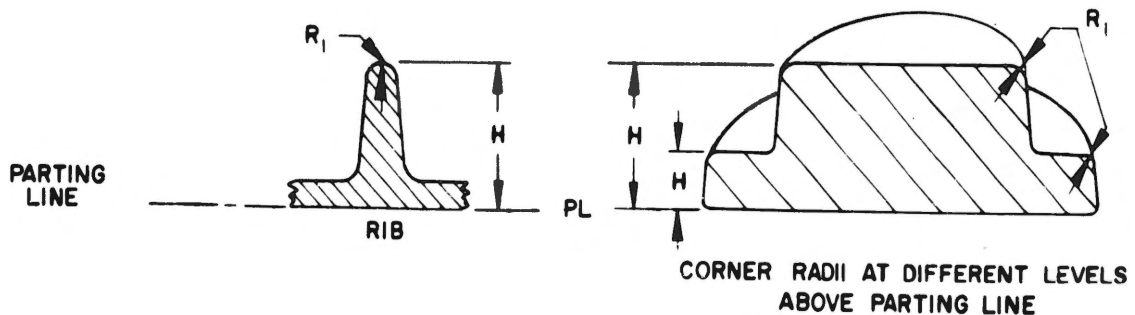


Figure 1.7 Minimum Forged Rib and Corner Radii

HEIGHT INCHES FROM TO	FORGING TYPES			
	PRECISION	CLOSE TOL.	CONVENTIONAL	BLOCKER
	$R_2$	$R_2$	$R_2$	$R_2$
0 $\frac{1}{2}$	.09	.18	$\frac{3}{16}$	$\frac{3}{8}$
$\frac{1}{2}$ 1	.12	.24	$\frac{1}{4}$	$\frac{1}{2}$
1 $1\frac{1}{2}$	.15	.30	$\frac{3}{8}$	$\frac{3}{4}$
$1\frac{1}{2}$ 2	.18	.36	$\frac{1}{2}$	1
2 $2\frac{1}{2}$	.21	.42	$\frac{5}{8}$	$1\frac{1}{4}$
$2\frac{1}{2}$ 3	.24	.48	$\frac{3}{4}$	$1\frac{1}{2}$
3 $3\frac{1}{2}$	.27	.54	$\frac{7}{8}$	$1\frac{3}{4}$
$3\frac{1}{2}$ 4	.30	.60	1	2
4 $4\frac{1}{2}$	.33	.66	$1\frac{1}{8}$	$2\frac{1}{4}$
$4\frac{1}{2}$ 5	.36	.72	$1\frac{1}{4}$	$2\frac{1}{2}$
5 $5\frac{1}{2}$	.39	.78	$1\frac{5}{16}$	$2\frac{3}{4}$
$5\frac{1}{2}$ 6	.42	.84	$1\frac{7}{16}$	3

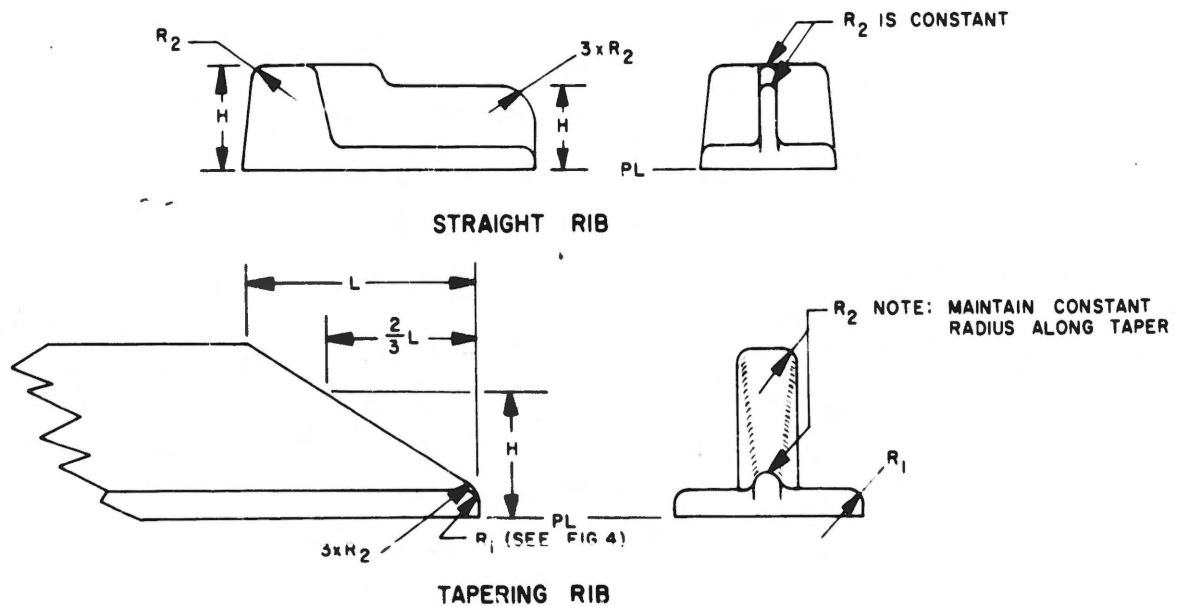


Figure 1.8 Minimum Forged Rib End Radii

HEIGHT INCHES FROM TO		FORGING TYPES			
		PRECISION $R_4$	CLOSE TOL. $R_4$	CONVENTIONAL $R_4$	BLOCKER $R_4$
0	$\frac{1}{2}$	.06	.06	$\frac{1}{8}$	$\frac{3}{16}$
$\frac{1}{2}$	1	.06	.10	$\frac{7}{32}$	$\frac{1}{4}$
1	$1\frac{1}{2}$	.08	.15	$\frac{3}{16}$	$\frac{3}{8}$
$1\frac{1}{2}$	2	.10	.20	$\frac{13}{32}$	$\frac{1}{2}$
2	$2\frac{1}{2}$	.12	.25	$\frac{1}{2}$	$\frac{5}{8}$
$2\frac{1}{2}$	3	.15	.30	$\frac{19}{32}$	$\frac{3}{4}$
3	$3\frac{1}{2}$	.18	.35	$\frac{11}{16}$	$\frac{7}{8}$
$3\frac{1}{2}$	4	.20	.40	$\frac{3}{4}$	1
4	$4\frac{1}{2}$	.23	.45	$\frac{7}{8}$	$1\frac{1}{8}$
$4\frac{1}{2}$	5	.25	.50	$\frac{15}{16}$	$1\frac{1}{4}$
5	$5\frac{1}{2}$	.28	.55	1	$1\frac{3}{8}$
$5\frac{1}{2}$	6	.30	.60	$1\frac{1}{8}$	$1\frac{1}{2}$

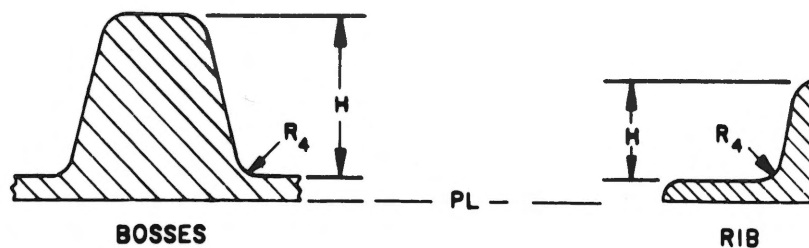
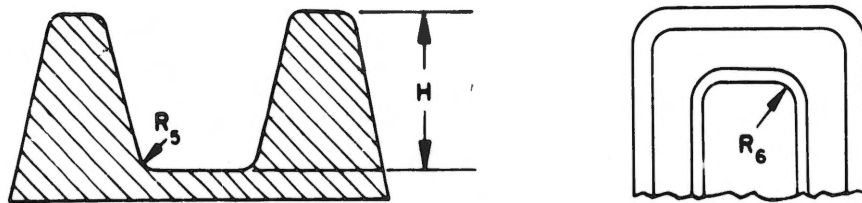


Figure 1.9 Minimum Forged Fillet Radii (unconfined)

HEIGHT INCHES FROM TO		FORGING TYPES			
		PRECISION $R_5$	CLOSE TOL. $R_5$	CONVENTIONAL $R_5$	BLOCKER $R_5$
0	$\frac{1}{2}$	.06	.100	$\frac{1}{8}$	$\frac{1}{4}$
$\frac{1}{2}$	1	.06	.200	$\frac{1}{4}$	$\frac{3}{8}$
1	$1\frac{1}{2}$	.08	.300	$\frac{3}{8}$	$\frac{1}{2}$
$1\frac{1}{2}$	2	.10	.400	$\frac{1}{2}$	$\frac{3}{4}$
2	$2\frac{1}{2}$	.120	.500	$\frac{5}{8}$	1
$2\frac{1}{2}$	3	.150	.600	$\frac{3}{4}$	$1\frac{1}{4}$
3	$3\frac{1}{2}$	.180	.700	$\frac{7}{8}$	$1\frac{1}{2}$
$3\frac{1}{2}$	4	.200	.800	1	$1\frac{3}{4}$
4	$4\frac{1}{2}$	.230	.900	$1\frac{1}{8}$	2
$4\frac{1}{2}$	5	.250	1.00	$1\frac{1}{4}$	$2\frac{1}{4}$
5	$5\frac{1}{2}$	.280	1.10	$1\frac{3}{8}$	$2\frac{1}{2}$
$5\frac{1}{2}$	6	.300	1.20	$1\frac{1}{2}$	$2\frac{3}{4}$



NOTE:  $R_6$  (VERTICAL FILLET) MUST  
BE EQUAL TO OR LARGER  
THAN  $R_5$

Figure 1.10 Minimum Forged Fillet Radii (confined)

## Webs and Ribs

When webs and ribs are used in the design of a piece, consideration must be given to the fact that in the forging operation, the thinner the cross section, the more quickly the section cools. This rapid cooling of the metal often makes forging difficult since it requires severe hammering, thus causing a shortened die life. Also this severe hammering can cause rupture at the web or rib base.

Often a tapered web, as shown in Figure 1.5, will facilitate forging. Another alternative in design may be a punched out opening in the web or rib. This enables a thicker section to be forged. Figure 1.11 shows some minimum web thicknesses which can be readily forged. Figure 1.12 shows some minimum web and rib thicknesses which can be attained on confined forgings and Figure 1.13 shows minimum forgeable rib thickness for open forgings.

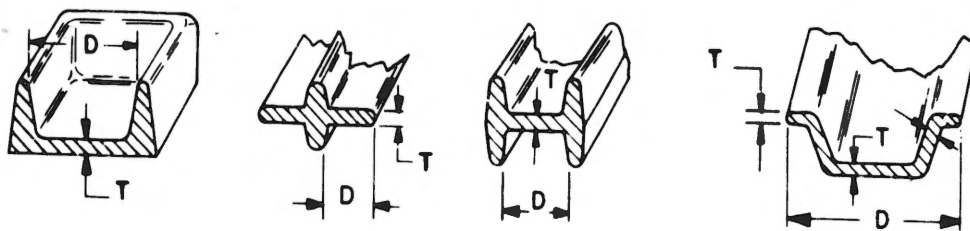
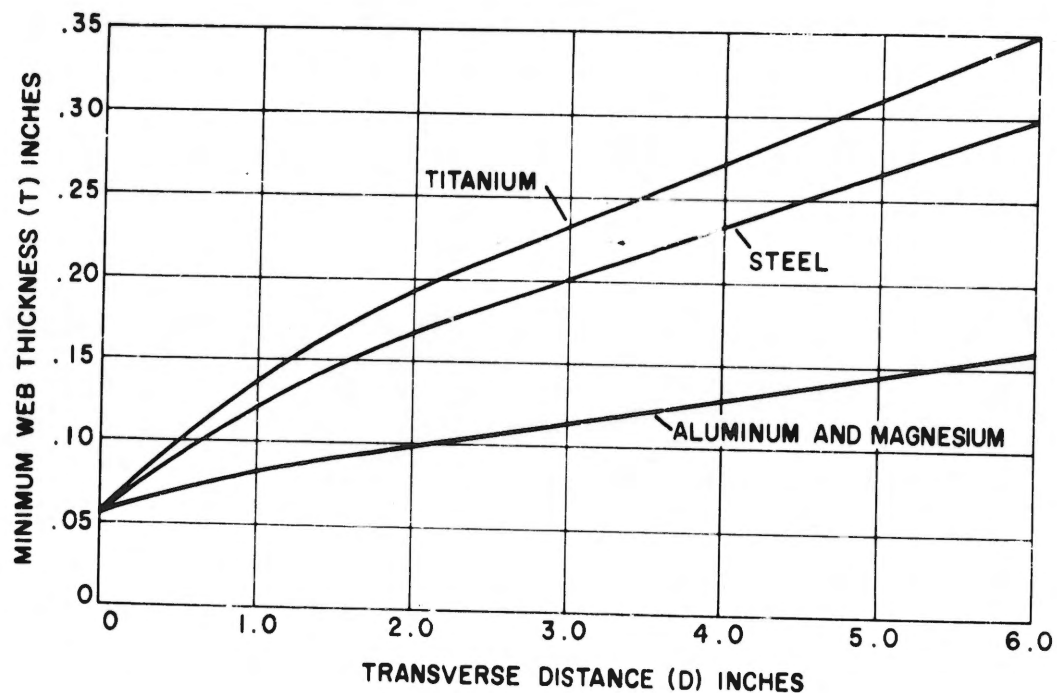


Figure 1.11 Minimum Forgeable Web Thickness

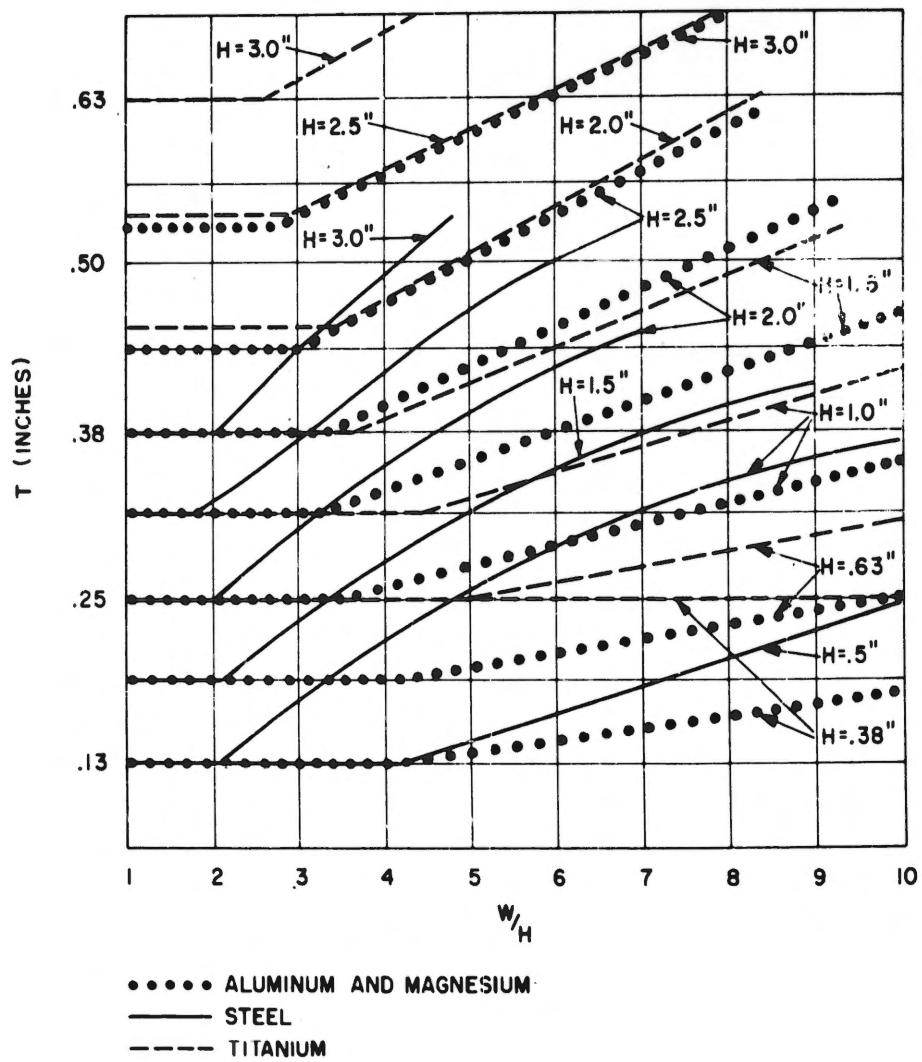
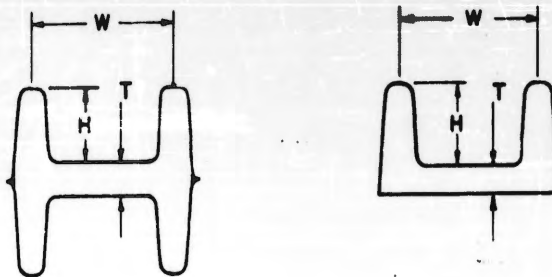


Figure 1.12 Typical Forgeable Web and Rib Thickness (confined)

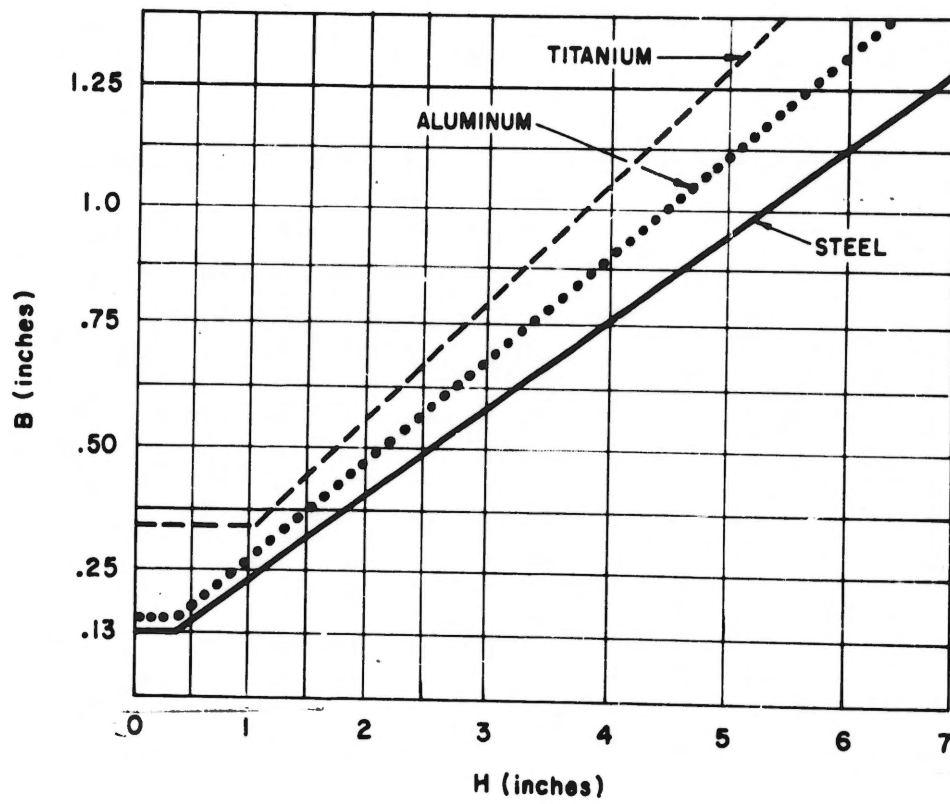
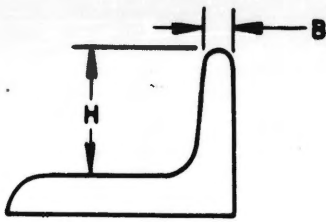
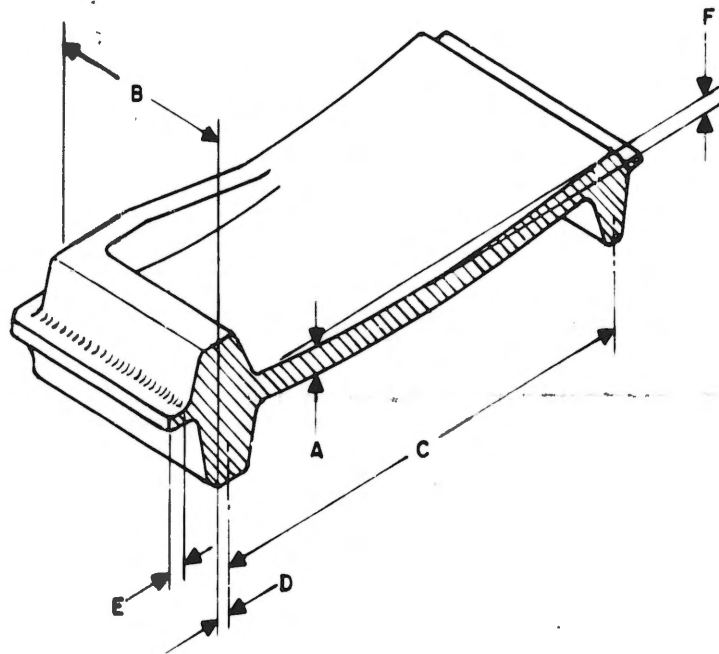


Figure 1.13 Minimum Forgeable Fillet Thickness (unconfined)

## Tolerances

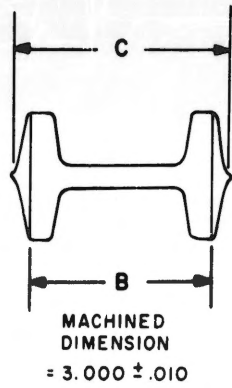
Tolerances are another of the vitally important factors to be considered when designing for forging. Since tolerance limits are determined basically by the future purpose and uses of the part, no specific limits can be given for specific designs. Rather, limitations of forging processes are presented in order that the designer may, upon investigation, determine for himself which would conform to the design limits he requires. With this information, it is anticipated that the designer may adjust his plan to be within forging limitations, or to determine where finish machining is required to complete the manufacturing process of the part.

Tables 1.4 through 1.7 give some general forging tolerances for various materials. Figure 1.14 indexes these tables and illustrates the tolerances to which the tables refer. Figure 1.15 is an example of the use of the tables.



- A - THICKNESS TOLERANCES---(NORMAL TO PARTING LINE)---SEE TABLE 1.4
- B - WIDTH TOLERANCES------(PARALLEL TO PARTING LINE)--SEE TABLE 1.5
- C - LENGTH TOLERANCES------(PARALLEL TO PARTING LINE)--SEE TABLE 1.5
- D - MISMATCH TOLERANCES-----SEE TABLE 1.4
- E - FLASH EXTENSION-----SEE TABLE 1.6
- F - STRAIGHTNESS TOLERANCES-----SEE TABLE 1.7

Figure 1.14 Index to Forging Tolerance Tables



STEEL — APPROX. WGT. = 4 LBS.

TO DETERMINE EXTERNAL FORGING DIMENSION C:

MAXIMUM MACHINED DIMENSION, B	3.010
NEGATIVE EXTERNAL FORGING TOLERANCE	.015
MACHINING ALLOWANCE, 2 FACES	.120
MISMATCH TOLERANCE	.015
	<hr/>
	3.160

WIDTH OR LENGTH TOLERANCE  $\begin{matrix} +.030 \\ -.015 \end{matrix}$

THUS:

DIMENSION C IS  $3.160 \begin{matrix} +.030 \\ -.015 \end{matrix}$

Figure 1.15 Example of Use of Forging Tolerance Tables

STEEL			
APPROXIMATE FORGING WEIGHT (LBS.)	THICKNESS TOLERANCE	MISMATCH	MACHINING ALLOWANCE (PER SURFACE)
0 TO 5	+ .030 - .015	.015	.060
5 TO 15	+ .033 - .015	.015	.090
15 TO 25	+ .033 - .015	.020	.090
25 TO 40	+ .043 - .015	.020	.090
40 TO 55	+ .048 - .020	.020	.090
55 TO 80	+ .055 - .020	.030	.120
80 TO 105	+ .065 - .020	.030	.120
105 TO 132	+ .072 - .032	.045	.120
132 TO 160	+ .080 - .032	.045	.150
160 TO 190	+ .087 - .040	.060	.150
190 TO 240	+ .095 - .040	.060	.150
240 TO 290	+ .105 - .055	.080	.180
290 TO 345	+ .120 - .055	.080	.180
345 TO 400	+ .135 - .075	.105	.180
OVER 400	+ .150 - .075	.120	.210

ALUMINUM AND MAGNESIUM				
APPROXIMATE FORGING WEIGHT		THICKNESS TOLERANCE	MISMATCH TOL.	MACHINING ALLOWANCE (PER SURFACE)
ALUMINUM	MAGNESIUM			
0-1	0-1	+ .030 - .015	.015	.090
1-4	1-3	+ .045 - .030	.020	.090
4-17	3-11	+ .060 - .030	.025	.090
17-24	11-16	+ .075 - .030	.030	.120
24-50	16-33	+ .090 - .030	.035	.120
50-100	33-67	+ .125 - .045	.055	.150
100-250	67-170	+ .185 - .060	.090	.150
250 AND UP	170 AND UP	+ .250 - .060	.125	.190

TITANIUM		
APPROXIMATE FORGING WEIGHT (LBS.)	MISMATCH TOLERANCE	MACHINING ALLOWANCE (PER SURFACE)
0 TO 1	.015	FOR SMALL FORGINGS (<6 LBS. WITH MAX DIMENSION OF 12 IN.) ALLOWANCE IS .12 IN.
1 TO 8	.018	
8 TO 24	.025	
24 TO 44	.032	
44 TO 64	.040	
64 TO 89	.048	FOR LARGE FORGINGS MINIMUM ALLOWANCE IS .06 IN.
89 TO 119	.062	
119 TO 150	.093	

Table 1.4 Thickness, Mismatch, and Machining Tolerances for Forgings

STEEL		
WIDTH AND LENGTH TOLERANCES		
DIMENSION (INCHES)	TOLERANCE WIDTH OR LENGTH	
	EXT	INT
0 TO 5	+ .030 - .015	+ .015 - .030
5 TO 10	+ .045 - .015	+ .015 - .045
10 TO 15	+ .060 - .030	+ .030 - .060
15 TO 20	+ .075 - .030	+ .030 - .075
20 TO 25	+ .090 - .045	+ .045 - .090
25 TO 30	+ .105 - .045	+ .045 - .105
30 TO 35	+ .120 - .060	+ .060 - .120
35 TO 40	+ .135 - .060	+ .060 - .135
40 TO 45	+ .150 - .075	+ .075 - .150
45 TO 50	+ .165 - .075	+ .075 - .165
50 TO 55	+ .180 - .090	+ .090 - .180
55 TO 60	+ .195 - .090	+ .090 - .195
60 TO 65	+ .210 - .105	+ .105 - .210
65 TO 70	+ .225 - .105	+ .105 - .225
70 TO 75	+ .240 - .120	+ .120 - .240
75 TO 80	+ .255 - .120	+ .120 - .255

ALUMINUM AND MAGNESIUM		
WIDTH AND LENGTH TOLERANCES		
DIMENSION	WIDTH OR LENGTH	
	EXT	INT
0 TO 8	+ .030 - .015	+ .015 - .030
8 TO 12	+ .045 - .020	+ .020 - .045
12 TO 16	+ .060 - .025	+ .025 - .060
16 TO 20	+ .075 - .030	+ .030 - .075
20 TO 24	+ .090 - .040	+ .040 - .090
24 TO 28	+ .105 - .050	+ .050 - .105
28 TO 32	+ .120 - .060	+ .060 - .120
32 TO 36	+ .135 - .070	+ .070 - .135
36 TO 40	+ .150 - .080	+ .080 - .150
ADD PER INCH	+ .004 - .002	+ .002 - .004

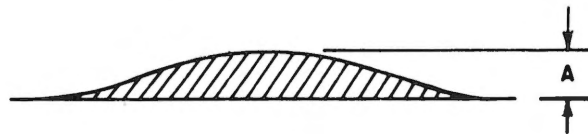
TITANIUM	
WIDTH AND LENGTH TOLERANCES	
DIMENSION (INCHES)	TOLERANCE WIDTH OR LENGTH
0 TO 6	± .032
6 TO 8	± .040
8 TO 10	± .050
10 TO 18	± .062
18 TO 24	± .078
24 TO 30	± .093
30 TO 60	± .109

Table 1.5 Width and Length Tolerances for Forgings

APPROXIMATE FORGING WEIGHT (LBS)				MAXIMUM EXTENSION (INCHES)
TITANIUM	STEEL	ALUMINUM	MAGNESIUM	
0 TO 1.5	0 TO 5	0 TO 1	0 TO 1/2	.030
1.5 TO 28	5 TO 100	1 TO 12	1/2 TO 8	.060
28 TO 39	100 TO 200	12 TO 24	8 TO 16	.090
39 TO 163	OVER 200	OVER 24	OVER 16	.120



Table 1.6 Maximum Flash Extension for Forgings



TITANIUM		STEEL, ALUMINUM, AND MAGNESIUM	
SURFACE LENGTH (INCHES)	TOLERANCE A (INCHES)	SURFACE LENGTH (INCHES)	TOLERANCE A (INCHES)
0 - 9	.016	0 - 6	.010
9 - 18	.032	6 - 12	.020
18 - 30	.048	12 - 18	.030
30 - 45	.062	18 - 24	.040
45 - 60	.094	24 - 30	.050
60 - 80	.125	FOR EACH ADDITIONAL 6 INCHES ADD	.010

Table 1.7 Straightness Tolerances for Forgings

## Design Considerations For Upsetting

General design considerations are as follows:

body diameter -	1-inch maximum.
length of part -	1 to 10 body diameters for solid dies; 1 to any length for open dies.
volume of upset metal -	4 body diameters.
diameter of upset -	4 body diameters.
thickness of upset -	1/4 body diameter.
Tolerances (plus and minus):	
diameter of upset -	1/32 inch.
thickness of upset -	0.005 inch.
length of shank -	1/64 inch.
diameter of shank -	0.0015 inch for solid die; 0.003 inch for open die.
materials -	almost any metal capable of cold working with a hardness range of Rockwell B75 to B85.

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## CHAPTER 2

### EXTRUSION

#### PROCESS

Extrusion is a plastic forming process usually done hot, but in some instances cold. It differs basically from forging in that the extruded shape has a constant cross-section or the same type of cross-section with a tapered effect along its length. Because of its severe metal working characteristics, extrusion provides fiber-oriented and fine-grained wrought products.

An extruded product may be placed in one of these general classes, according to the finish required. These classes are divided into those parts which can be finished by cutting to length, those parts which are finished by simple machining or forming operations, and those parts, which, when cut to proper lengths, form the stock for further machining, forging, and other forming processes. The illustrations in Figure 2.1 show some typical applications of the extrusion process in lieu of other types of forming methods.

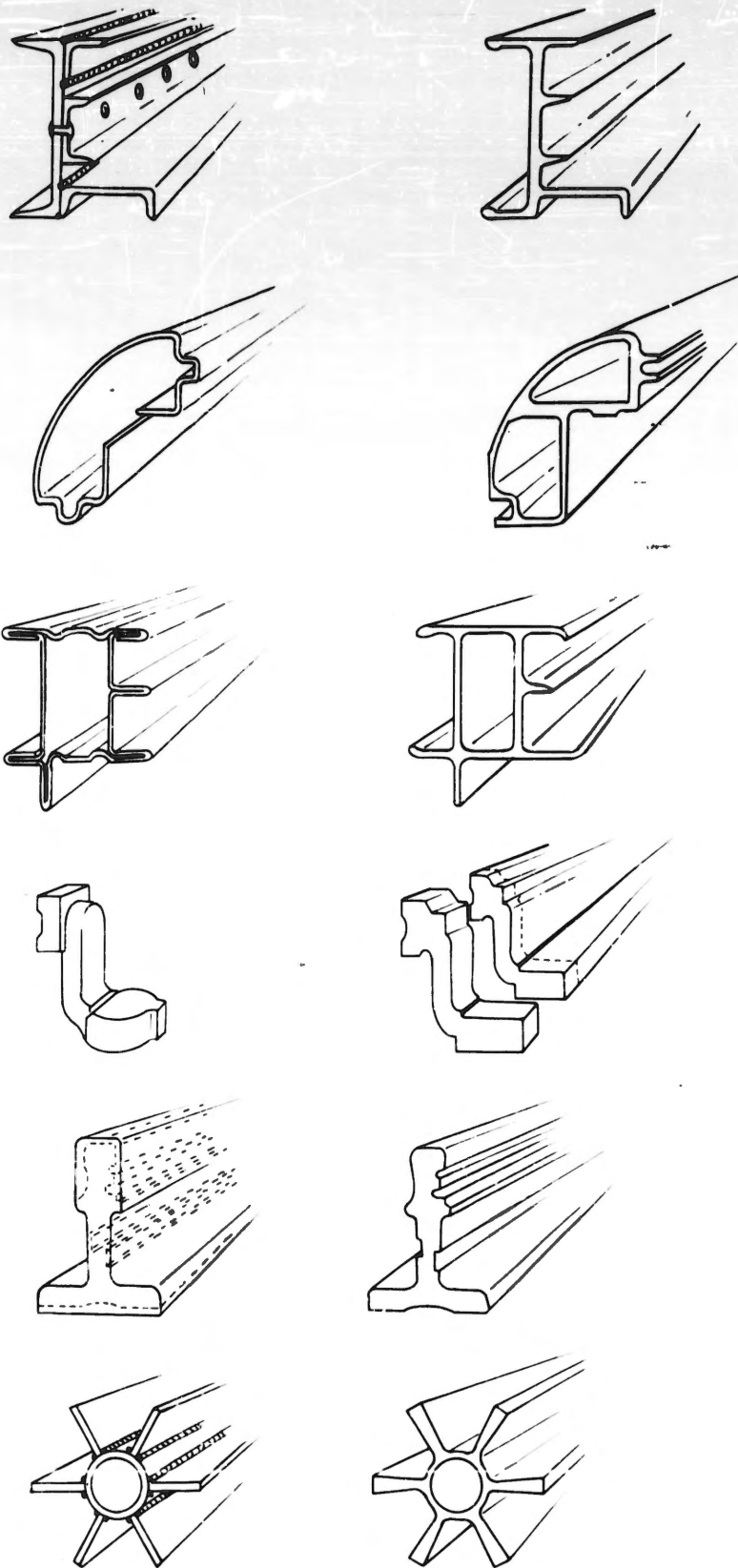
Extrusion equipment is in one of two categories of machinery; impact or press. Within either of these categories, extrusions can be made by the direct method, whereby the material is extruded in the same direction as the pressure ram is applied, or by the inverse method, whereby the extrusion travels backwards along the outside or inside of the pressure ram. A limitation of the latter method is that the length of the ram available restricts the extrusion of very long pieces. The illustrations in Figures 2.2, 2.3, 2.4, and 2.5, on the following page, show the various extrusion methods, and some capability comparisons.

Extrusion variations include the use of a fixed or movable mandrel placed in the center of a die opening so that a tubular product (tapered if the mandrel is tapered and movable) is formed between the die and mandrel; the use of a fixed, multi-mandrel-type die is called a port hole die and is used typically for wing products which have more than one longitudinal chamber; the use of multi-sized dies inserted at intervals during the extrusion produces a stepped product.

#### ADVANTAGES AND LIMITATIONS

Particular advantages to the extrusion process include the following:

- (1) the exact placement of metal where it is needed, thereby utilizing the quantity of metal to maximum advantage, and providing **maximum** structural and mechanical properties.
- (2) extensive plastic working usually at elevated temperatures which produces a dense and homogeneous product, free from porosity, and having favorable grain flow characteristics.
- (3) easy production of sharp corners.
- (4) easy production of **reentrant** angles.
- (5) elimination of burrs and rough edges.
- (6) incorporation of controlled twist in parts.
- (7) efficient production of large diameter, thin-walled tubular products having excellent concentricity and tolerance characteristics.
- (8) application of changing section thicknesses.
- (9) consolidation into a single extrusion of several individually fabricated pieces.
- (10) lowering of machinery costs with attendant savings in wasted material.
- (11) relatively economic die design as compared for forging and some drawing methods, thus allowing good application to short production runs and to design revisions.



OTHER METHOD

EXTRUSION

Figure 2.1 Typical Applications of Extrusion

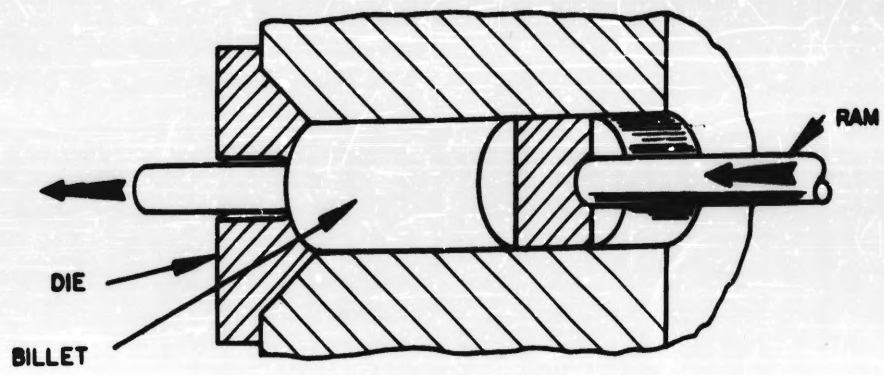


Figure 2.2 Direct Extrusion Method

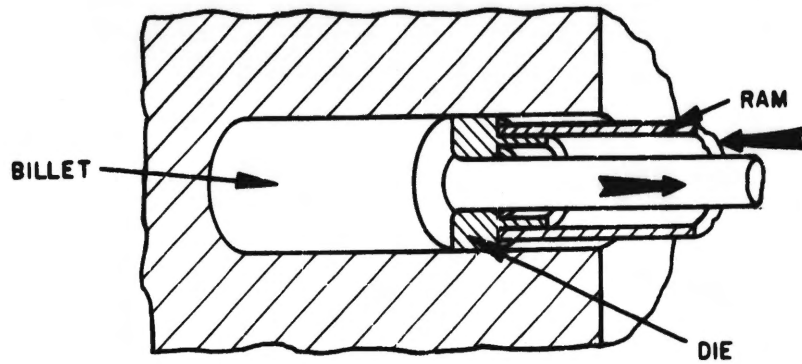


Figure 2.3 Inverse Extrusion Method

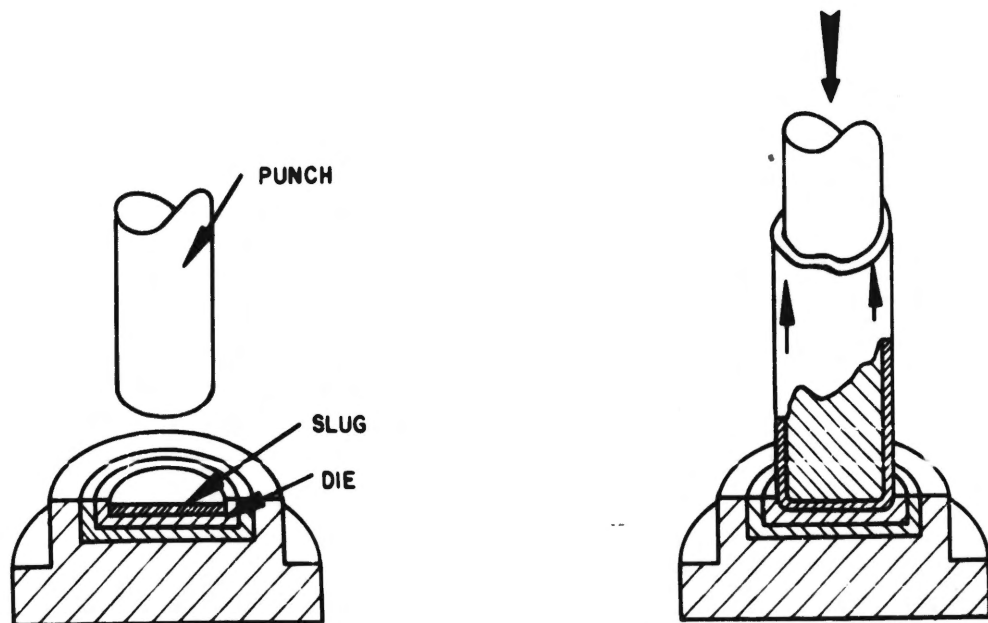


Figure 2.4 Impact Extrusion Method

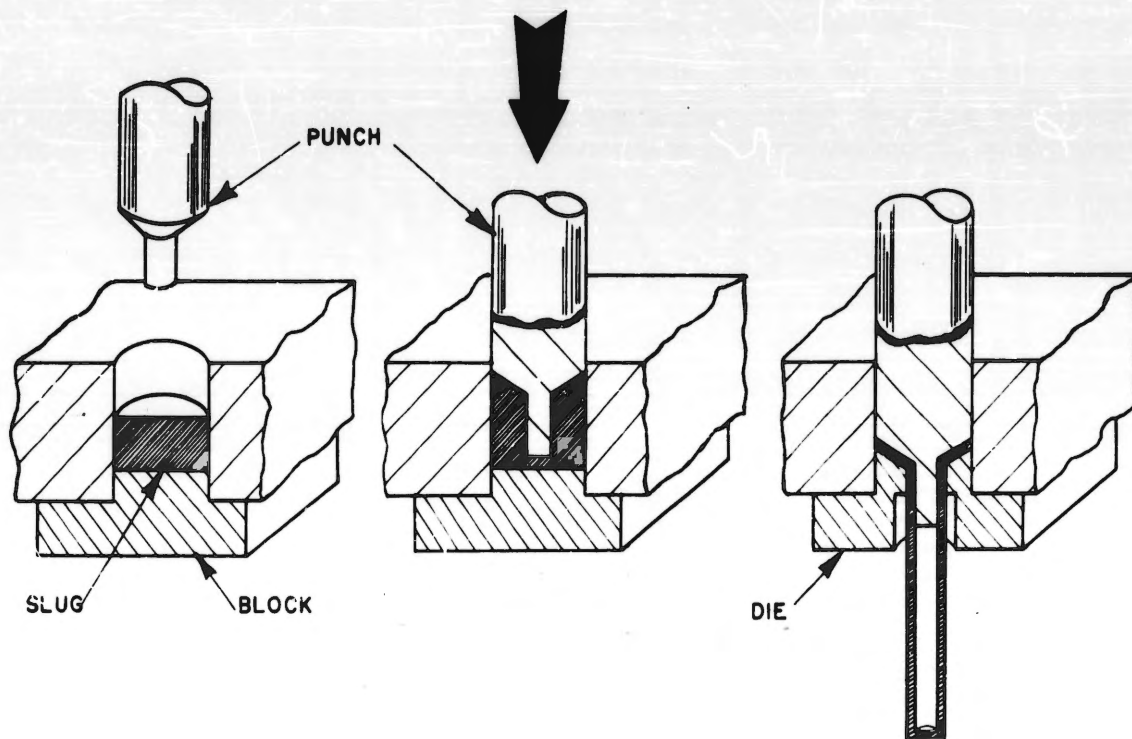


Figure 2.5 Hooker Extrusion Method

Particular limitations to the extrusion process include the following:

- (1) dimensional tolerances are not as close as machining.
- (2) for certain applications, the size of shape is limited according to die and press capacities.
- (3) warpage and distortion require subsequent correction operations.
- (4) certain sizes and shapes have limited applications in steels and titanium.
- (5) production speed is slower than processes such as rolling.

Materials available for extrusion processes include many of the carbon and alloy steels, titanium, aluminum, magnesium, and copper and its alloys.

### DESIGN CONSIDERATIONS

#### General

While it may appear that the greater the capacity of a press, the larger and more intricate the cross section of the extruded shapes it can produce, this is only partially true. For the extrusion of standard and generally uniform sections, such as angles, channels, and tubes, it is true that a larger press is capable of producing larger sections, as well as a greater number of the sections simultaneously.

The extrusion ratio (ratio of the cross-sectional areas of the billet to the extruded shape) determines the pressure required for the extrusion of a particular shape. Most common extrusion ratios are in the range between 15/1 and 50/1. However, for certain intricate and

especially thin sections, extrusions with ratios up to 100/1 have been used. Extrusion ratios below 15/1 are seldom used because insufficient hot working is provided to impart satisfactory mechanical properties to the extrusion.

Low extrusion ratios are sometimes used for purposes of intermediate extrusion whereupon billets are pre-extruded to a given diameter prior to final extrusion. Such an extrusion can be accomplished in several successive stages and is applicable to mandrel-type extrusion. Progressive extrusion is helpful in cases where prolonged working of the metal during a single cycle may result in cooling of the billet and work hardening it to the extent of developing metal defects. Therefore, following each successive extrusion cycle, the partially extruded billet is stress-relieved and then reheated to extrusion temperature for the next cycle.

Progressive extrusion cannot be accomplished where porthole dies are used since, in a porthole die, the metal flow is separated into several streams through the holes in the die and the mandrel cannot be extracted until after completion of the operation.

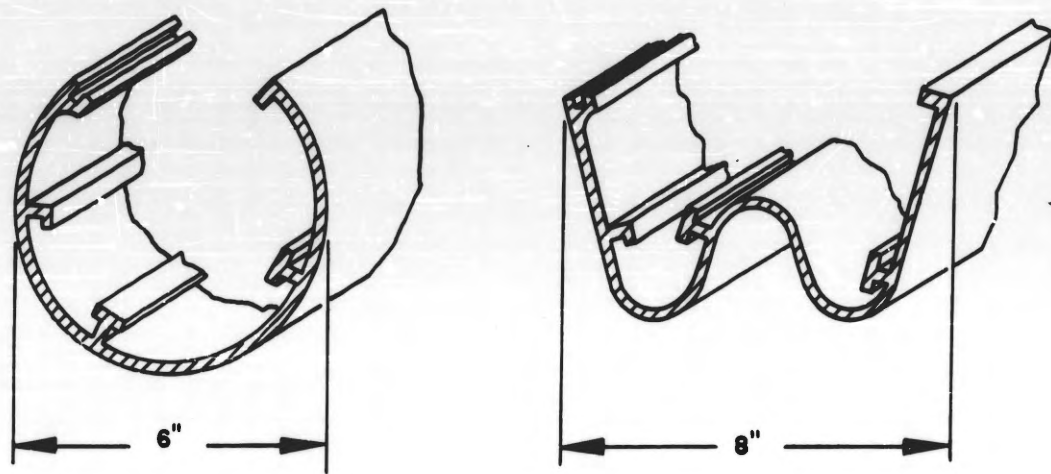
### Size

In general, the size of extrusions is limited by available press capacities. These capacities have been considerably increased in the last few years through the addition of new presses built in connection with the USAF Heavy Press Program. The overall size of an extruded section is determined by the diameter of the smallest circle completely enveloping the shape; this is known as the circumscribing circle. This diameter controls the size of the die which in turn is limited by the size of the extrusion presses. Before designing an extruded shape, an investigation should be made to determine that the existing press capacity will be satisfactory.

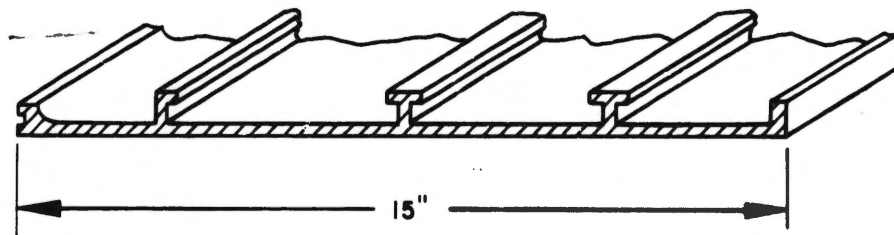
Until several years ago, sections generally considered commercial were governed by a maximum circumscribing circle of approximately 12 inches in diameter. A limited number of 5500-ton presses increased the diameter to 17 inches; the new presses previously mentioned have further increased it to 27 inches. Table 2.1 shows some of the manufacturing limits in extrusion.

Table 2.1 Typical Manufacturing Limits

Press Capacity (tons)	Weight (lbs.)	Container I.D. (inches)	Length (inches)	Max. Circle (inches)	Approximate PSI on Dummy Block	
1600	190/325	6	22 - 36	4-7/8	100,000	
2400						5-3/4
2500				4-7/8	157,000	
				6-1/2	93,000	
				7-1/4	74,000	
2750				7	5-3/4	126,000
				8	6-1/2	
3850				8	6-1/2	86,000
				9	7-1/4	
				11	9-1/4	
4250				9	7-1/4	52,000
				11	9-1/4	
				14	12	
				16	14	
5500	11	9-1/4	41,000			
	14	12				
	16	14				
				17		



SHAPE AS EXTRUDED



FINAL SHAPE

Figure 2.6 Typical Methods of Extruding Wide Shapes

Although the size of extrusion is limited by press capacities, it does not always follow that large pieces cannot be made by extrusion. There are several methods of circumventing the size limitations. For example, a circular shape can be extruded and straightened, as shown in Figure 2.6. This illustration shows a method of making aircraft skin with integral stiffeners. Cylinders of 60 inch diameters have been built up from wide extruded segments.

It is possible, therefore, to change the configuration of certain large sections so that they may be enclosed in the largest circumscribing circle available, and later straightened to a cross-section larger than can be expected from the maximum size circle. Typical sections have been extruded as long ribbed cylinders, with an inside diameter of 8.858 inches and a circumscribing circular diameter of 11.86 inches. Slit lengthwise, the cylinder is laid out by a series of straightening and stretching processes to become a flat aluminum skin nearly 28 inches in width, weighing 5.784 pounds per square foot, and having 14 T-shaped integral stiffeners running longitudinally at equally spaced intervals. Various aluminum skin thicknesses, such as 0.04 inch and 0.07 inch, have been used in 2042, 6061, and 7075 alloys.

Similar integrally stiffened skins have been made in widths up to 60 inches in larger presses using higher pressures.

### Thickness

A problem often posed by extrusion designers concerns the minimum thickness to be achieved in extruding a section of given overall dimension. Thickness limitations are based on the size of the cross-section since, when the diameter of the circumscribing circle is large it becomes increasingly difficult to force the metal through thin sections in the die, especially if the shape has adjacent thick and thin sections. Figure 2.7 shows a typical relation of extrusion equipment size needed for forming various thicknesses.

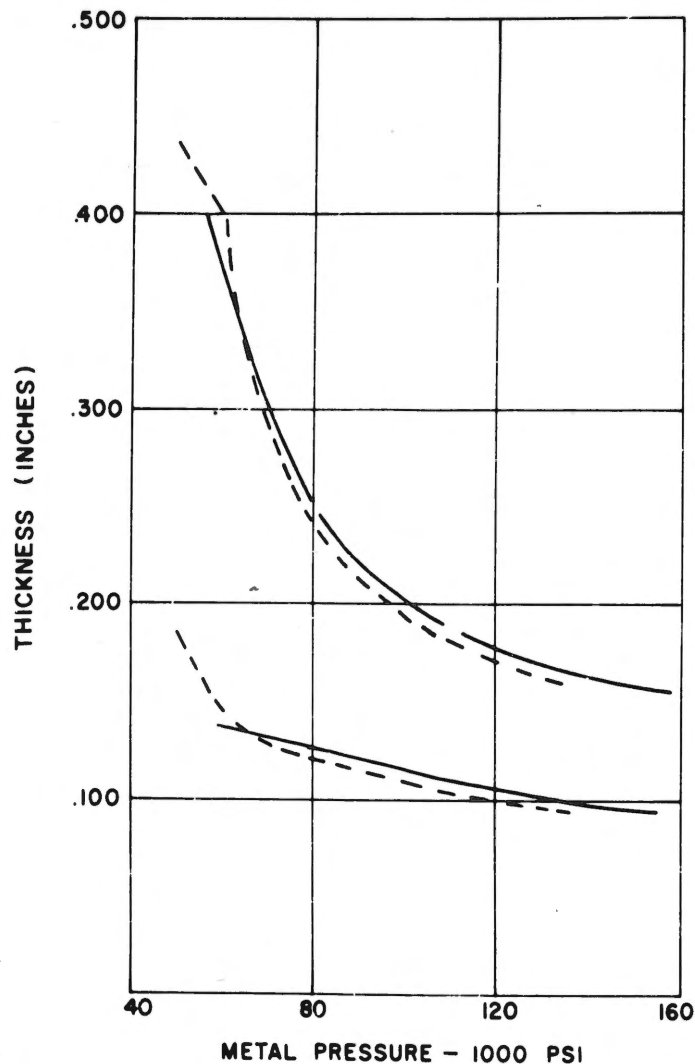


Figure 2.7 Equipment Size Required for Various Extruded Thicknesses

As a general rule, a thicker wall is required with the increase in the size of the section. This is true because friction of the metal against die surfaces on large cross sections having thin walls may exceed pressures that dies and presses can exert. This occurs because the pressure required to force metal through a narrow die cavity is greater than that required for a wider cavity. From the standpoint of straightening, the wall should also be strong enough to assure that the extrusion will maintain its contour during its manufacture and use.

Thickness limitations also depend on other important factors, such as flow or yield strength of the particular alloy extruded. This, in turn, is determined by the alloy composition. Among other important factors is the extrusion ratio.

Thickness of extrusions range generally from 0.050 inch to several inches, but thinner sections have also been extruded. In general, it is easier to extrude thin sections on solid parts than on hollow parts.

A common ratio of thickness to width governs aluminum and magnesium extrusions, but the ratio varies with the alloy. Aluminum alloys, such as 3003 and 6063, have a ratio of 8-inch width to 3/32-inch thickness; 2014, for example, has a ratio of 8-inch width to 1/8-inch thickness.

Figure 2.8 shows the interrelationship of width to thickness for two hard alloys, 7075 and 2024. The important factor limiting the minimum extrusion thickness is the magnitude of the unit pressure on the extrusion billet.

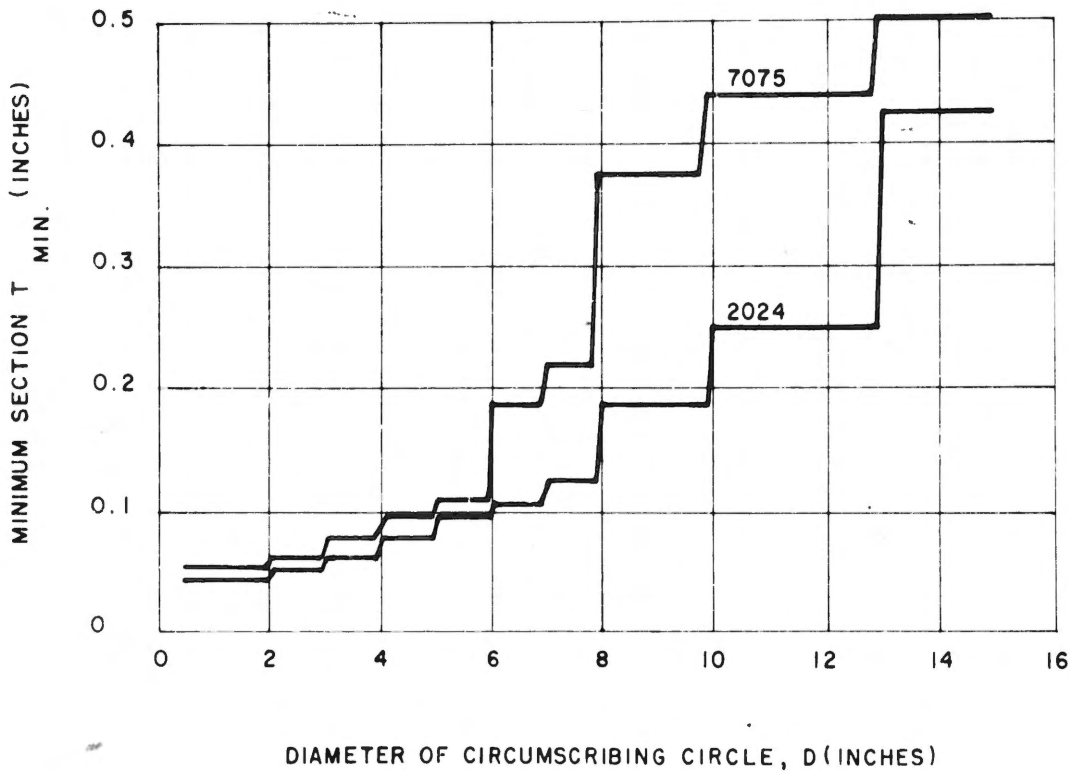


Figure 2.8 Typical Extruded Width to Thickness Relations

### Weight

Weight of an aluminum extrusion is also governed by the limits of the extrusion ratio. Generally, this ratio should not be smaller than 15 to 1 nor greater than 50 to 1 in order to obtain proper magnitude of reduction to produce minimum physical requirements.

Within these limitations, the weight per foot of aluminum extrusions usually ranges from an ounce or less to about 20 pounds; this corresponds to a **cross sectional** area of over 15 square inches.

Length

Table 2.2 shows typical approximate maximum extruded finish lengths for hard alloys in increments of cross sectional area or weight per foot and section factor.

Table 2.2 Typical Maximum Extrudable Finish Lengths

Hard Alloys (Excluding 2014)

Area In. <sup>2</sup>	Wt./Ft. Lbs.	SECTION FACTOR *											
		2 and Less	3 and Up	3 and Less	4 and Up	5 and Less	6 and Up	9 and Less	10 and Up	15 and Less	16 and Up	Holes per Die	
.10	.12										40	22	10
.12	.15										40	19	8
.15	.18										40	22	6
.20	.24										40	20	5
.25	.30										40	19	4
.30	.36										40	23	3
.35	.42										39	19	3
.40	.48										34	15	3
.45	.54										40	22	2
.50	.60										40	19	2
.55	.66										37	17	2
.60	.72										31	15	2
.65	.78										30	13	2
.70	.84										27	11	2
.75	.90										25	10	2
.80	.96										23	9	2
.85	1.02										21	8	2
.90	1.06										40	22	1
1.00	1.20										40	19	1
1.25	1.50										32	14	1
1.50	1.80					40	34						1
1.75	2.10					40	28						1
2.00	2.40							40	36				1
2.25	2.70							40	31				1
2.50	3.00							40	27				1
2.75	3.30			40	40								1
3.00	3.60			40	40								1
3.50	4.20			40	37								1
4.00	4.80			40	31								1
4.50	5.40	40	40										1
5.00	6.00	40	40										1
5.50	6.60	40	38										1
6.00	7.20	40	35										1
6.50	7.80	40	31										1
7.00	8.40	40	28										1
8.00	9.60	38	24										1
9.00	10.80	32	20										1
10.00	12.00	28	17										1
11.00	13.20	25	15										1
12.00	14.40	22	13										1
14.00	16.80	18	10										1
16.00	19.20	15	8										1

\* Ratio of total perimeter to weight per foot.

Table 2.2 Maximum Extrudable Finish Lengths (contd)

2014 Alloy

Area In. <sup>2</sup>	Wt. Ft. Lbs.	3 and Less	4 and Up	6 and Less	7 and Up	11 and Less	12 and Up	See Note	Holes per Die
.10	.12							38	10
.12	.15							38	8
.15	.18							40	6
.20	.24							38	5
.25	.30							38	4
.30	.36							40	3
.35	.42							36	3
.40	.48							29	3
.45	.54							40	2
.50	.60							38	2
.55	.66							34	2
.60	.72							30	2
.65	.78							27	2
.70	.84							25	2
.75	.90							23	2
.80	.96							21	2
.85	1.02							19	2
.90	1.08							40	1
1.00	1.50							29	1
1.50	1.80					40	39		1
1.75	2.10					40	32		1
2.00	2.40					40	27		1
2.25	2.70					38	23		1
2.50	3.00					33	20		1
2.75	3.30					29	17		1
3.00	3.60					26	15		1
3.50	4.20					21	12		1
4.00	4.80			40	28				1
4.50	5.40			40	24				1
5.00	6.00			35	21				1
5.50	6.60			31	18				1
6.00	7.20			28	16				1
6.50	7.80			25	14				1
7.00	8.40			23	13				1
8.00	9.60	40	24						1
9.00	10.8	35	21						1
10.0	12.0	31	18						1
11.0	13.2	27	15						1
12.0	14.4	24	13						1
14.0	16.8	20	10						1
16.0	19.2	16	8						1

NOTE: Lengths shown in this column are not designated by section factor but must comply with manufacturing limits regarding minimum thickness and circle size.

As shown in the table, the maximum length for all hard alloys and all tempers, except the "O" temper, is 40 feet. This limitation is caused primarily by the poor surface quality which develops in longer lengths, and by the facilities limitations in heat treating. The maximum length available, at present, in any shape of the "O" temper is 30 feet due to the

annealing facilities limitations. Presently there can be no exceptions to this maximum length. Other limitations on larger sections are caused by maximum billet size, maximum pressures, and other similar physical characteristics of the extrusion press.

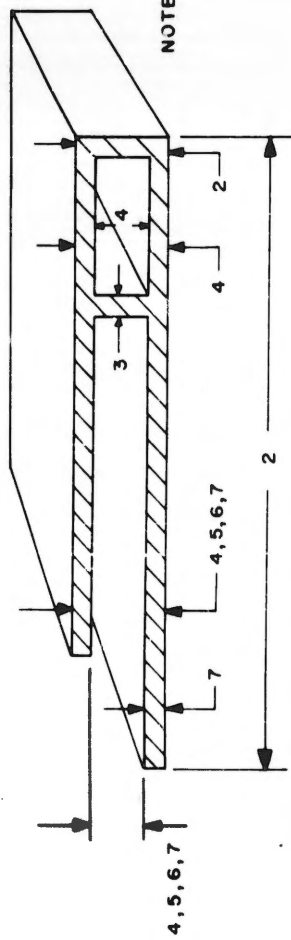
It will appear in many cases that the difference in lengths at the section factor breaking point is a finely drawn line set up on an arbitrary basis. This is not the case, however, as these breaking points are based on definite physical characteristics of the extrusion press and its operating limitations.

### Tolerances

Some general tolerance indications for extruded aluminum shapes are shown in Table 2.3 and some specific tolerances are shown in Figures 2.9, 2.10, 2.11, and Table 2.4.

Table 2.3 General Shape Tolerances

Type of Tolerance	Dimensions to Which Tolerance Applies	Tolerance (plus and minus)
Straightness	Circumscribing circle dia.: up through 1.499 inch . . . . . up through 1.499 inch . . . . .  1.5 inch and up. . . . .	0.05 inch per foot for min. thickness up through 0.094 inch 0.0125 inch per foot for min. thickness 0.095 and up 0.0125 inch per foot
Twist	Circumscribing circle dia.: up through 1.499 inch . . . . . 1.50-2.99 inch . . . . . 3.0 inch and up . . . . .	1° per foot 1/2° per foot; 5° total 1/4° per foot; 3° total
Contour	Deviation from specified. . . . .	0.005 inch per inch of chord width (0.005 inch min.)
Corner and Fillet Radii	Sharp corners . . . . . Radius up through 0.197 inch . . Specified radius 0.188 inch and up	1/64 inch 1/32 inch 10 per cent
Angles	Min. leg thickness: Under 0.188 inch . . . . . 0.188 to 0.750 inch . . . . . 0.750 inch to solid . . . . .	2° 1 1/2° 1°
Flatness		0.004 inch per inch of width (0.004 inch min.)
Surface Roughness	Section thickness: up through 0.063 inch . . . . . 0.064-0.125 inch . . . . . 0.126-0.188 inch . . . . . 0.189-0.250 inch . . . . . 0.251 inch and up. . . . .	Max. depth of defect: 0.0015 inch 0.002 inch 0.0025 inch 0.003 inch 0.004 inch



SPECIFIED DIMENSION, INCHES	METAL DIMENSIONS			SPACE DIMENSIONS			
	ALLOWABLE DEVIATION FROM SPECIFIED DIMENSION WHERE 75 PER CENT OR MORE OF THE DIMENSION IS METAL	WALL THICKNESS COMPLETELY ENCLOSED SPACE 0.11 SQ. IN. AND OVER (ECCENTRICITY)	AT DIMENSIONED POINTS EXCEPTING THOSE COVERED BY COLUMN 3	AT DIMENSIONED POINTS 0.250-0.624 INCH FROM BASE OF LEG	AT DIMENSIONED POINTS 0.625-1.249 INCHES FROM BASE OF LEG	AT DIMENSIONED POINTS 1.250-2.499 INCHES FROM BASE OF LEG	AT DIMENSIONED POINTS 2.500 INCHES OR MORE FROM BASE OF LEG
COL. 1	COL. 2	COL. 3	COL. 4	COL. 5	COL. 6	COL. 7	
UNDER 0.125	± .006		± .010	± .012	± .014	± .014	± .016
0.125-0.249	± .007		± .012	± .014	± .016	± .016	± .020
0.250-0.499	± .008		± .014	± .016	± .018	± .018	± .022
0.500-0.749	± .009		± .016	± .018	± .020	± .020	± .026
0.750-0.999	± .010	PLUS	± .018	± .020	± .022	± .022	± .030
1.000-1.499	± .012	PLUS AND MINUS 10%	± .020	± .022	± .026	± .026	± .034
1.500-1.999	± .016		± .024	± .028	± .034	± .034	± .050
2.000-3.999	± .024		± .032	± .036	± .048	± .048	± .064
4.000-5.999	± .034	MAX. ± .060 MIN. ± .010	± .042	± .050	± .064	± .064	± .088
6.000-7.999	± .044		± .054	± .062	± .082	± .082	± .112
8.000-9.999	± .054		± .064	± .074	± .100	± .100	± .136
10.000-11.999	± .064		± .074	± .088	± .116	± .116	± .160
12.000-13.999	± .074		± .084	± .100	± .134	± .134	± .184
14.000-15.000	± .080		± .090	± .106	± .142	± .142	± .196

Table 2.4 Detail Extrusion Tolerances

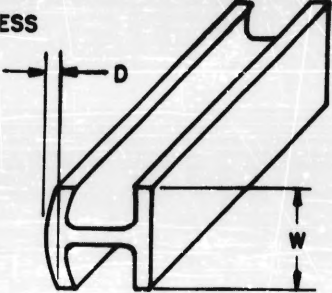
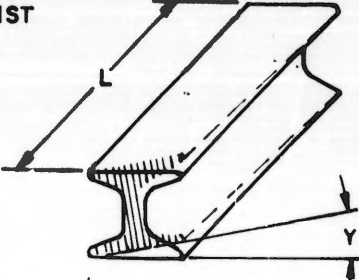
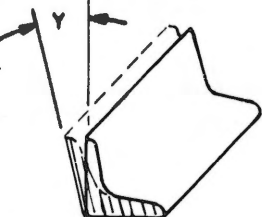
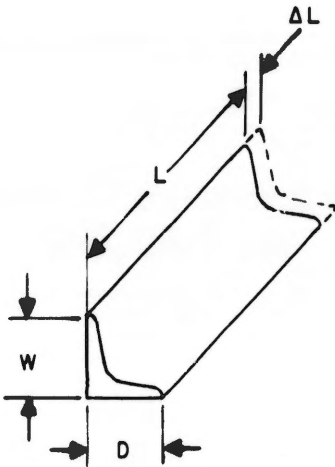
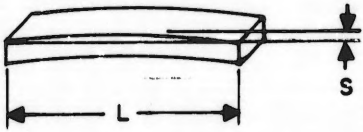
CHARACTERISTIC	TOLERANCE	
<b>FLATNESS</b> 	$D(\text{MAX}) = .004 \times W$	
<b>TWIST</b>  	<b>WIDTH OR LENGTH</b> <b>(WHICHEVER IS LARGER)</b>	<b>Y (PER FOOT L)</b> <b>MAX</b>
	UNDER 1.5 INCHES	1°
	1.5 TO 2.99	1/2°
	3.0 AND OVER	1/4°
<b>ANGULARITY</b>	<b>LEG, WEB OR FLANGE</b> <b>(WHICHEVER IS SMALLER)</b>	Y <sub>MAX</sub>
<b>DIMENSIONS</b>	UNDER 0.188 INCHES	2°
	.188 TO .749	1-1/2°
	.750 AND OVER	1°
<b>ANGLES</b>	T: ± 2-1/2%, ± .010 IN. MIN	
	B: ± 2-1/2%, ± 1/16 IN. MIN	
<b>ZEE'S</b>	T: ± 2-1/2%, ± .010 IN. MIN	
	B: ± 2-1/2%, ± 1/16 IN. MIN	
	D: ± 2-1/2%, ± 1/16 IN. MIN	
<b>CHANNELS</b>	T: ± 2-1/2%, ± .010 IN. MIN	
	B: ± 4%	
	D: + 3/32 - 1/16 IN. MIN	
<b>I-BEAMS</b>	T: ± 2-1/2% ± .010 IN. MIN	
	B: ± 4%	
	D: + 3/32 - 1/16 IN. MIN	

Figure 2.9 Typical Tolerances for Extruded Structural Shapes



LENGTH	S
TO 5 FT.	.125 IN.
OVER 5 FT.	.025 x L (FT.) IN.

WIDTH OR DEPTH (LARGEST ONE) INCHES	$\Delta L$ (IN.)			
	L UP TO 12 FT	L 12 TO 30 FT	L 30 TO 50 FT	L OVER 50 FT
UNDER 3.0	1/8	1/4	3/8	1
3.0 TO 7.9	3/16	5/16	7/16	1
8.0 AND OVER	1/4	3/8	1/2	1

CUT END SQUARENESS

1°

WEIGHT

± 2-1/2% FOR SIZES 3 INCHES AND LARGER,  
(FOR SIZES SMALLER THAN 3 INCHES ONLY  
CROSS SECTION AND LENGTH TOLERANCES  
APPLY).

Figure 2.9 (cont'd)

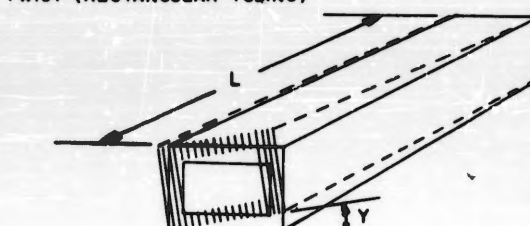
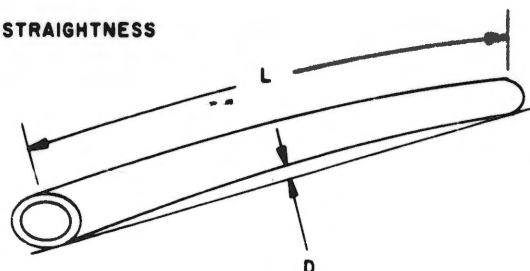
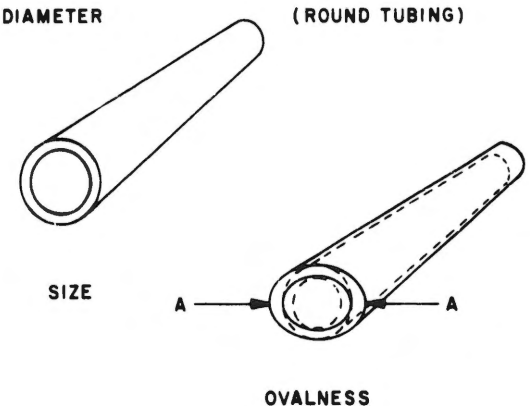
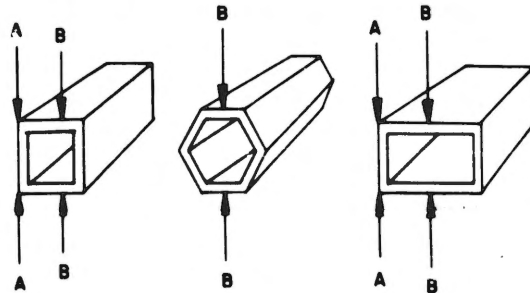
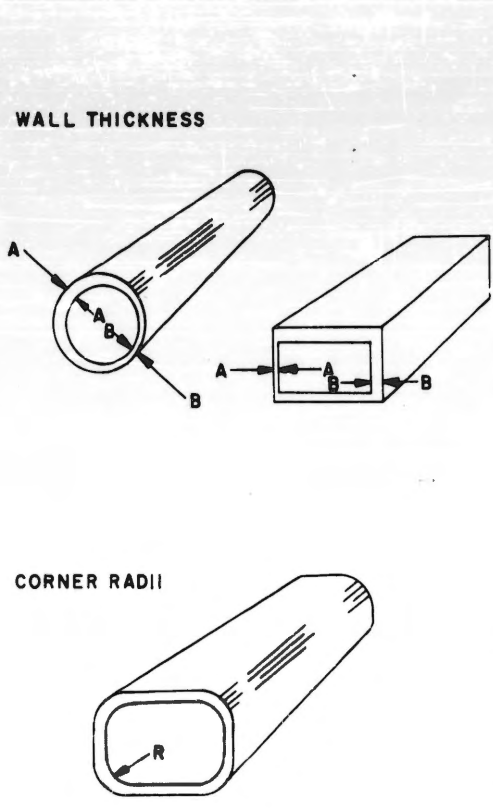
CHARACTERISTIC		TOLERANCE		
<b>TWIST (RECTANGULAR TUBING)</b> 	WIDTH OR DEPTH WHICHEVER IS GREATER	Y		
	UNDER 1.5 IN.	$1^\circ \times L$ (FT)		
	1.5-2.9 IN.	$\frac{1^\circ}{2} \times L$ (FT); $5^\circ$ MAX		
	3.0 IN. AND OVER	$\frac{1^\circ}{4} \times L$ (FT); $3^\circ$ MAX		
<b>STRAIGHTNESS</b> 	WIDTH, DEPTH OR DIAMETER, WHICHEVER IS GREATER	D (INCHES)		
	0.5-5.9 IN.	.010 X L (FT)		
	6.0 IN. AND OVER	.020 X L (FT)		
<b>DIAMETER (ROUND TUBING)</b> 	DIAMETER (INCHES)	SIZE TOLERANCE (INCHES)	OVALNESS DIFFERENCE BETWEEN A A AND DIAMETER (INCHES)	
	0.5 - 0.9	$\pm .010$	$\pm .020$	
	1.0 - 1.9	$\pm .012$	$\pm .025$	
	2.0 - 3.9	$\pm .015$	$\pm .030$	
	4.0 - 5.9	$\pm .025$	$\pm .050$	
	6.0 - 7.9	$\pm .035$	$\pm .075$	
	8.0 - 9.9	$\pm .045$	$\pm .100$	
	10.0 - 11.9	$\pm .055$	$\pm .125$	
12.0 - 12.875	$\pm .065$	$\pm .150$		
<b>WIDTH AND DEPTH (RECTANGULAR TUBING)</b> 	WIDTH OR DEPTH (INCHES)	DEVIATION ON CORNERS - A A (INCHES) SQUARES, RECT.	DEVIATION ON FACE - B B (INCHES) SQUARES, HEX, OCT., RECT.	
	.50- .749	$\pm .012$	$\pm .020$	
	.75- .99	$\pm .014$	$\pm .020$	
	1.00- 1.9	$\pm .018$	$\pm .025$	
	2.0 - 3.9	$\pm .025$	$\pm .035$	
4.0 - 4.9	$\pm .035$	$\pm .045$		

Figure 2.10 Typical Tolerances for Extruded Tubular Shapes



WALL THICKNESS (INCHES)	DEVIATION FROM MEAN WALL THICKNESS *					
	ROUND OD (INCHES)				NON-ROUND CIRCUM, CIRCLE	
	UNDER 1.250	1.250 TO 2.99	3.00 TO 4.99	5.00 AND OVER	UNDER 5.00	5.00 AND OVER
UNDER .047	± .006	—	—	—	± .005	± .005
.047-.061	± .007	± .008	± .008	± .010	± .006	± .009
.062-.077	± .008	± .008	± .009	± .012	± .007	± .010
.078-.124	± .009	± .009	± .010	± .015	± .007	± .010
.125-.249	± .009	± .009	± .013	± .020	± .008	± .015
.250-.374	± .011	± .011	± .016	± .025	± .011	± .020
.375-.499	—	± .015	± .021	± .035	± .014	± .030
.500-.749	—	± .020	± .028	± .045	± .025	± .040
.750-.999	—	—	± .035	± .055	± .035	± .050
1.00 -1.49	—	—	± .045	± .065	± .045	± .060
1.50 -2.00	—	—	—	± .075	—	± .070

\* MEAN WALL THICKNESS IS AVERAGE OF TWO OPPOSITE FACE MEASUREMENTS.

RADIUS	A
SHARP	± 1/64 IN.
UNDER .188 IN.	± 1/64 IN.
.188 IN. AND OVER	± 10%

LENGTH	OD., WIDTH OR DEPTH WHICHEVER IS GREATER (INCHES)	TOLERANCE (INCHES)							
		LENGTH (FEET)							
		STRAIGHT				COILED			
		UNDER 12	12 TO 30	30 TO 50	OVER 50	100 AND LESS	101 TO 250	251 TO 500	501 AND OVER
UNDER 0.50	—	—	—	—	+5%-0	± 10%	± 15%	± 20%	
0.50 - 1.249	± 1/8	± 1/4	± 3/8	± 1	+5%-0	± 10%	± 15%	± 20%	
1.250- 2.99	± 1/8	± 1/4	± 3/8	± 1	—	—	—	—	
3.0 - 7.9	± 3/16	± 5/16	± 7/16	± 1	—	—	—	—	
8.0 AND OVER	± 1/4	± 3/8	± 1/2	± 1	—	—	—	—	

Figure 2.10 (cont'd)

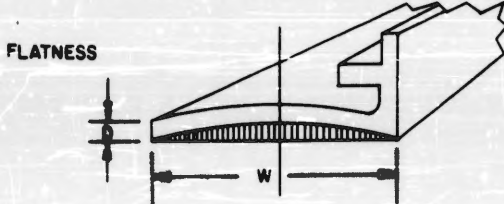
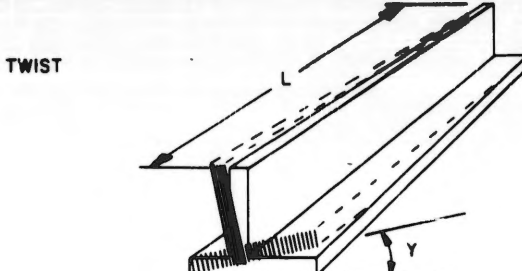
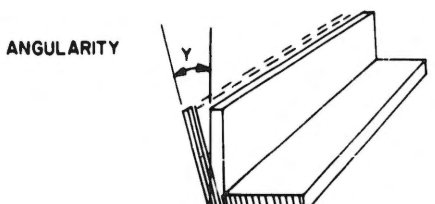
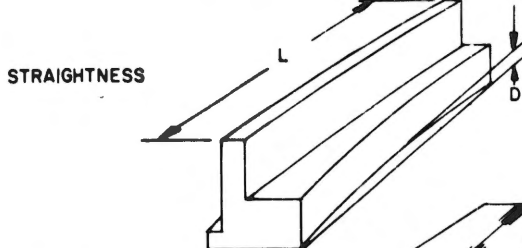
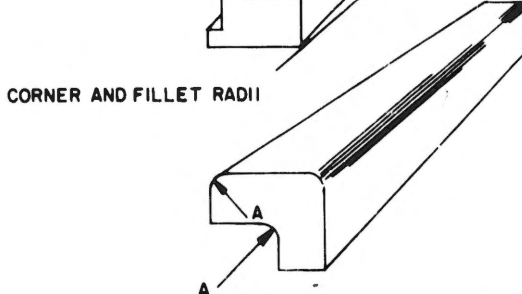
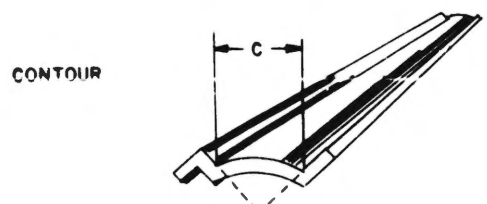
CHARACTERISTIC	TOLERANCE													
<p><b>FLATNESS</b></p> 	$D(\text{MAX}) = .004 \times W \text{ IN.}$													
<p><b>TWIST</b></p> 	<p>CIRCUMSCRIBING CIRCLE DIAMETER (SHAPES), WIDTH OR DEPTH (ROD AND BAR) WHICHEVER IS LARGER</p> <table border="1"> <tr> <td></td> <td>Y</td> </tr> <tr> <td>UNDER 1.5 IN.</td> <td><math>1^\circ \times L \text{ (FT)}</math></td> </tr> <tr> <td>1.5 - 2.9 IN.</td> <td><math>\frac{1^\circ}{2} \times L \text{ (FT)}; 5^\circ \text{ MAX}</math></td> </tr> <tr> <td>3.0 IN. AND OVER</td> <td><math>\frac{1^\circ}{4} \times L \text{ (FT)}; 3^\circ \text{ MAX}</math></td> </tr> </table>			Y	UNDER 1.5 IN.	$1^\circ \times L \text{ (FT)}$	1.5 - 2.9 IN.	$\frac{1^\circ}{2} \times L \text{ (FT)}; 5^\circ \text{ MAX}$	3.0 IN. AND OVER	$\frac{1^\circ}{4} \times L \text{ (FT)}; 3^\circ \text{ MAX}$				
	Y													
UNDER 1.5 IN.	$1^\circ \times L \text{ (FT)}$													
1.5 - 2.9 IN.	$\frac{1^\circ}{2} \times L \text{ (FT)}; 5^\circ \text{ MAX}$													
3.0 IN. AND OVER	$\frac{1^\circ}{4} \times L \text{ (FT)}; 3^\circ \text{ MAX}$													
<p><b>ANGULARITY</b></p> 	<table border="1"> <tr> <td>LEG THICKNESS</td> <td>Y</td> </tr> <tr> <td>UNDER .188 IN.</td> <td><math>\pm 2^\circ</math></td> </tr> <tr> <td>.188 - .749 IN.</td> <td><math>\pm 1\frac{1}{2}^\circ</math></td> </tr> <tr> <td>.75 IN. AND OVER</td> <td><math>\pm 1^\circ</math></td> </tr> </table>		LEG THICKNESS	Y	UNDER .188 IN.	$\pm 2^\circ$	.188 - .749 IN.	$\pm 1\frac{1}{2}^\circ$	.75 IN. AND OVER	$\pm 1^\circ$				
LEG THICKNESS	Y													
UNDER .188 IN.	$\pm 2^\circ$													
.188 - .749 IN.	$\pm 1\frac{1}{2}^\circ$													
.75 IN. AND OVER	$\pm 1^\circ$													
<p><b>STRAIGHTNESS</b></p> 	<table border="1"> <tr> <th>CIRCUMSCRIBING CIRCLE DIAMETER (SHAPES); WIDTH OR DEPTH (ROD AND BAR) WHICHEVER IS LARGER</th> <th>MINIMUM THICKNESS</th> <th>D (INCHES)</th> </tr> <tr> <td>UNDER 1.5 IN.</td> <td>UNDER .095 IN.</td> <td>.050 X L (FT)</td> </tr> <tr> <td>UNDER 1.5 IN.</td> <td>.095 IN. AND OVER</td> <td>.0125 X L (FT)</td> </tr> <tr> <td>1.5 IN. AND OVER</td> <td></td> <td>.0125 X L (FT)</td> </tr> </table>		CIRCUMSCRIBING CIRCLE DIAMETER (SHAPES); WIDTH OR DEPTH (ROD AND BAR) WHICHEVER IS LARGER	MINIMUM THICKNESS	D (INCHES)	UNDER 1.5 IN.	UNDER .095 IN.	.050 X L (FT)	UNDER 1.5 IN.	.095 IN. AND OVER	.0125 X L (FT)	1.5 IN. AND OVER		.0125 X L (FT)
CIRCUMSCRIBING CIRCLE DIAMETER (SHAPES); WIDTH OR DEPTH (ROD AND BAR) WHICHEVER IS LARGER	MINIMUM THICKNESS	D (INCHES)												
UNDER 1.5 IN.	UNDER .095 IN.	.050 X L (FT)												
UNDER 1.5 IN.	.095 IN. AND OVER	.0125 X L (FT)												
1.5 IN. AND OVER		.0125 X L (FT)												
<p><b>CORNER AND FILLET RADI</b></p> 	<table border="1"> <tr> <th>SPECIFIED RADIUS A (IN.)</th> <th>DEVIATION</th> </tr> <tr> <td>SHARP CORNERS</td> <td><math>\pm \frac{1}{64} \text{ IN.}</math></td> </tr> <tr> <td>UNDER .188</td> <td><math>\pm \frac{1}{64} \text{ IN.}</math></td> </tr> <tr> <td>.188 AND OVER</td> <td><math>\pm 10\%</math></td> </tr> </table>		SPECIFIED RADIUS A (IN.)	DEVIATION	SHARP CORNERS	$\pm \frac{1}{64} \text{ IN.}$	UNDER .188	$\pm \frac{1}{64} \text{ IN.}$	.188 AND OVER	$\pm 10\%$				
SPECIFIED RADIUS A (IN.)	DEVIATION													
SHARP CORNERS	$\pm \frac{1}{64} \text{ IN.}$													
UNDER .188	$\pm \frac{1}{64} \text{ IN.}$													
.188 AND OVER	$\pm 10\%$													
<p><b>CONTOUR</b></p> 	<p>DEVIATION FROM DESIRED CONTOUR IS .005 X C IN. (APPLICABLE TO LESS THAN 90° ARC ONLY.)</p>													

Figure 2.11 Typical Tolerances for Extruded Odd Shapes

CHARACTERISTIC	TOLERANCE			
	CIRCUMSCRIBING CIRCLE DIAMETER (SHAPES), WIDTH OR DEPTH (ROD AND BAR) WHICHEVER IS LARGER	$\Delta L$ (IN.)		
LENGTH		L UP TO 12 FT.	12-30 FT.	30-50 FT.
UNDER 3.0 IN.	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	1
3.0-7.9 IN.	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{7}{16}$	1
8.0 IN. AND OVER	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	1

Figure 2.11 (cont'd)

## TYPICAL DESIGN CONSIDERATIONS

### General

Although the extrusion process is capable of producing a wide variety of configurations, certain limitations exist because of the characteristics of die design and other manufacturing factors which should be considered in designing an extruded section.

As in all design problems, the first step entails the establishment of the basic function of the section. This step includes consideration of the most important requirements, such as strength, decorative characteristics, machinability, formability, resistance to corrosion, weldability, or some other fundamental characteristic. Usually a combination of several of these characteristics is desired, with selection of one or two as more critical than the others.

Of equal importance with the choice of proper alloy is selection of proper structural design. Here, also, the flexibility allowed by the extrusion process makes it possible to design to exact values and requirements without undue concern for the restrictions imposed by other less flexible processes.

Two factors which generally govern the characteristics of extrusion design are:

- (1) configuration to accomplish the desired function.
- (2) distribution of metal for necessary mechanical properties at maximum production economy.

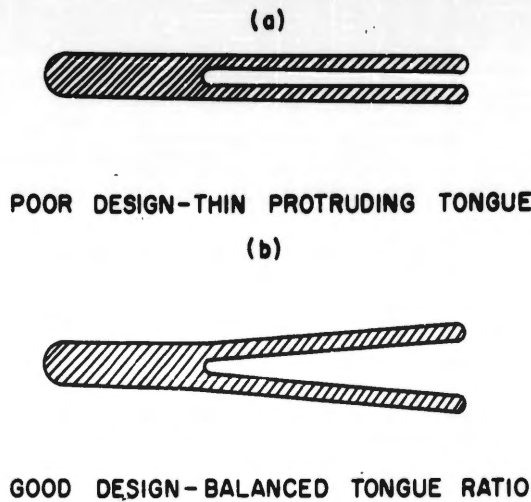
These basic variables, applied to conventional strength and design formulas, will result in the most desirable structural and economical cross sections.

Although from the manufacturing standpoint, the extrusion process imposes few restrictions, effective designing will depend to a great extent on an understanding of the shapes that can be extruded most efficiently and upon limitations imposed by die configuration as it affects metal flow.

**Typical Sections**

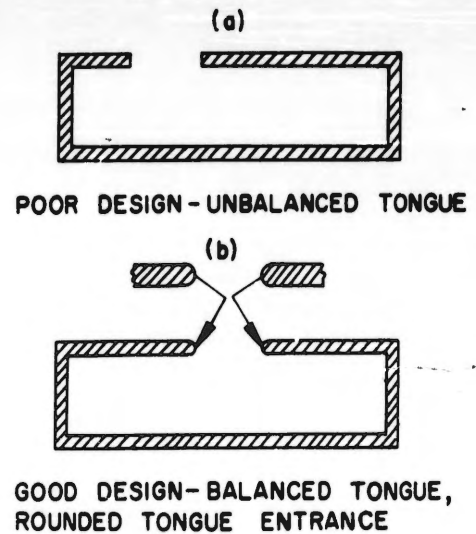
The following examples are typical methods of design modification which will yield optimum economy and maximum efficiency.

**Tongue Sections.** Severe tongue ratios create one of the most common extrusion die difficulties. This may readily be appreciated by visualizing what die tongues actually represent. They are thin protrusions that are attached at the base, and suspended into the path of the metal flow as shown in Figure 2.12. The tremendous pressure behind the flow of metal is transferred onto the tongue, causing it to bend, twist, and often break.



POOR DESIGN - THIN PROTRUDING TONGUE

GOOD DESIGN - BALANCED TONGUE RATIO



POOR DESIGN - UNBALANCED TONGUE

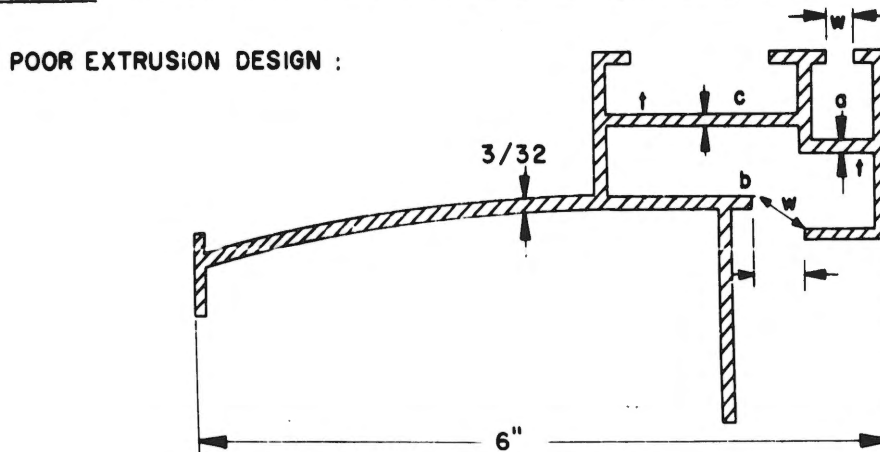
GOOD DESIGN - BALANCED TONGUE, ROUNDED TONGUE ENTRANCE

Figure 2.12 Extrusion Die Tongue Design

Figure 2.13 Extrusion Die Tongue Design

Other typical examples of the shapes requiring large overhanging die tongues are shown in Figures 2.13, 2.14, and 2.15. The twisting action of the aluminum metal flowing past the die tongues, such as the unbalanced tongue in Figure 2.13(a), may cause die breakage. Section (b) of Figure 2.13 shows preferred balanced tongue with the entrance to the tongue well-rounded. In shapes with several adjacent die tongues, such as a, b and c in Figure 2.14, an increase of section thickness "t" between the tongues is desirable. Long, narrow tongues flanked by a heavy mass of metal as shown in Figure 2.15(a) are undesirable. The preferred design, which should be approached as closely as possible, is shown in Figure 2.15(b). Tongue width is increased, tongue depth is reduced, the thin section is narrowed down, and a radius is added at the tongue gap. The dotted line indicates the open position in which the leg will be extruded, to be closed by a rolling pass after extrusion.

**Sharp Edges.** Sharp, knifelike edges as shown in Figure 16(a) should be avoided.



POOR EXTRUSION DESIGN :

Figure 2.14 Extrusion Die Tongue Design

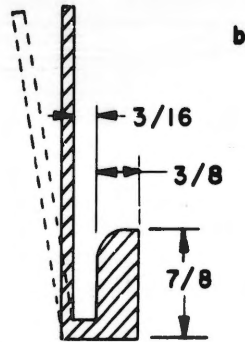
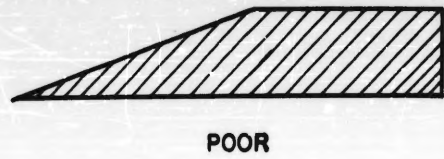
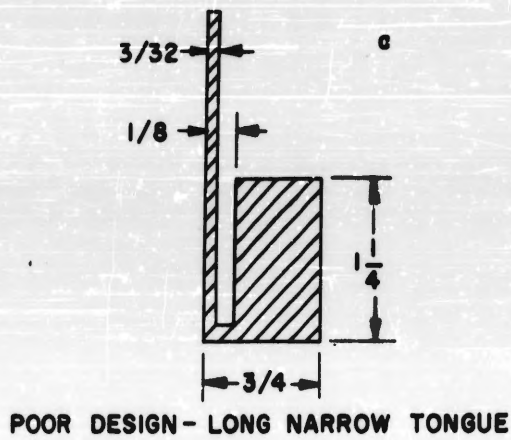


Figure 2.16 Design of Extruded Sharp Edges

GOOD DESIGN - INCREASED TONGUE WIDTH, DECREASED DEPTH, RADIUS GAP, BALANCED THICKNESS, EXTRUDE IN OPEN POSITION

Figure 2.15 Extrusion Die Tongue Design

**Protruding Legs** Large, heavy concentrations of metal from which thin, light walls or legs protrude present some difficulty in production. This is due to the tendency of the metal to flow faster in the larger opening and, consequently, not fill out the thinner portion. Examples of this are shown in Figures 2.12 and 2.17.

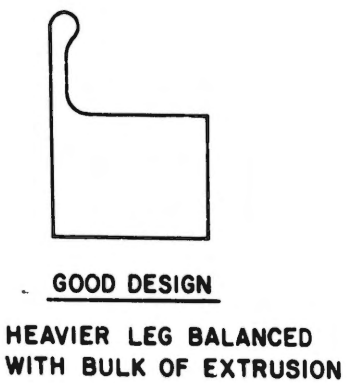
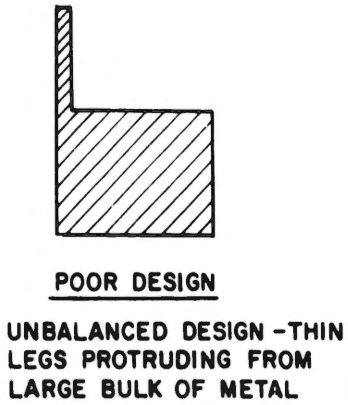
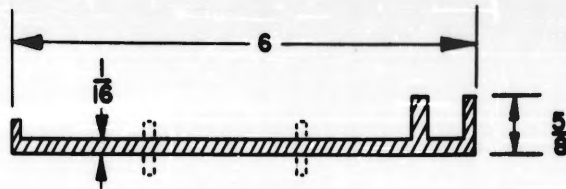


Figure 2.17 Design of Extruded Protruding Legs

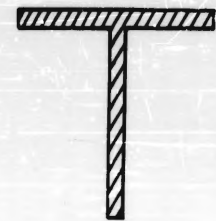
**Fillet Radii.** Generous fillet radii will often aid the extrusion process greatly and also add substantially to the structural strength of the section. This is particularly true of thin wall cross sections, as illustrated in Figures 2.18 and 2.19. In very thin shapes, such as Figure 2.20, a generous fillet radius helps to maintain straightness tolerances.



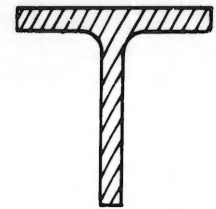
**POOR DESIGN**

THIN WALLED SHAPE WITH LARGE CIRCUM-SCRIBING CIRCLE IMPROVED BY STIFFENING RIBS, AS SHOWN IN DOTTED LINES, OR BY INCREASE IN WALL THICKNESS

Figure 2.18 Design of Extruded Thin-Walled Shapes

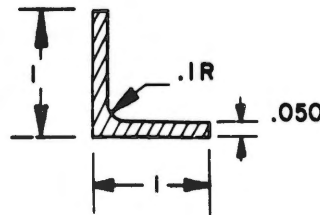


**NO FILLET RADIi**



**ADEQUATE FILLET RADIi**

Figure 2.19 Design of Fillet Radii in Extrusions



**GOOD DESIGN**

**GENEROUS FILLET RADIUS HELPS MAINTAIN STRAIGHTNESS**

Figure 2.20 Use Generous Fillet Radii to Obtain Better Straightness

**Wall Thickness.** Several guides have been prepared concerning sections containing an enclosed void or voids. Wall thickness, in general, should be slightly greater than on a solid shape, particularly one that divides two voids, Figure 2.21 illustrates a poorly designed section. Another important factor is symmetry. It is important to strive as much as possible toward a symmetrical section, as shown in Figures 2.22 and 2.23.

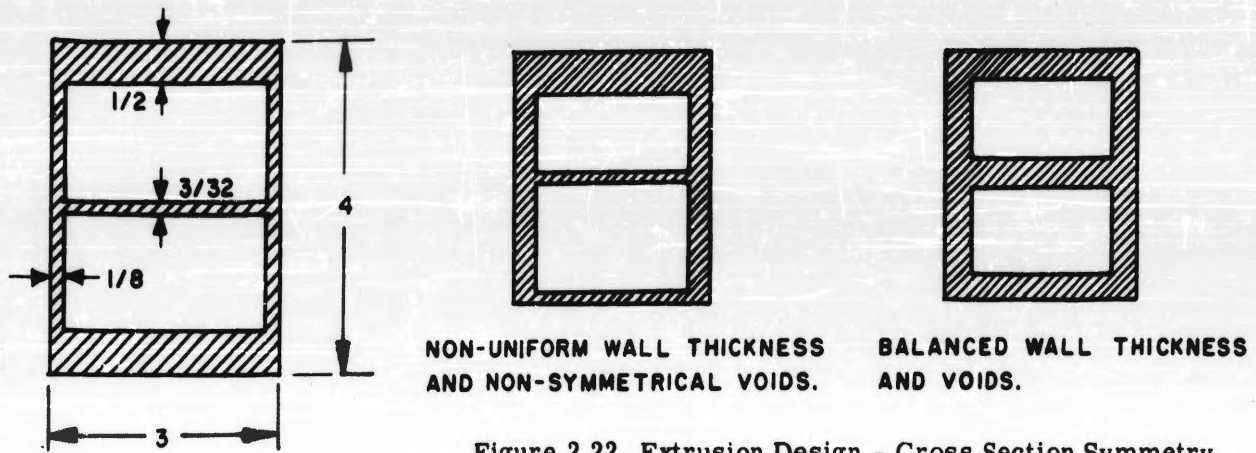


Figure 2.22 Extrusion Design - Cross Section Symmetry

Figure 2.21 Poor Extrusion Design  
Inadequate Wall Thickness

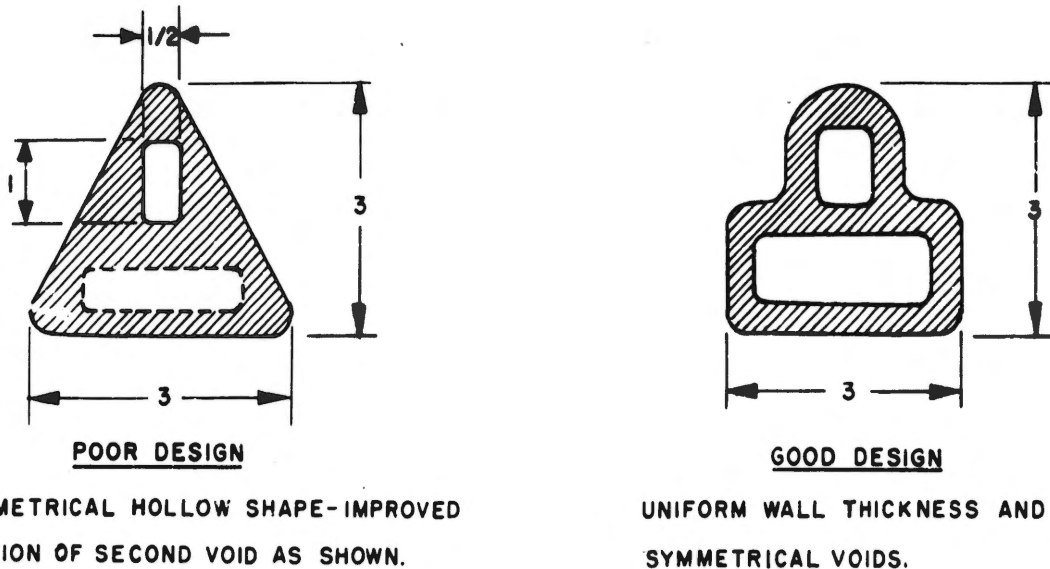
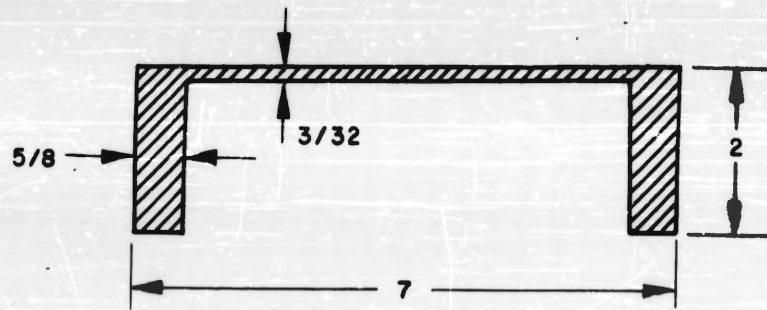


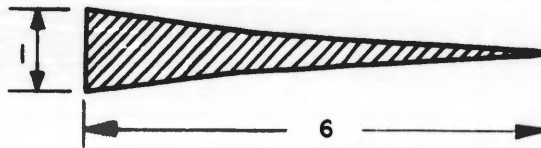
Figure 2.23 Extrusion Design - Cross Section Symmetry

Thin-Walled Shapes with Large Circumscribing Circle. Thin-walled shapes with large circumscribing circles, as shown in Figure 2.18 are difficult to straighten. A slight increase in wall thickness or stiffening ribs, as indicated by dotted lines in the illustration can help remedy this condition.

Section Thickness. To permit control of the metal flow, the length of the thin protruding legs should not exceed ten times their thickness. Commercial dimensional tolerances are difficult to maintain on these thin legs. Figure 2.24 shows severe variations from thick to very thin cross sections, making straightness and flatness hard to maintain. Waves tend to form in the thin end of (b); a blunt end is shown by dotted lines which would alleviate this condition.



NON-UNIFORM SECTION THICKNESS



NON-UNIFORM SECTION THICKNESS

Figure 2.24 Extrusion Design - Section Thickness Symmetry

Multihole Hollow Shapes. In multihole shapes, adequate thickness between holes is necessary. In Figure 2.21 for instance, the center web should be increased to  $1/8$  inch.

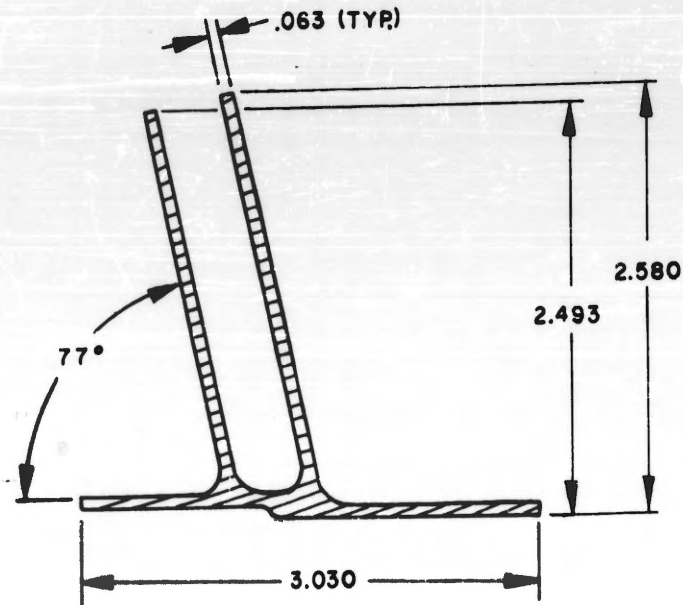
Unsymmetrical Hollow Shapes. The metal flow of heavy unsymmetrical hollow shapes, such as shown in Figure 2.23(a) where the void is near the edge of the section, is difficult to control. Extrudability is improved if a second void, as indicated in dotted lines, is added. The closer a hollow shape approaches uniform wall thickness, as illustrated by Figure 2.23(b), the more readily it can be extruded.

#### Typical Problems

The following discussion shows some of the typical problems which must be considered in extrusion design. The discussion is concerned basically with aluminum, but it is typical of other materials.

Shape I. This shape, Figure 2.25, was rejected for several major reasons. The first consideration is that the average thickness be increased from 0.063 inch to 0.094 inch. This thickness will bring the cross sectional area to 0.810 square inches which comes reasonably close to meeting metallurgical requirements on minimum area. Also, with a thickness of 0.063 inch and a leg length over 2.5 inches, no satisfactory surface quality or straightness could be expected. Heat treatment and water quench of this shape would tend to distort the shape further.

Another major problem is the construction of an extrusion die. The area on the face of the die between the two parallel legs is subject to the same high pressure as the rest of the die, but it has the disadvantage of being cantilevered. This portion of the die will deflect and result in loss of dimensional control. Certain ratios have been set up limiting the severity of this condition. These ratios involve the area of the tongue to the square of the distance across the support of the tongue.



**REMARKS:**

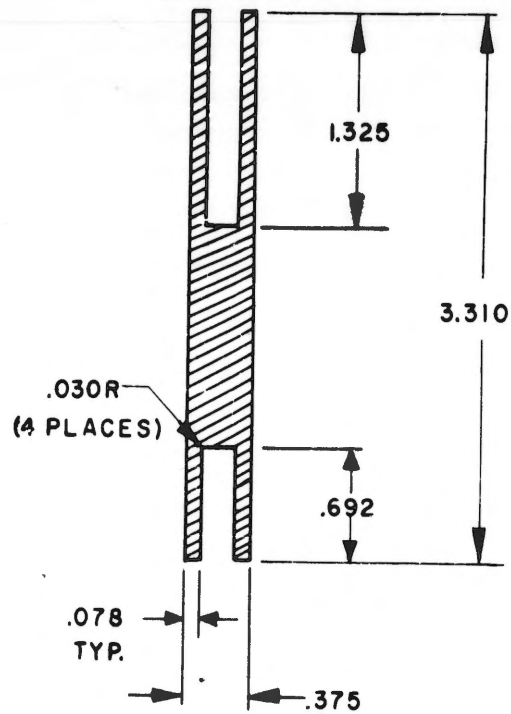
- (1) SHAPE EXTRUDED WITH LEGS IN THE OPEN OR BENT POSITION.  
BENT TO REQUIRED DIMENSION AFTER EXTRUSION.
- (2) AVERAGE THICKNESS SHOULD BE INCREASED FROM .063" TO .094."

ESTIMATED AREA	.544 SQ. IN.
ESTIMATED WT/FT	.653 LBS.
ESTIMATED PERIMETER	15.847 IN.
FACTOR	24
CIRCLE SIZE	3 1/2 - 4 IN.
ALLOY	HARD

Figure 2.25 Typical Extrusion Design - Shape I

In this case, the ratio is exceeded. The shape may still be extruded open, however, but it must be bent at the step between the legs so that the tongue support becomes much wider. This, of course, requires an additional manufacturing operation to bend the piece into the required shape after it has been extruded in the bent form. After the piece is bent into the desired shape, there will be a streak of rough surface along the line of the bend which may or may not be satisfactory.

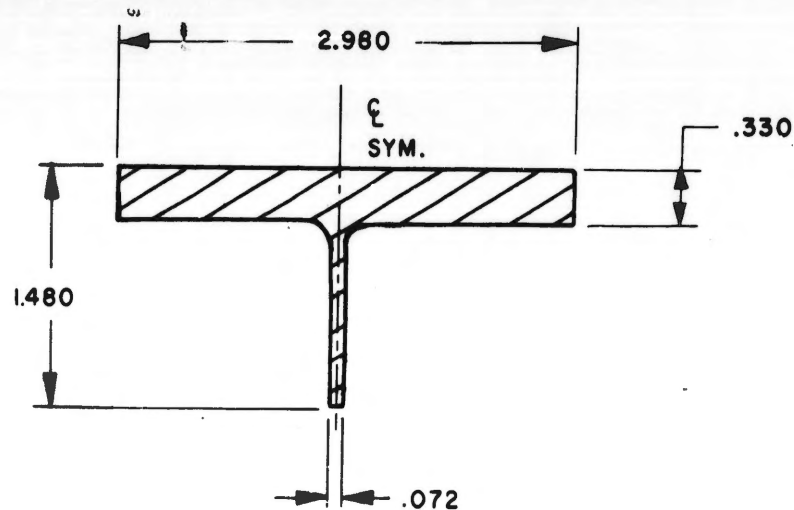
**Shape II.** The main consideration in accepting this shape, Figure 2.26, is the tongue strength required in the extrusion die in order to maintain thickness dimensions. Here again the piece must be extruded with one leg bent open on the 1.325 inch dimension with the resulting streak of rough surface when the piece is bent back to the desired shape. This practice is not desirable because of the inconsistent behavior in contouring the piece and the undesirable streak of rough surface.



ESTIMATED AREA	.800 SQ. IN.
ESTIMATED WT/FT	.960 LBS.
ESTIMATED PERIMETER	10.967 IN.
FACTOR	11
CIRCLE SIZE	3-3 $\frac{1}{2}$ IN.
ALLOY	2024T4

Figure 2.26 Typical Extrusion Design - Shape II

**Shape III.** This shape, Figure 2.27, is acceptable only in the "O" or "F" temper. If temper other than "O" or "F" is required, the minimum thickness must not be less than 0.125 inch. If this shape were heat-treated and water-quenched, the thin 0.072 inch leg would be badly distorted, and it would be extremely difficult, if not impossible, to straighten. Stretch-straightening is poor with such a shape because of the likelihood of pulling the heavy section below tolerance before any straightening effect takes place at the thin leg.



**REMARKS:**

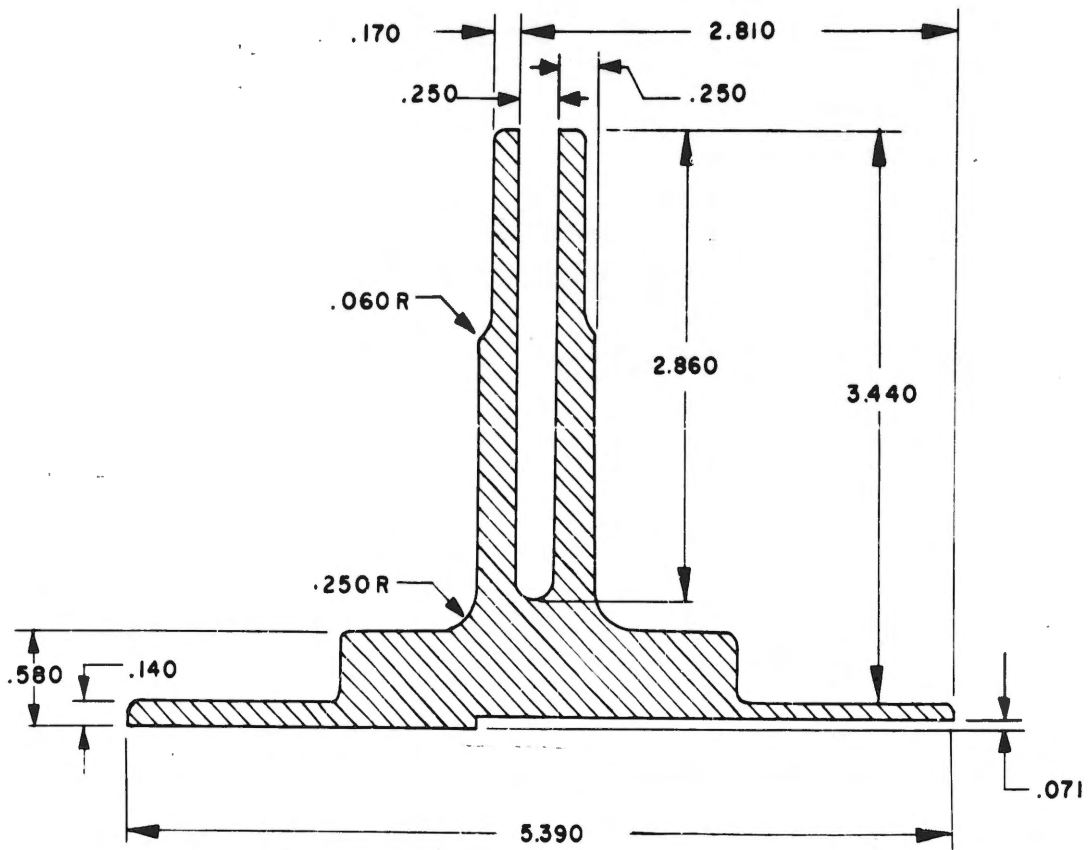
- 1) SHAPE ACCEPTABLE IN "O" OR "F" TEMPER.  
OTHER TEMPERS REQUIRE LEG TO HAVE MINIMUM THICKNESS NOT LESS THAN .125"

ESTIMATED AREA	1.073 SQ IN.
ESTIMATED WT/FT	1.288 LBS.
ESTIMATED PERIMETER	8.767 IN.
FACTOR	7
CIRCLE SIZE	2 1/2 - 3 IN.
ALLOY	2024 - O

Figure 2.27 Typical Extrusion Design - Shape III

**Shape IV.** This shape, Figure 2.28, is acceptable only with a minimum wall of 0.125 inch and a tongue depth of one inch. Even when these requirements are met, only a 20-foot length can be extruded. In addition, a minimum radius of 0.031 inch must be specified at the inside corners of the two vertical legs. A section such as this, having a main body or mass with thin legs projecting, presents tolerance problems regarding leg thickness, flatness, and straightness. Frequently, thickness must be increased to a point well inside the manufacturing limits to obtain dimensional stability. The variation or instability of dimensions varies with the length of the piece, and, from experience, it is determined that 20 feet would be maximum length for this shape.

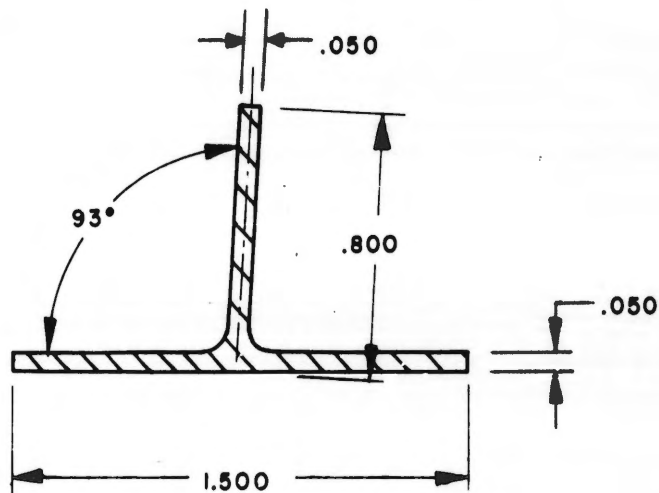
Also, for the sake of dimensional control, the void between the two vertical legs should be held to one inch, or in other words, the allowable maximum tongue length is one inch. Because of die-making difficulties and to avoid stress concentration, a minimum radius of 0.031 inch is required at the sharp corners on the vertical legs.



ESTIMATED AREA	3.362 SQ. IN.
ESTIMATED WT/FT	4.034 LBS.
ESTIMATED PERIMETER	25.696 IN.
FACTOR	6
CIRCLE SIZE	5-5 1/2 IN.
ALLOY	2024-T4

Figure 2.28 Typical Extrusion Design - Shape IV

**Shape V.** This shape, Figure 2.29, will be acceptable if the cross sectional area is increased to 0.135 square inches. An area of 0.114 square inches is not only below the listed manufacturing limits, but does not conform to metallurgical requirements regarding cold work and resulting grain size. The circle size of this shape does not permit extrusion from an 8-hole die. A 6-hole die could be used satisfactorily if the area is increased to meet the minimum metallurgical requirements. An area of 0.135 square inches is still below the published manufacturing limits, but, because of the simple configuration and uniformity of the shape, an exception may be made here.



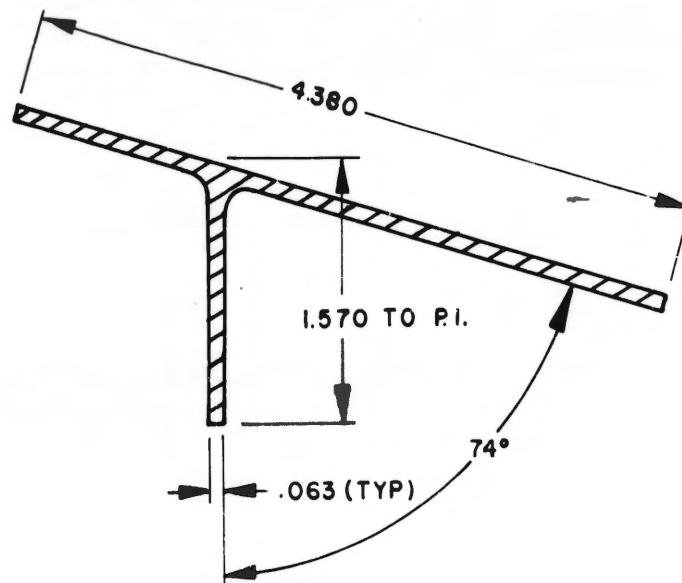
**REMARKS :**

- (1) CROSS SECTIONAL AREA BELOW MANUFACTURING LIMITS AND DOES NOT CONFORM TO METALLURGICAL REQUIREMENTS. SHAPE ACCEPTABLE IF CROSS SECTIONAL AREA INCREASED TO .135 SQ. IN.

ESTIMATED AREA	.114 SQ. IN.
ESTIMATED WT/FT	.137 LBS.
ESTIMATED PERIMETER	4.506 IN.
FACTOR	33
CIRCLE SIZE	$1\frac{1}{2}$ - 2 IN.
ALLOY	7075-T6

Figure 2.29 Typical Extrusion Design - Shape V

**Shape VI.** This shape, Figure 2.30, is acceptable only with a minimum thickness of 0.078 inch. With a thickness of 0.063 inch, the area is only 0.379 square inches which would require a 3-hole die to meet minimum metallurgical area requirements. Because of the long, thin legs of this shape and its general configuration, a 3-hole die is impossible. With an average thickness of 0.078 inch, the area will be 0.470 square inches and will satisfy minimum total area requirements with a 2-hole die. It should be noted that a heavy thickness is specified in this case, rather than a minimum area. Not only is there a problem of minimum required area in this case, but there is also a problem with such a thin wall, long leg shape involving thickness tolerance, straightness, wave, and bow. The area requirements could be met by placing a large mass at one point along the section, or by making one leg extremely heavy; however, this would not solve the dimensional problem on the remaining thin portion of the shape. Instead, it would tend to make it worse. A uniform increase in thickness will solve both the area and the dimensional problem.



**REMARKS:**

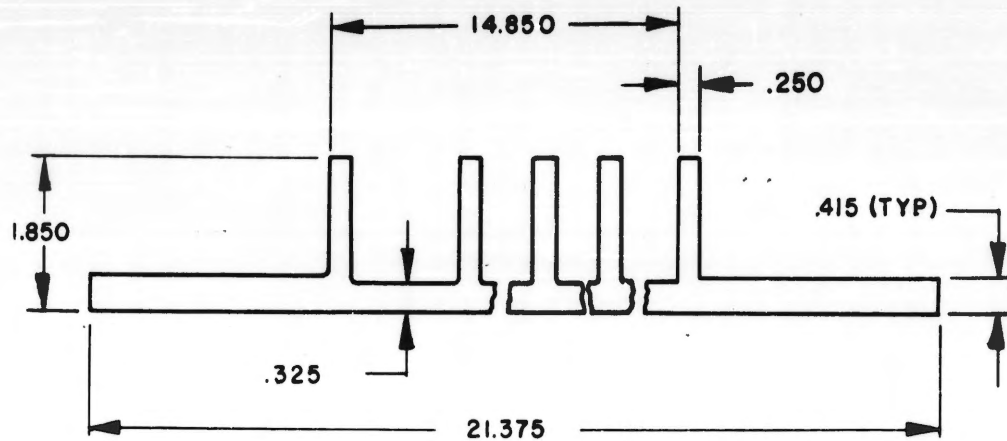
SHAPE ACCEPTABLE WITH A MINIMUM UNIFORM THICKNESS OF .078"

ESTIMATED AREA	.379 SQ. IN.
ESTIMATED WT/FT	.455 LBS.
ESTIMATED PERIMETER	11.614 IN.
FACTOR	26
CIRCLE SIZE	4 - 4 1/2 IN.
ALLOY	2024

Figure 2.30 Typical Extrusion Design - Shape VI

## Wide Panels

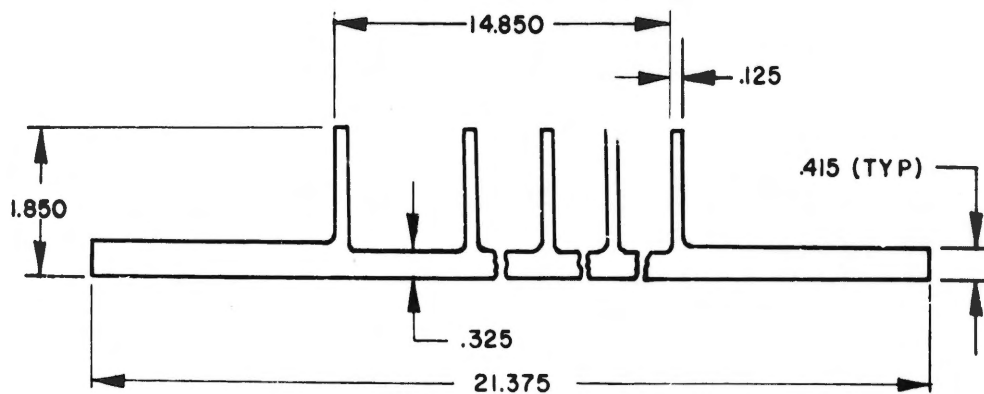
Presses are now available that will produce very wide extrusions. These are used to produce wide ribbed shapes for integrally stiffened panels of the type shown in Figures 2.31 and 2.32. The presses that produce these parts use the so-called flat container as opposed to the conventional round container. The flat container is better suited to producing these parts since it can form very thin ribs as shown in Figure 2.31.



### REMARKS :

EXTRUDABLE DUE TO INCREASE IN WIDTH OF RIBS TO .250  
ESTIMATED WT/FT 13.616 LBS,

Figure 2.31 Good Wide Shape Extrusion Design



### REMARKS :

DIFFICULT TO EXTRUDE DUE TO THINNESS OF RIBS (.125)  
ESTIMATED WT/FT 11.330 LBS,

Figure 2.32 Poor Wide Shape Extrusion Design

**Table 2.5 Approximate Extrusion Equipment Capacity (1957)**

Capacity of Presses (Tons)	Number of Presses Available		
	Aluminum	Magnesium	Steel and Titanium
Under 1000	54	2	
1000 - 1499	86	1	1
1500 - 1999	32	4	4
2000 - 2499	33	3	1
2500 - 2999	68	3	5
3000 - 3999	12		
4000 - 4999	12		2
5000 - 7000	3	1	1
8000	3		
12000	1		1
14000	1		
<b>Total</b>	<b>305</b>	<b>14</b>	<b>15</b>

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Harvey Aluminum Division, "Extrusion of New Titanium Alloys", AMC Report No. 8, August 1957

Mueller Brass Company, 'Cold-Prest Impact Extrusions' April, 1958

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"Impact Extrusion", Aircraft Production, May 1954

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**H. Chase, "Impact Extrusions, Their Design and Production", Machinery, August 1948,**

**W. N. Parker, "Rolled Extrusion of Thin-Walled Parts", ASTE Paper 22T1**

**D. I. Brown, "Successful Design of Steel Parts for Cold Extrusion", ASTE Paper 22T34**

**T. B. Merrill, Jr., "Hot Steel Extrusions", Materials and Methods, February 1954**

**H. V. Menking, "Aluminum Extrusions, Design Factors and Tolerances", Machine Design, November 1949**

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## CHAPTER 3

### CONTOUR ROLLING

#### PROCESS

Contour rolling as a hot forming process involves the distribution of hot metal over large areas for relatively thin parts having various types of integral stiffening. The configurations may be uniform (symmetrical about a centerline) such as longitudinal ribs or panels, transverse ribs or panels and isogon patterns (waffle-like stiffening); or they may be nonuniform (completely unsymmetrical) with ribs, panels, and bosses placed only in accordance with the stress and attachment requirements of the part.

This process combines the advantages of conventional rolling and extruding actions to produce varied configurations over relatively large areas not otherwise economically obtainable. Contour rolling has produced components for a wide variety of items such as landing gears, bulkheads, turbine blades, propeller blades, jet engine rings and shrouds, and other complex aircraft parts. A schematic of a typical equipment setup is shown in Figures 3.1 and 3.2.

The process normally consists of the forging of commercially obtainable bar, plate, or sheet into desired configurations. When necessary, specially shaped blanks may be prepared by machining, forging, or other appropriate means. Blanks are generally designed as wide as the rolled part, with the length and thickness varying as needed.

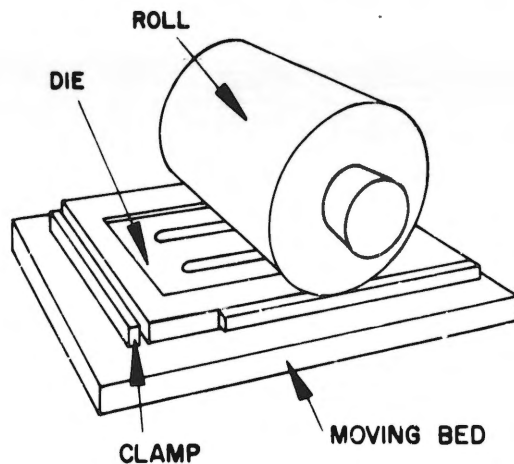


Figure 3.1 One-Sided Contour Rolling

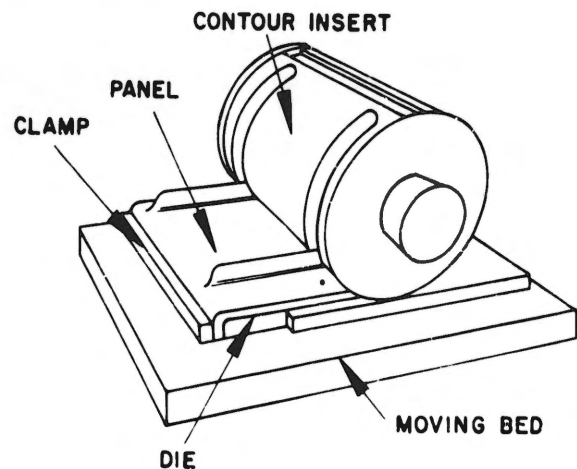


Figure 3.2 Two-Side Contour Rolling

#### ADVANTAGES AND LIMITATIONS

Contour rolling is a precision method capable of high production rates. Parts made with this tool afford attractive grain flow and material distribution advantages while minimizing or eliminating machining operations. The capability to produce parts having relatively large areas where the dimensional aspects of the part may prohibit the use of conventional impact or pressure-type forging machines is outstanding.

Normal usage produces parts which are flat on the roll side and contoured on the die side as shown in Figure 3.1. If the quantity to be produced were great enough to justify a contoured roll and die setup, parts with configurations on both sides could be produced as shown in Figure 3.2.

### DESIGN CONSIDERATIONS

Every contour can be classed as one of four basic types. These are ribs, straight panels, sculptured panels and bosses. For descriptive purposes, ribs are defined as those configurations for which the width is not more than twice the height. If this ratio is exceeded, the contour is called a panel. Ribs and panels may run in any direction on the part from longitudinal to transverse. Sculptured panels are those which vary in thickness without uniformity. They also differ from straight panels in the gradualness of the change in thickness. Bosses are distinguished from panels by the relatively small area involved.

Two general classifications cover the entire field of contour rolled parts and their relationships to blank sizes. The two classifications are: (a) those for which an extruding action is necessary to produce fillout; and (b) those for which the rolling action is sufficient to cause fillout. In the latter case, the blank thickness is always equal to or greater than the maximum rolled thickness, while in the former case the optimum blank thickness can be less than the maximum rolled thickness but greater than the minimum rolled thickness. The blank thickness for parts which require extruding can be approximated by calculating the volume required to fill the cavities per inch of length and converting this volume to thickness by dividing by the blank width. Adding the two thicknesses then approximates the required blank thickness. This approximation assumes that no increase in length or width will take place, this being the optimum condition for parts requiring the extruding action; however, the length of the part will usually increase by approximately 25 percent. An increase in blank thickness must be provided to compensate for the effect this length increase has on die fillout.

The slope of the walls of a rib may vary from perpendicular to an angle which, by definition, would increase the width-height ratio of the rib into the panel classification. For extruding, ribs with small draft angles (two degrees) and small fillet radii, facilitate removal of the part from the die. Illustrations depicting a number of rolled sections are shown in Figure 3.3. Limits for extruding thin-high ribs are being developed.

The surface finish normally obtained in the rolling process falls in the range between 63 and 125 microinches. This range is common to all materials and will ordinarily permit using the final product in the as-rolled condition. Care must be taken during cleaning and heat treating, however, to preserve the finish obtained by rolling.

Table 3.1 illustrates some typical thickness variations that can be expected from the contour rolling process. Edge trimming is normally required on all sides of a part after rolling, consequently the associated tolerances are dictated by the type of trimming to be done. Dimensional control on width between ribs and panels is very good. Variations in length between two points on a part can occur due to a phenomenon known as "back-extrusion." This phenomenon can normally be controlled by a number of methods. It occurs when the column strength of the portion of the part which has been rolled cannot cope with the force component in the direction of die movement. The material actually moves faster, through the orifice created between the roll and the die, than the die is moving, thus increasing the effective distance between two points on the die.

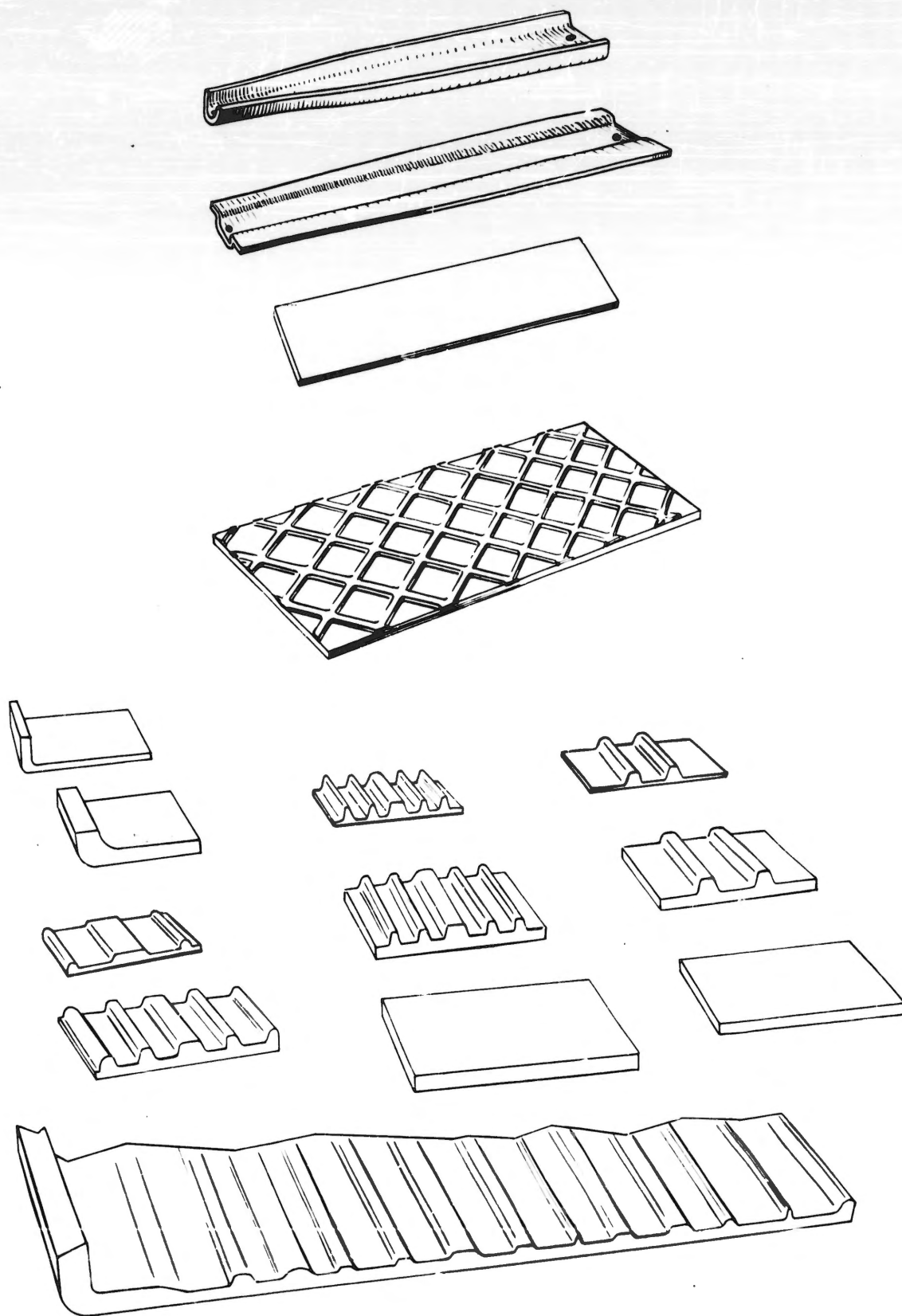


Figure 3.3 Typical Contour Rolled Sections

Table 3.1 Thickness Tolerances for Contour Rolled Aluminum Parts

Thickness (inches)	Minimum Rolled Thickness (inches)		Maximum Rolled Thickness (inches)	
	Plus	Minus	Plus	Minus
.050 - .078	.013	.005	.015	.010
.079 - .109	.012	.006	.015	.011
.110 - .141	.011	.007	.015	.012
.142 - .187	.010	.008	.015	.013
.188 - .250	.010	.010	.015	.015
.251 - .375	.010	.010	.020	.015
.376 - .500	.010	.010	.020	.015
.501 and UP	.010	.010	.020	.015

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I. J. Altman, "Contour Rolling of Temperature Resistant Aircraft Components". Machinery, July 1956

A. E. Felt, "Precision Contour Rolling Teams with Welding to Produce Steel Propellers", Steel Processing, May 1955

A. O. Smith, "Processing and Materials Review for Aircraft Design Manual, ARDC-TR-56-7,

## CHAPTER 4

### DRAWING

#### PROCESS

This process is generally described as pulling a sheet metal blank over a drawing radius into a die cavity. During the process the metal is subjected to a combination of compressive and tensile stresses, normal to each other. Typical drawing methods are shown in Figures 4.1 through 4.4.

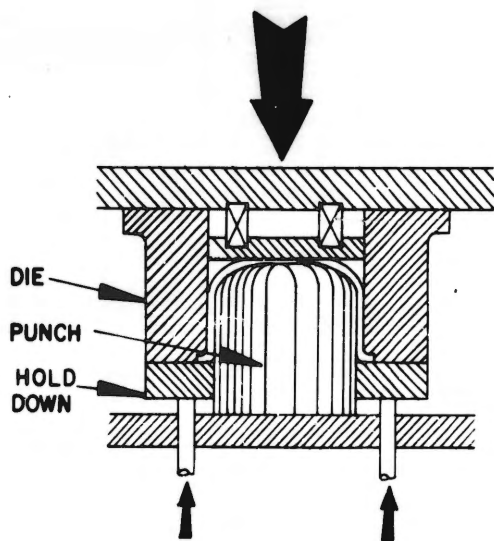


Figure 4.1 Typical Air Draw Operation

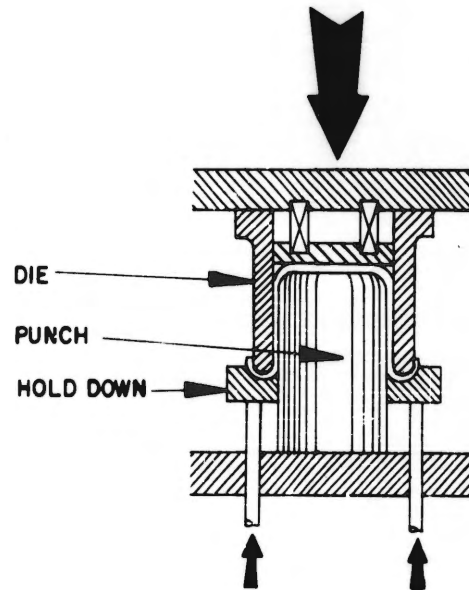


Figure 4.2 Typical Air Draw (Reverse Redraw) Operation

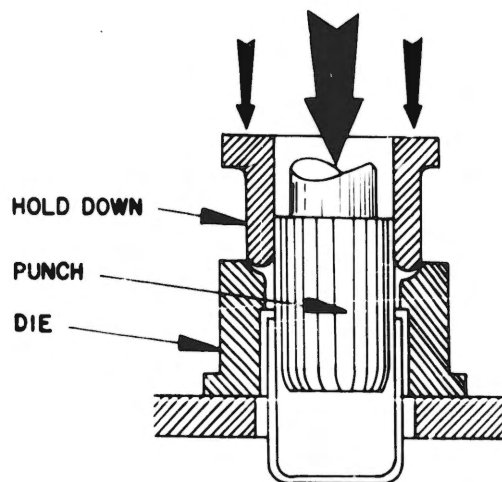


Figure 4.3 Typical Toggle Draw (Through Redraw) Operation

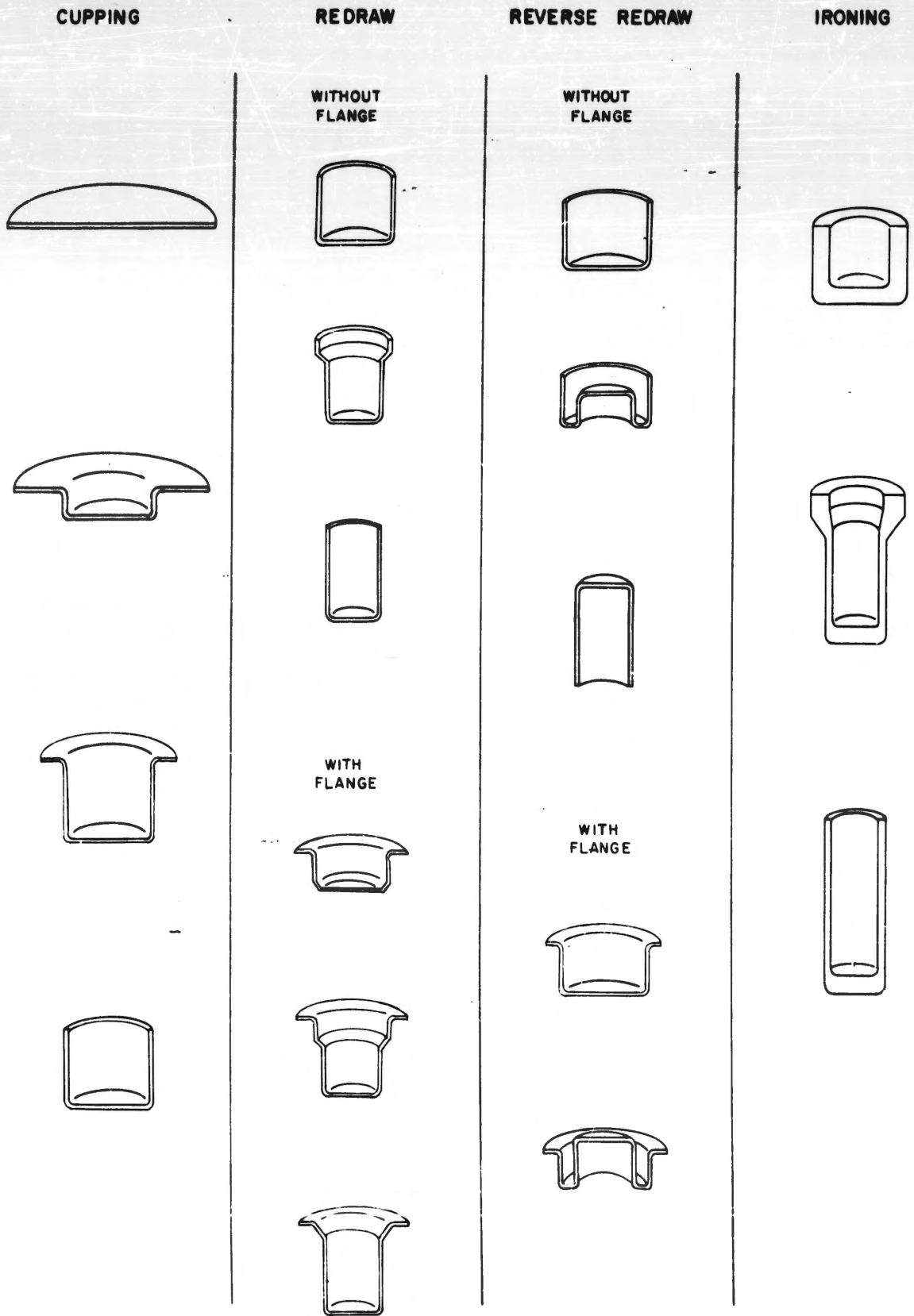


Figure 4.4 Typical Drawing Methods

Materials applicable to drawing operations include low carbon steels, austenitic stainless steels, copper, brass, bronze, zinc, aluminum, tin, nickel alloys, magnesium, and titanium. Magnesium and titanium drawing is usually done at elevated temperatures; a temperature range that could be classed as somewhere between hot drawing and cold drawing.

Some parts have very shallow draws and others, with a large height to diameter ratio, are known as deep drawn parts. A great many parts which were formerly drawn are now produced by rubber forming (described later in this book). However, for very deep parts, drawing is still widely used.

When working with lower strength non-ferrous metals (aluminum and its alloys, etc.), the finish of the die face and the pressure plate face becomes much more critical than in working with higher strength ferrous metals. In order to assist metal flow across the die face, the die should be polished, after grinding, with an oil stone so that all marks are radial. The radius should also be blended perfectly with the die face and bore wall.

### ADVANTAGES AND LIMITATIONS

Circumstances alter somewhat when drawing shapes other than circular. In a rectangular or square shape with radii at the four corners and around the bottom edge, the condition of drawing applies only at the corners. Along the straight sides there is no true drawing. Rather, there is plastic bending under tension occurring at these places. This must be taken into account when redrawing work is done. At the corners, the amount of reduction must be small.

Most deep drawing operations have been done on double-action crank or toggle presses for many years and the use of these presses has become an accepted practice. There is, however, an inherent disadvantage in the use of these type presses. Due to the harmonic motion of the crank press, the speed at which the punch (slide) operates is not constant throughout the stroke. The punch starts slowly, reaches its maximum speed halfway down the stroke, and then decreases until it reaches zero at the bottom of the stroke. Actually this is entirely contrary to ideal drawing conditions. In drawing the speed should be slow at first and gradually it should increase throughout the draw. It is impossible to achieve this condition on conventional presses. Some of the modern hydraulic presses incorporate valve-gear and pump control units to regulate the flow of fluid to the hydraulic cylinder. High cost of this extra control has made its usage very limited.

### DESIGN CONSIDERATIONS

Two important factors which influence successful deep drawing are:

- (1) radius on die edge
- (2) clearance between punch and die

Since "A", in Figure 4.5, is a deep tubular piece, the die radius will not have too great an effect on the finished part since the edge will probably have to be trimmed anyway. But on "B", the metal is not taken beyond its yield point except at the punch end and thus spring back will occur at the top edge. Theoretically "C" condition should occur, but in actual practice, the result is similar to "B".

There are two possibilities for reducing this defect. The reduction of the die radius and a decrease in clearance will both tend to eliminate spring back. However, a decrease in clearance is usually a better choice since it tends to eliminate thickening at the mouth. In "A", there is a considerable tendency to thicken at the mouth. In "B" or "C", this is not as prevalent.

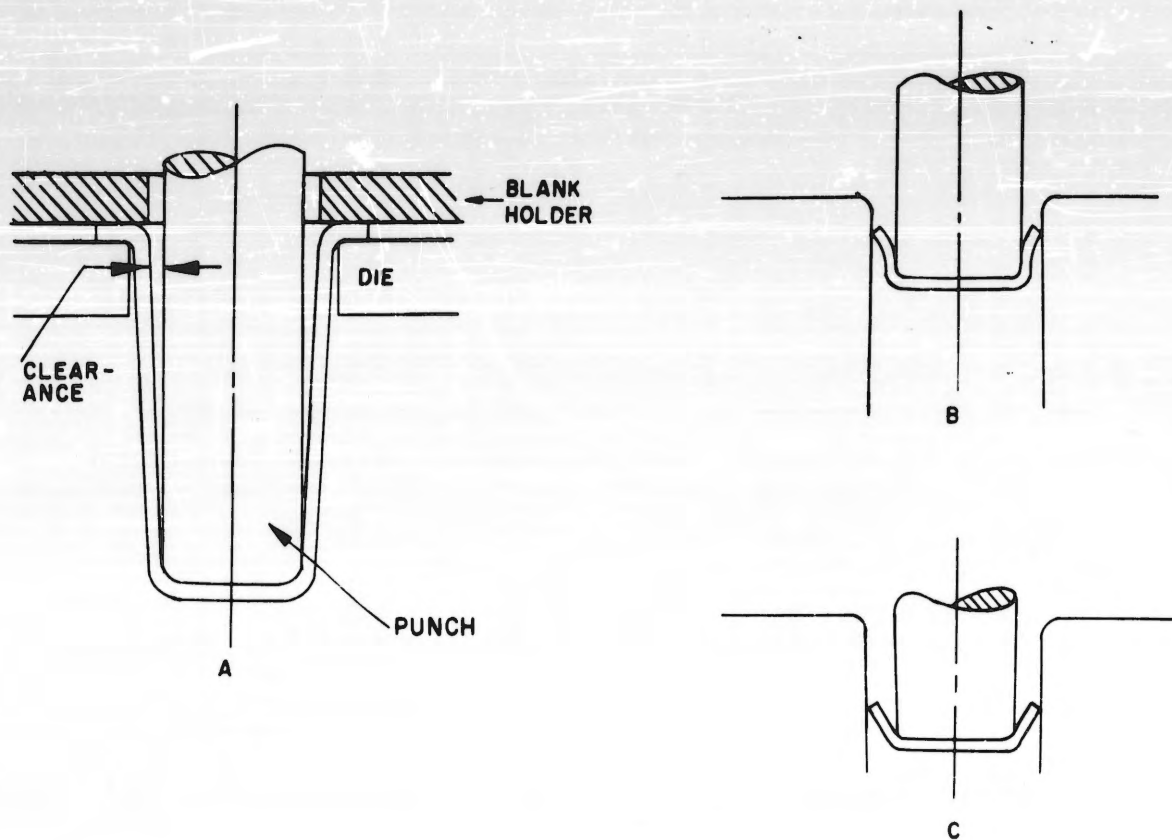


Figure 4.5 Draw Radius and Clearance in Drawing

In deep drawing, the depth of the initial draw is a variable dependent upon many factors such as material, thickness, bottom and corner radius, permissible wall thickness and others. A general rule is that a reduction of 45% to 65% for round parts and 4 to 6 times the corner radius for rectangular parts is the maximum initial reduction.

In redrawing, several reduction steps are used, each reducing the diameter by a smaller amount. In double action redrawing, a typical set of reductions may be 25%, 20%, 16%, 13%, 10%, etc. This arrangement must be modified according to stock thickness and frequency of annealing. Since single action redrawing does not use a blankholder, smaller reduction steps are necessary. A typical set of single action reductions may be 19%, 15%, 12%, 10%, etc.

Figures 4.6 through 4.11 show some of the design considerations of drawing. Some permissible deep drawing reductions are shown in Table 4.1. Radius limitations on drawn parts are shown in Table 4.2. Some common drawing defects are listed in Table 4.3.

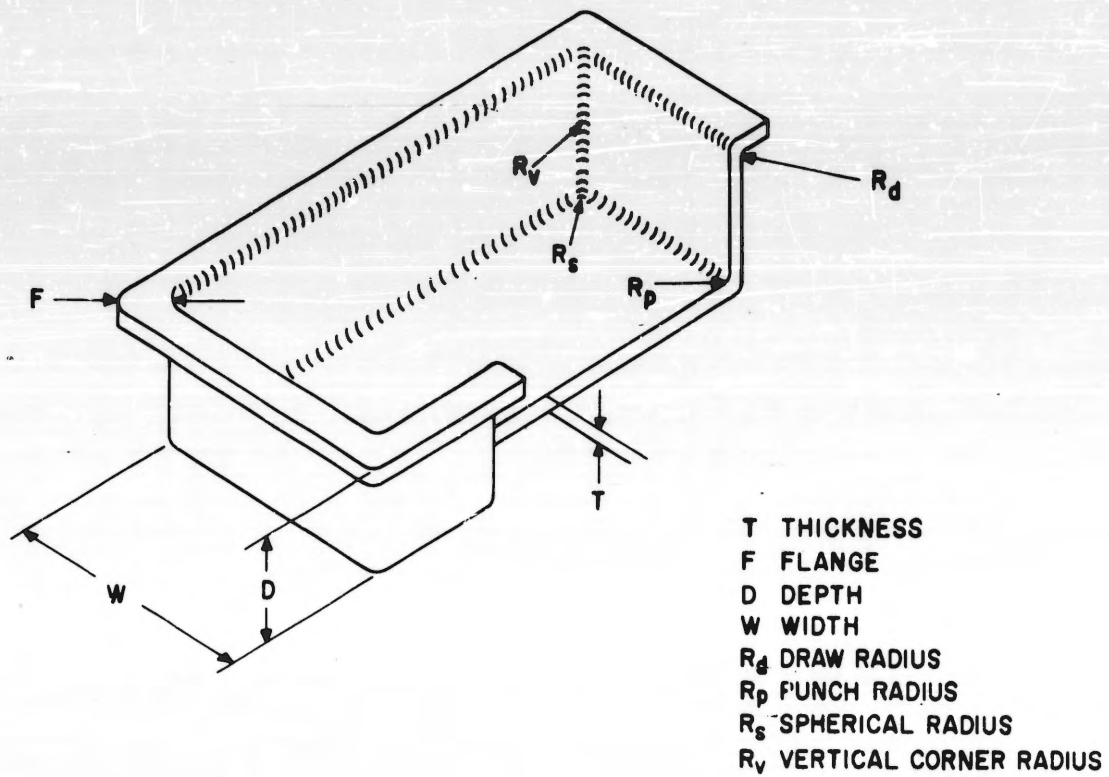


Figure 4.6 Drawing Nomenclature

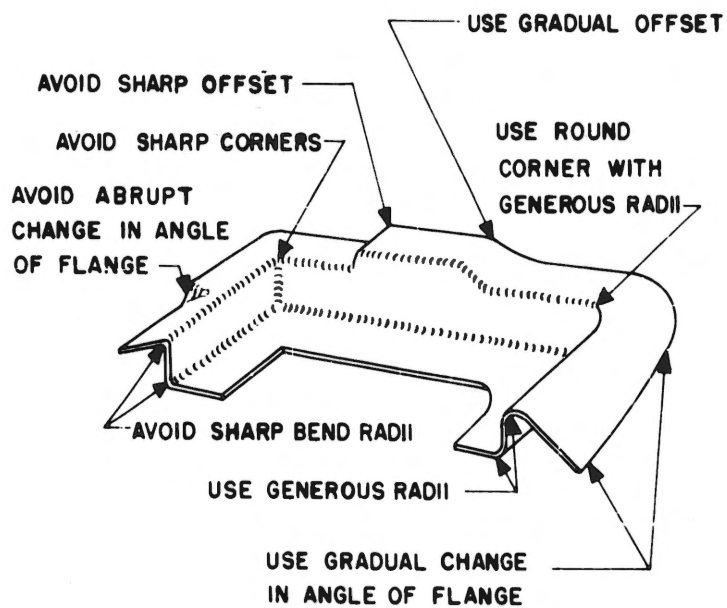
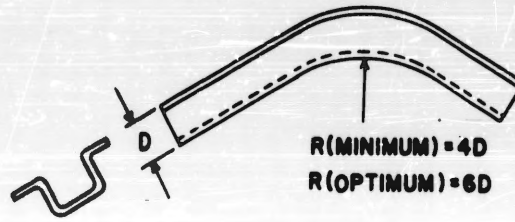
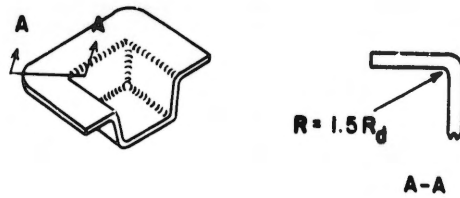


Figure 4.7 General Drawing Design Considerations

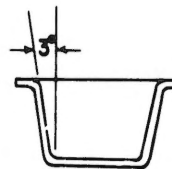
**CONTOUR LIMITS**



**IN COMPRESSION AREA**



**DRAFT (DROP HAMMER)  
 FOR 90° SIDES**



**FORMING METHODS**

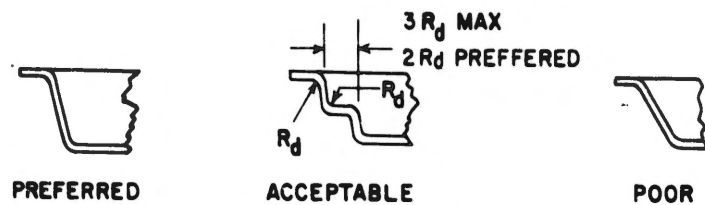


Figure 4.8 Miscellaneous Drawing Design Considerations

ALLOY	PUNCH RADIUS WITH PUNCH RADIUS EQUAL TO ONE HALF PART DEPTH OR MORE		PUNCH RADIUS WITH PUNCH RADIUS LESS THAN ONE FOURTH PART DEPTH	
	DROP HAMMER	DOUBLE ACTION PRESS	DROP HAMMER	DOUBLE ACTION PRESS
	3003-O	.6D	.4D	.75D
2024-O, 5052-O 7075-O, 6061-W 7078-W	.8D	.65D	.9D	.8D
CRES (ANNEALED) LAC 1-580, 1-582 LOW CARBON STEEL	.5D	.35D	.65D	.5D

Figure 4.9 Typical Radius of Curvature Limits in Drawing

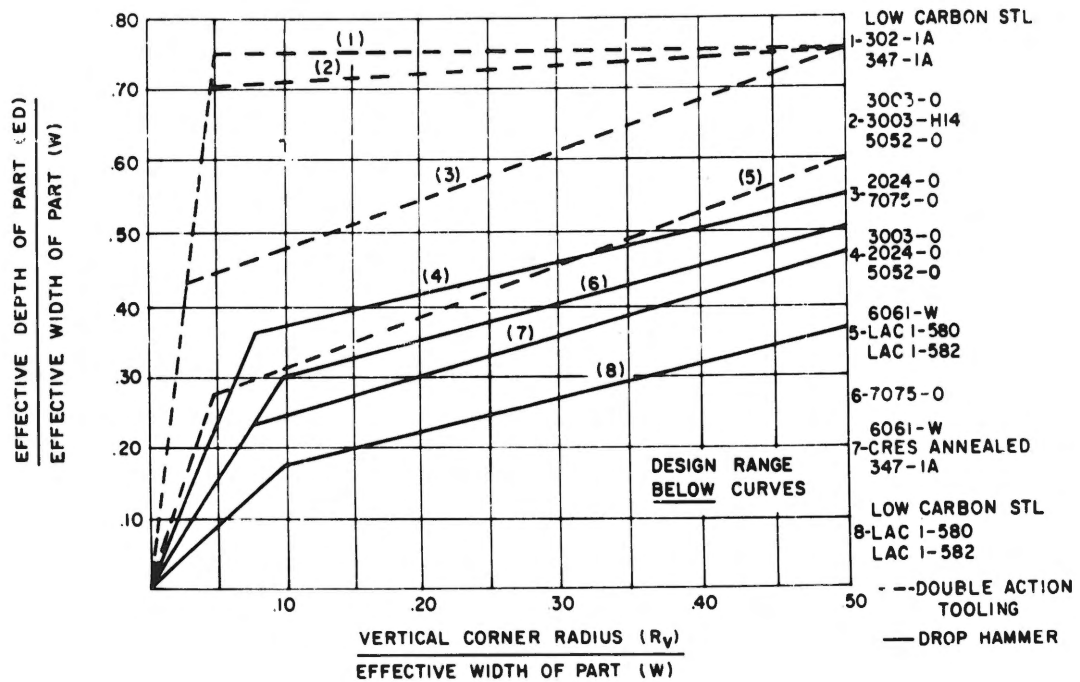
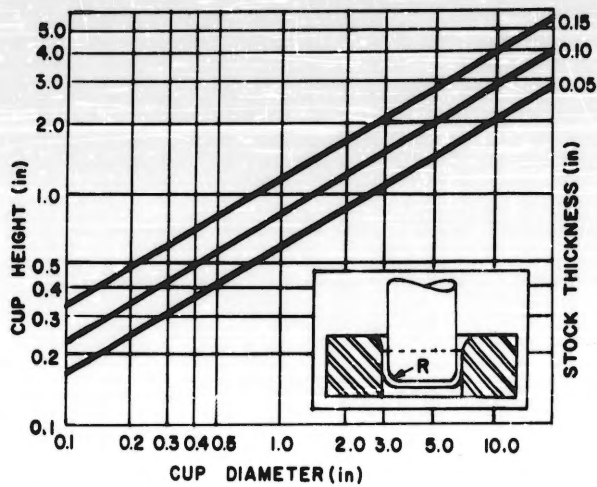
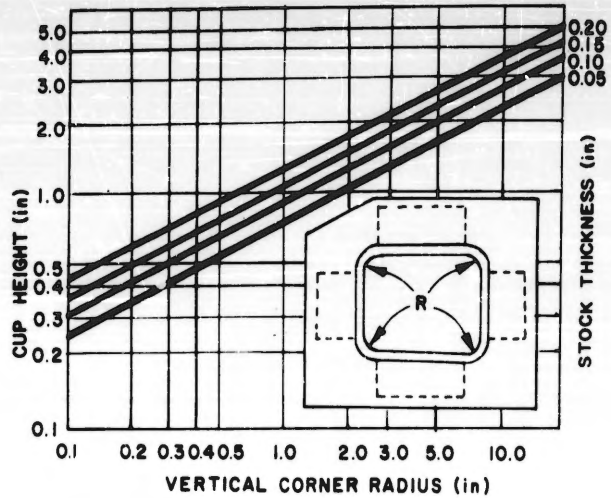


Figure 4.10 General Dimensional Considerations in Drawing



DRAWING ROUND SHELLS WITHOUT  
BLANKHOLDER (MAXIMUM DIMENSIONS)



DRAWING RECTANGULAR BOXES WITHOUT  
BLANKHOLDER (MAXIMUM DIMENSIONS)

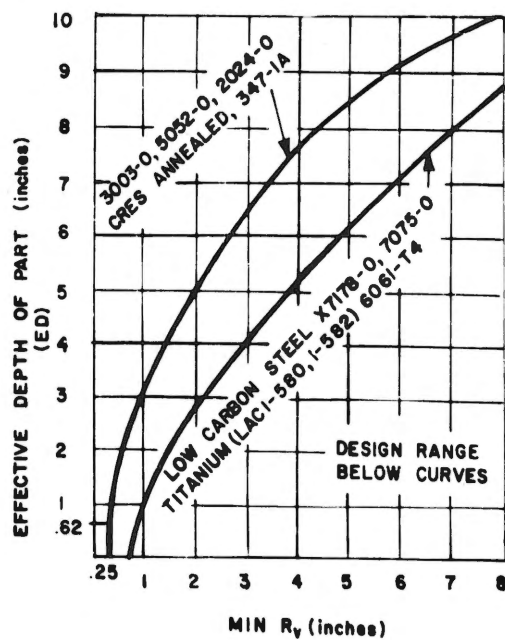


Figure 4.11 Typical Dimensions in Drawing

**Table 4.1 Permissible Reduction in Deep Drawing**

<b>Material</b>	<b>Recommended Reduction Between Annealings (Per Cent)</b>
Steel	20
Stainless Steel	15-20
Aluminum	20-30
Copper	15-20
Brass	20-25
Zinc	10-15

$$\text{Per Cent Reduction} = \frac{D - O}{D}$$

where:

D = predrawn shell dia.

O = re drawn shell dia.

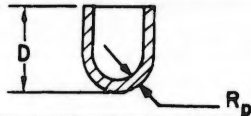
RADIUS	DROP HAMMER	MECHANICAL PRESS	
$R_d$	8T MIN. WHEN D IS GREATER THAN 1.00" 5T MIN. WHEN D IS LESS THAN 1.00" FOR BEST DRAW USE 10T TO 12T	5T MIN. 10T MAX. 8T FOR BEST DRAW	
$R_p$ FOR STANDARD PARTS	MIN. = GREATER OF 8T OR .25" 3T MIN. WHERE H EQUALS OR IS LESS THAN 1.00" 12T FOR BEST DRAW.	5T MIN. FOR FIRST BOTTOM PARTS WHERE D APPROACHES MAXIMUM:- $R_p$ SHOULD BE EQUAL TO OR GREATER THAN $R_d$	
	PROVIDE A MORE GENEROUS RADIUS THAN SHOWN ABOVE AS THE DRAW APPROACHES MAXIMUM.		
$R_p$ FOR HEMI-SPHERICAL PARTS	EFFECTIVE DEPTH = $D - \frac{R_p}{2}$ (Requires two stages)		
$R_v$	MIN. = GREATER OF 5T OR .25"	5T MIN. WHERE MAX. D IS NOT REQUIRED	
	DEPTH	$R_v$ MINIMUM	
		61S-T4, 75S-0, LOW CARBON STEEL	3S-0, 24S-0, 52S-0 GRES (ANNEALED)
	.50	.85	.25
	1.00	1.10	.32
	1.50	1.25	.45
	2.00	1.55	.65
	2.50	1.85	.80
	3.00	2.20	1.00
	3.50	2.55	1.25
4.00	2.95	1.45	
4.50	3.35	1.75	
5.00	3.80	2.00	
5.50	4.25	2.30	
6.00	4.80	2.70	
6.50	5.30	3.10	
7.00	5.85	3.60	
7.50	6.45	4.00	
8.00	7.00	4.60	
8.50	7.65	5.20	
9.00	8.17	5.80	
9.50	8.90	6.00	
10.00	9.70	7.35	
$R_s$	PARTS OF UNIFORM DEPTH	GREATER OF $2R_v$ OR 10T FOR $R_v$ UP TO 1.00	
	PARTS OF NON-UNIFORM DEPTH	$R_v$	$R_s$
		0 TO .50"	GREATER OF $3R_v$ OR .75"
		.56" TO 1.00"	LESSER OF $2R_v$ OR 1.50"
	GREATER OF 2.00" OR 1.30 $R_v$ WHEN $R_v$ IS MORE THAN 1.00"		
Rs SHOULD BE AT LEAST TWO TIMES VALUES ABOVE WHEN METAL FLOW INTO THE DIE IS RESTRICTED BY PART SHAPE OR DRAWING FORCE CONCENTRATED AT A FOCAL POINT ON THE PUNCH.			

Table 4.2 Typical Radii in Drawing

Table 4.3 Common Drawing Defects

DEFECT	CHARACTERISTICS	CAUSES
Flange wrinkles	Radial ridges on shell flange metal	Insufficient blank holder pressure, excess lubrication, die and blank faces not parallel
Wall wrinkles	Vertical ridges on the side wall of drawn shells	Insufficient blank holder pressure
Puckers	Ripples on the wall running down from the flange	Insufficient blank holder pressure, too few drawing operations
Step rings	Depressions on the side walls of shells	Level radii are too sharp, redraw die radius too sharp
Draw marks	Vertical score lines on the outside of the shell	Rough draw surface, inadequate lubrication, dirt or foreign matter on metal or die
Orange peel	Rough or open appearance on side wall or at corner of shell	Excessive blank holder pressure, insufficient cold working
Miss strike	Uneven shell height or flange width	Incorrect tool setting, misalignment of punch or blank, blank skidding due to uneven pressure
Earing	High points on top of shell	Worn die on blank holder causing pinch, poor physical properties of metal
Burnished spots	Wide burnished portions on shell wall	Insufficient clearance
Fractures	Defects appearing in shell corners	Excessive pressure, radii too small or too sharp, insufficient clearance

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## CHAPTER 5

### SPINNING

#### PROCESS

The spinning process involves the forming of a disc of sheet metal into a conical, hemispherical, or cylindrical shape. The forming is done by application of pressure by a roller or spinning tool on the metal piece while it is being rotated by a revolving wood or metal form called a "chuck" in a spinning lathe. Conventional spinning and displacement spinning are the two categories in this method of metal forming.

Conventional spinning involves forming of the metal back along the chuck. The area of the blank must be about equal to the shell area and the shell thickness remains constant. Displacement spinning involves an ironing of the metal back along the chuck. In this process a smaller and thicker blank is used so the difference between the blank and shell areas is equalized by thinning out a portion of the thick blank. A comparison of these two spinning methods is shown in Figure 5.1.

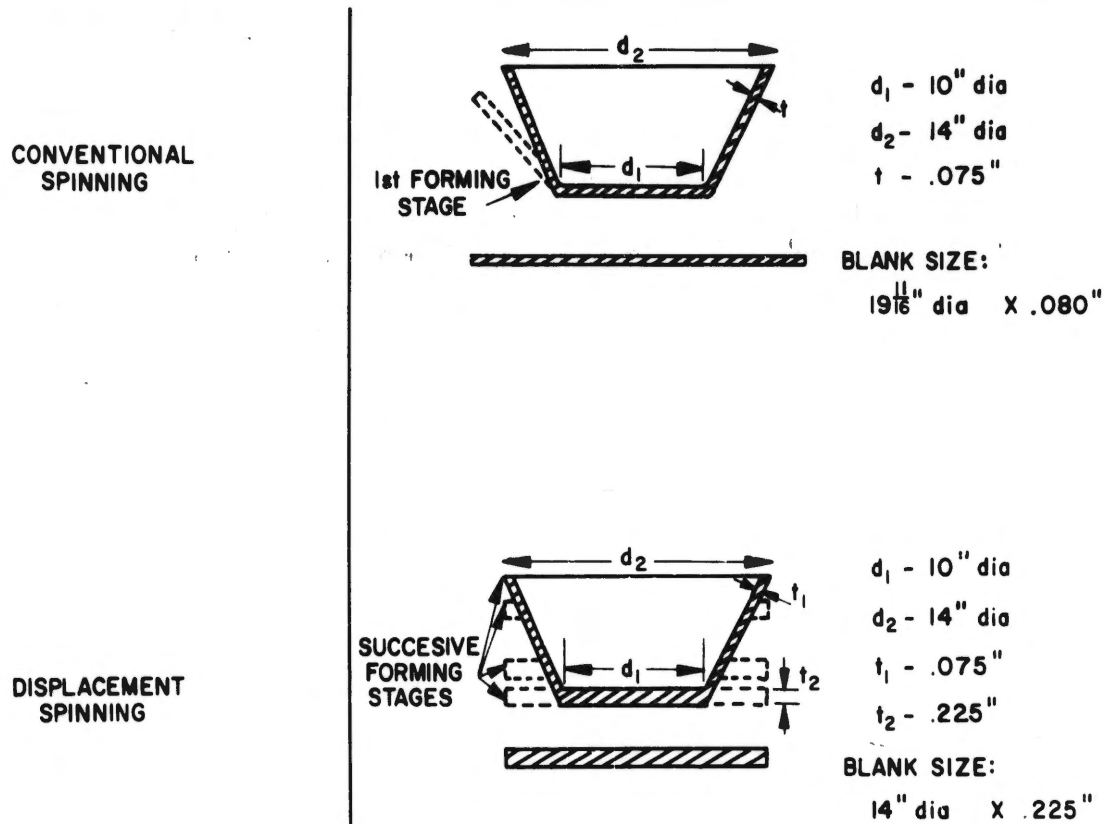


Figure 5.1 Comparison of Basic Spinning Methods

#### Conventional Spinning

**Chuck Spinning.** This method refers to the spinning of open shapes with no reentrant contours. The shape in chuck spinning can be produced in tiers and by one or more regular spinning operations. This is the most common method of spinning.

**Sectional Chuck Spinning.** This method is used mainly on drawn shells to produce shapes having reentrant contours in which the neck or opening is smaller than the body. Sectional chucks must be carefully made and well matched at the section joints to prevent marks from showing on the finished shell. The best material for these sections is steel but cast iron, hardwood, masonite, or other cheap materials can be used for short runs. These cheaper materials, however, break down more readily and thus require more frequent servicing of the joints.

**Internal roll spinning.** This is an improved method of spinning reentrant shapes, such as bulges and necks, is capable of higher production speeds since the piece can be quickly removed from the roll without taking the tool apart. The chuck and tail bar are on the same center and the roll is offset to make contact with the shell wall. A typical operation is shown in Figure 5.2.

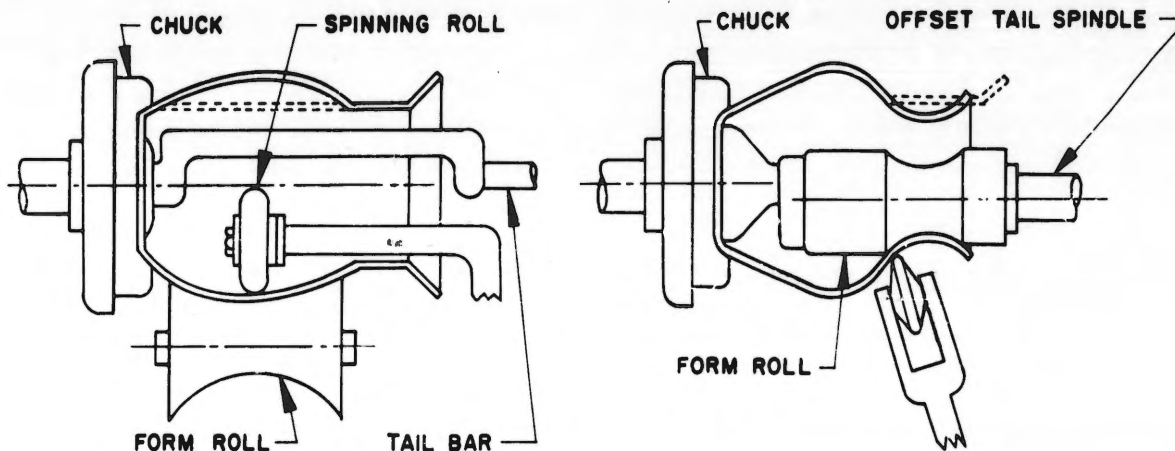


Figure 5.2 Typical Internal Roll Spinning Setup

**Other Spinning Methods.** In addition to the regular production of spun holloware, spinning lathes may be used for finishing operations on shells which have been partially fabricated on draw presses. These operations include ironing wrinkle marks from drawn shells, trimming and beading, rolling grooves or ribs, knurling decorative lines or shells, and other similar processes.

### Displacement Spinning

**Hydrospin Process.** In the Hydrospin process, a metal disc type blank is rotated at high speed while two opposed rollers force the material onto a rotating mandrel. The Hydrospin machine is semiautomatic and hydraulically controlled giving it both tremendous power and unusual flexibility.

A major use of the Hydrospin machine is in the production of dome-shaped contoured aircraft components. These parts were previously produced by fabricating two sections and then welding them together. It is used also in the manufacture of high temperature parts such as jet exhaust cones and engine parts.

Hydrospinning has the advantage of producing extremely strong parts with maximum resistance to fatigue failure. When the metal is Hydrospun, it undergoes a shear deformation which greatly elongates the grain structure. This deformation results in work hardening of the metal with a resultant increase in tensile strength.

**Floturn Process.** Floturn is a trade name of a Lodge and Shipley process. In Floturning the metal is displaced parallel to the centerline of a part in a spiral manner. This spiral displacement is accomplished by flowing the metal over a mandrel using a roller that is actuated by mechanical or hydraulic forces.

Basically Floturn differs from spinning in the following manner. In spinning, a blank considerably larger than the finished piece is used. Using pressure, the blank is folded in a circular manner, using a hard tool against a round mold. This requires considerable skill by the operator. In the Floturn method, the blank diameter is the same as that of the finished part, but the thickness is heavier, and the additional metal provided by this heavier thickness is flowed into the extended shape. The machine controls all operations and all workpieces are produced to uniform accuracy.

Advantages of Floturn include low tooling costs, increased strength and hardness, and excellent surface finish. A typical Floturn lathe (#40) will handle blanks up to 42 inches in diameter and 24 inches in length. Other units can handle lengths up to 50 inches.

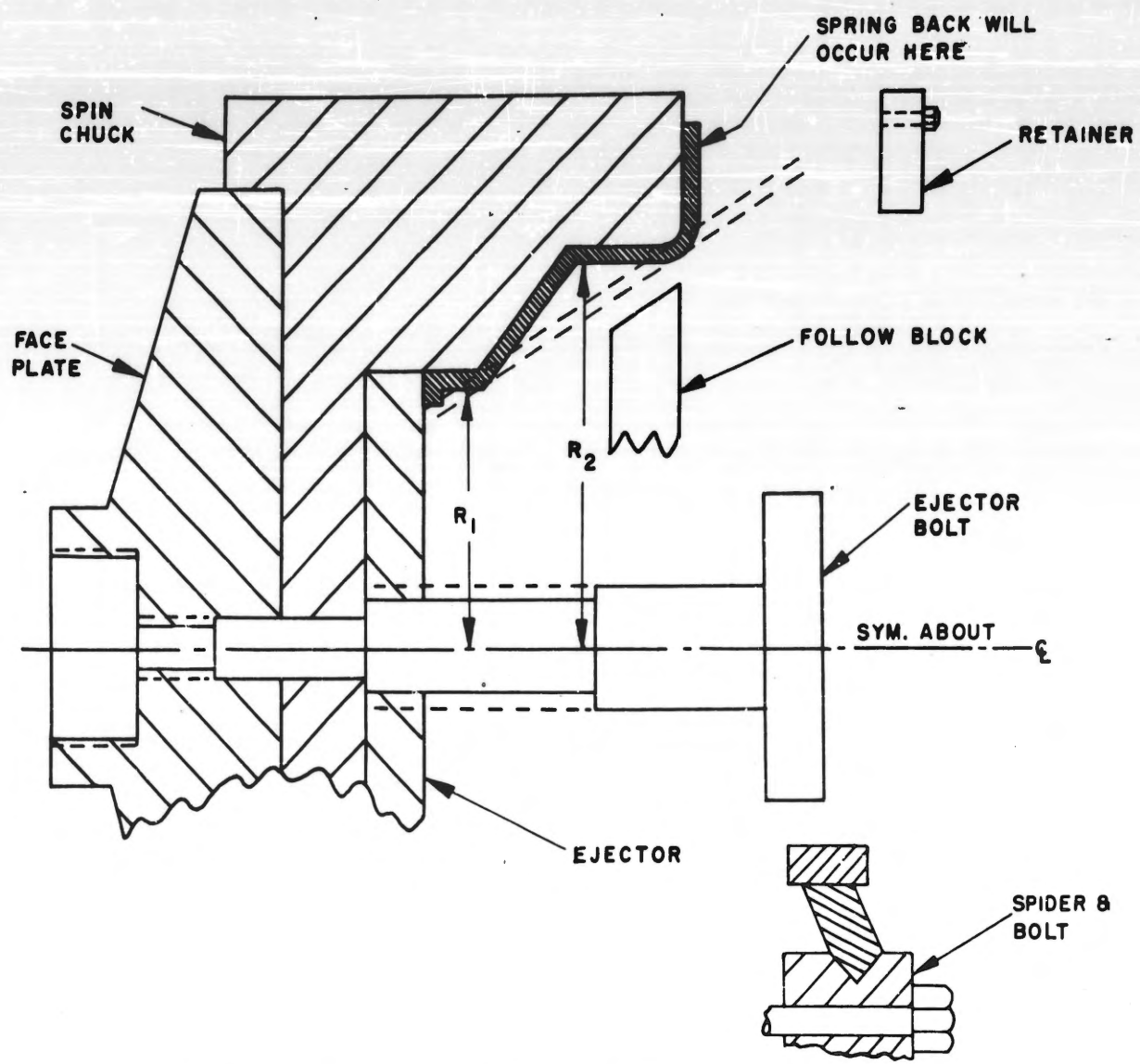
Typical tolerances that may be held are 0.002 inch on wall thickness, 0.002 inch on inside diameters up to 6 inches, 0.003 inch on inside diameters over 6 inches, and 0.005 inch on length.

#### Equipment

Spinning equipment is basically a special design of lathe, larger and more powerful with a speed control. Typical spinning capacities are shown in Table 5.1 and a typical set-up is shown in Figure 5.3.

MATERIAL	ALLOYS ( IN ORDER OF FORMABILITY )	PART DEPTH ( INCHES )	MATERIAL GAGE ( INCHES )	
			MINIMUM	MAXIMUM
ALUMINUM AND MAGNESIUM	3003 Magnesium (Hot Form) 7075	0 TO 2.5	.020	.125
		2.6 TO 5.0	.032	
		OVER 5.0	.051	
	2024  5052	0 TO 2.5	.032	
		2.6 TO 5.0	.051	
		OVER 5.0	.064	
STEEL	Low Carbon Steel			.075
	CRES 302 Annealed			.062

Table 5.1 Typical Capacities of Spinning Equipment



IF  $R_1$  &  $R_2$  DIFFER GREATLY, THERE IS A LARGE CHANGE IN DIAMETER AND THE SET-UP SHOWN ABOVE (WITH CONICAL BLANK) SHOULD BE USED. IF THERE IS NO GREAT DIFFERENCE BETWEEN DIAMETERS AT  $R_1$  &  $R_2$ , A CYLINDRICAL BLANK SHOULD BE USED, AND THE FOLLOW BLOCK AND RETAINER SHOULD BE REPLACED BY THE SPIDER AND BOLT.

Figure 5 3 Typical Spinning Setup

Spinning tools are either bar-type or roller-type. Bar-type spinning tools are usually made from brass or bronze while the roller-type are usually hardened and polished steel discs. Usually yellow naphtha soap is used as the lubricant in spinning.

The spinning blank can be either a flat disc, a piece of tubing, or a welded tubular or conical section. The blanks may have sheared edges but they must be cut cleanly. Rough edges must be ground or machined smooth before spinning to avoid cracking. Most spinning operations require trimming either before or after the finish forming. The cutting tool used in trimming is similar to a bar type spinning tool but is provided with sharp cutting edges.

### Materials

Practically all metals that are available in sheet form can be spun. Hand spinning can be done on aluminum alloys up to 1/4 inch thickness, low carbon steels and brasses up to 3/16 inch thickness, and stainless steels up to 1/8 inch thickness; recommended stock thicknesses are shown in Figure 5.4. Although most common metals are cold spun, it is sometimes advantageous to hot spin in order to reduce the forces required. Molybdenum, titanium, and magnesium alloys are all usually spun at moderately elevated temperatures, somewhere between the range of cold spinning and true hot spinning.

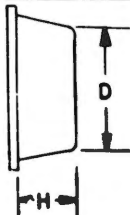
BLANK DIAM. (INCHES)	ALUMINUM		STEEL	
	MIN.	MAX.	MIN.	MAX.
LESS THAN 4	.025	.045	.020	.040
4 TO 20	.032	.080	.025	.063
MORE THAN 20	.040	.125	.032	.080

Figure 5.4 Recommended Stock Thickness for Spinning

### DESIGN CONSIDERATIONS

The height-to-diameter ratio, as shown in Figure 5.5, may be used as a general guide to the number of operations required, assuming other factors do not add to the difficulty of working the blank to shape. If the ratio is high, there will be a relatively large area of metal to be worked and, in order to maintain control of the flow, one or more breakdown steps may be necessary. If the height-to-diameter ratio is low, the blank can be easily spun to shape in one operation.

ALLOY	METAL THICKNESS (INCHES)		
	LESS THAN .032	.032 TO .064	MORE THAN .064
3003	.60	.75	.80
2024	.45	.60	.65
5052	.37	.55	.62
6061	.50	.70	.75
7075	.60	.75	.80
LCS	.40	.52	.60
CRES (STABILIZED)	.37	.45	--
CRES 302 - A	.32	.40	--



NOTE: FLANGES LESS THAN .060" NEED NOT BE CONSIDERED AS AFFECTING DEPTH (H)

Figure 5.5 Height - to - Depth Ratios for Spinning

Spinnability and thickness are also important design considerations. A tough metal will not respond as easily to spinning as one which is highly plastic. Also, as blank thickness increases, it becomes more difficult to work the metal thus necessitating additional operations. Very thin blanks may require more careful spinning than average blanks, even to the extent of extra operations, because of their higher tendency to wrinkle. Table 5.2 lists the adaptability of various metals to spinning.

Although springback is usually a condition that has to be corrected by the shop, it is mentioned here to acquaint the designer with the fact that such a condition does occur. Springback oftentimes makes it difficult to produce a flat surface on a flange within any strict tolerances. If thicker material is allowed for the flange, there will be less springback. Thin sections at radii should be avoided whenever possible to eliminate springback.

General design considerations regarding tolerance, configuration, and stock thinning are shown in Figures 5.6, 5.7, and 5.8.

NOMINAL DIAMETER OF PART (INCHES)	MINIMUM TOLERANCE		
	D (INCHES)	L (INCHES)	$\theta$ (DEGREES)
UNDER 1.5	$\pm .010$	$\pm .015$	$\pm 1$
1.5 TO 5.0	$\pm .015$	$\pm .030$	$\pm 3$
5.0 TO 20.0	$\pm .030$	$\pm .030$	$\pm 3$
20.0 TO 36.0	$\pm .060$	$\pm .045$	$\pm 5$
36.0 TO 72.0	$\pm .120$	$\pm .060$	$\pm 5$

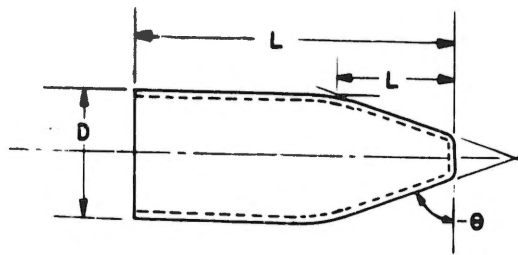


Figure 5.6 Typical Spinning Tolerances

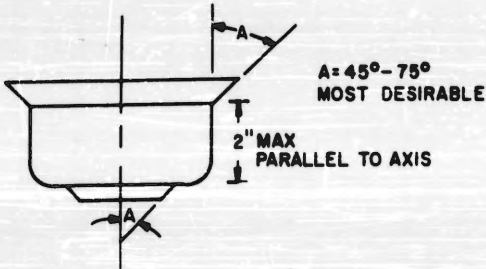
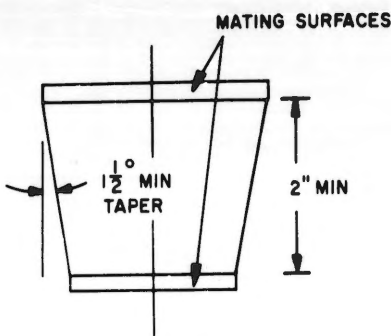
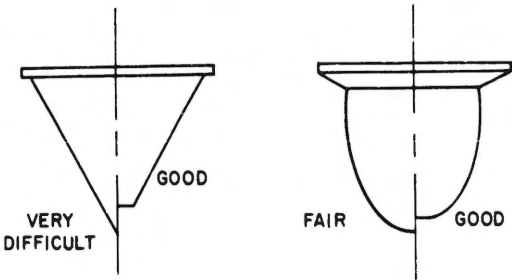
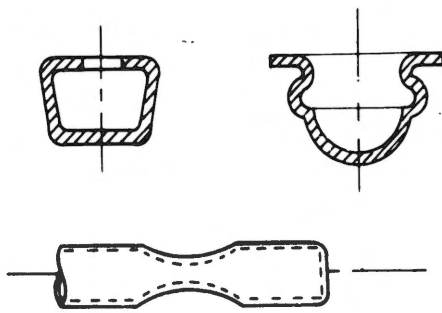
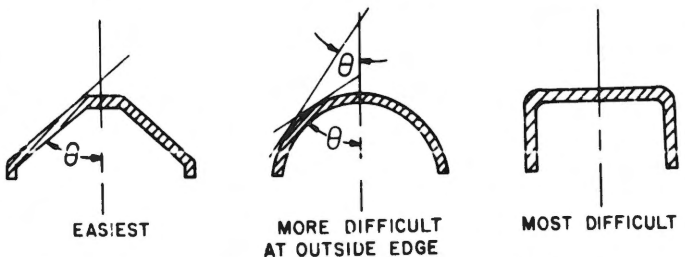
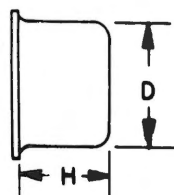
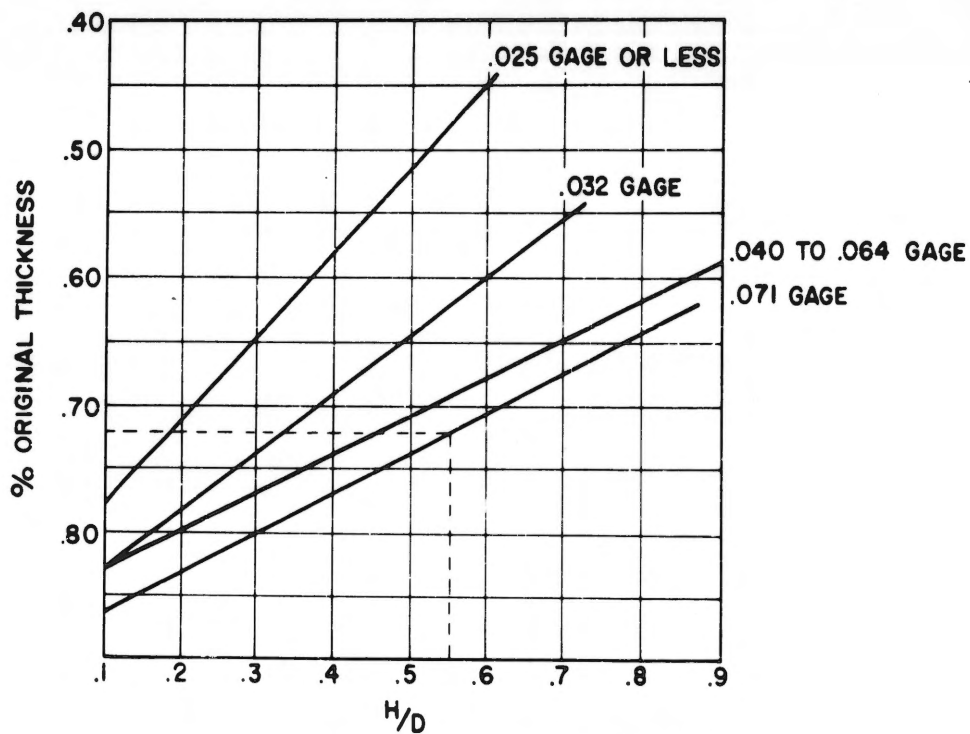
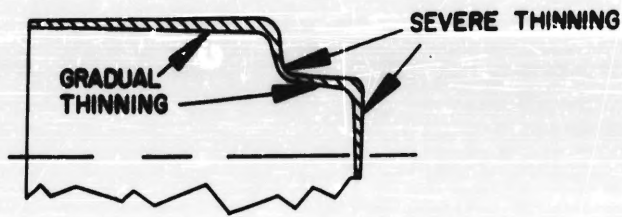
<p>MINIMIZE NUMBER OF SURFACES PARALLEL TO PART AXIS.</p>	
<p>USE <math>1\frac{1}{2}^\circ</math> MINIMUM TAPER ON PARTS DEEPER THAN 2 INCHES, EXCEPT FOR MATING SURFACES.</p>	
<p>MAINTAINING A SMALL FLAT AT BOTTOM OF PART IS DESIRABLE WHEN POSSIBLE: DIAMETER SHOULD BE AT LEAST 10% OF OVERALL DIAMETER.</p>	
<p>AVOID REENTRANT CONTOURS.</p>	
<p>SPINNING DIFFICULTY INCREASES AS ANGLE BETWEEN SURFACE AND AXIS DECREASES.</p>	

Figure 5.7 Spinning Shape Considerations



EXAMPLE: .071 GAGE, H=5.5, D=10  
 $H/D = .55$ ; AT .071 GAGE LINE,  
 THINNING IS .724 %.

MIN. THICKNESS AFTER SPINNING  
 IS  $.724 \times .071 = .051$ .

Figure 5 8 Stock Thinning in Spinning Aluminum Parts

Table 5.2 Relative Adaptability of Metals to Spinning (see note)

Material Type	Shallow Spinning	Deep Spinning
<b>Aluminum Products</b>		
1100	1.00	1.00
3003	1.00	.99
2024	.65	.45
5052	.80	.55
6061	.90	.80
<b>Copper Products</b>		
Cold Rolled, Annealed	1.00	1.00
Hot rolled	.99	.88
Yellow Brass	.99	.92
Low Brass	.96	.89
Red Brass	.90	.83
Commercial Bronze	.88	.80
Gilding Metal	.85	.75
Admiralty Brass	.82	.70
Naval Brass	.75	.45
Muntz Metal	.55	.30
Phosphor Bronze, Grade A	.85	.40
Phosphor Bronze, Grade C	.85	.45
Cupro Nickel, 70-30	.95	.65
Nickel Silver, Grade A	.95	.65
Silicon Bronze	.94	.60
<b>Carbon Steel Products</b>		
Cold Rolled, Deep Drawing Quality	1.00	1.00
Vitreous Enameling, Deep Drawing and Spinning Quality	1.00	.95
Standard Cold Rolled	1.00	.92
Hot Rolled, Pickled and Oiled	1.00	.92
Hot Rolled Low Carbon	.90	.55
Hot Rolled Copper Bearing	.88	.51
Lead Coated (Long Terne)	1.00	Impractical*
Galvannealed	1.00	Impractical*
Galvanized	.90	Impractical*
High Tensile	.45	.15
High Carbon	.25	.10
<b>Stainless Steel Products</b>		
302	.98	.60
304	.98	.90
305	1.00	1.00
309S	.80	.45
316	.90	.60
321	.85	.50
347	.90	.50
430	.90	.50

Table 5.2 Relative Adaptability of Metals to Spinning (see note) (Contd)

Material Type	Shallow Spinning	Deep Spinning
<b>Nickel Products</b>		
Monel, Spinning Quality	1.00	.90
Monel, Special Cold Rolled Soft Temper	1.00	.85
Inconel	.90	.70
'L' Nickel	1.00	1.00
Nickel	1.00	.92
Haynes Alloy, Multimet N155	.90	.50
Haynes Alloy, Hastelloy A	.75	.35
Haynes Alloy, Hastelloy B	.70	.30
Haynes Alloy, Hastelloy C	.50	.10
<b>Other Metal Products</b>		
Lead	.96	.90
Pewter	1.00	.99
Zinc	1.00	1.00
Tantalum	.86	.45
Magnesium	.80	.45
Molybdenum	.55	.15

\* Coating will flake off.

Note: The unit 1.00 is given to the type of material in each group which lends itself most readily to forming by the cold metal spinning process. The lower the figure, the higher the cost. These figures will vary somewhat, depending on special circumstances such as contour of article to be spun, gauge, size, etc.

All metals listed are formed by cold spinning except magnesium and molybdenum which, for all practical purposes, must be hot spun.

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**CHAPTER 6**  
**RUBBER FORMING**

**PROCESS**

Rubber forming is a method of forming sheet metal in which a block of rubber is used usually as the female die. This process is sometimes referred to as entrapped rubber forming. Figure 6.1 shows a typical operation. Bulging operations, as shown in Figure 6.2 may also be performed by this method.

**General**

The fact that rubber readily changes its shape under pressure and flows in all directions offers a practical, low cost method of producing parts from sheet stock. The aircraft industry pioneered the rubber forming processes as early as 1935 and today, it is one of the industry's major production techniques.

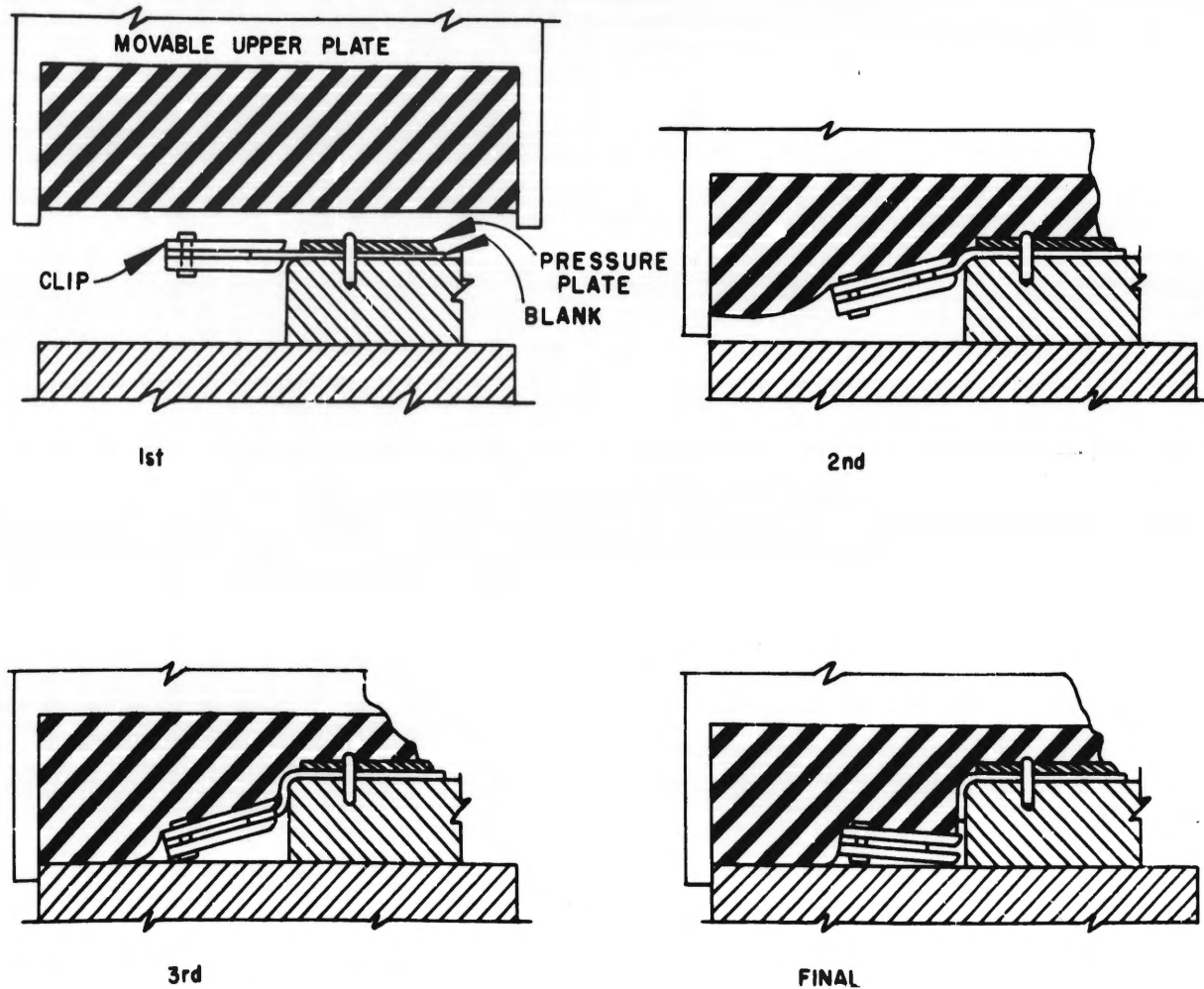


Figure 6.1 A Typical Rubber Forming Operation

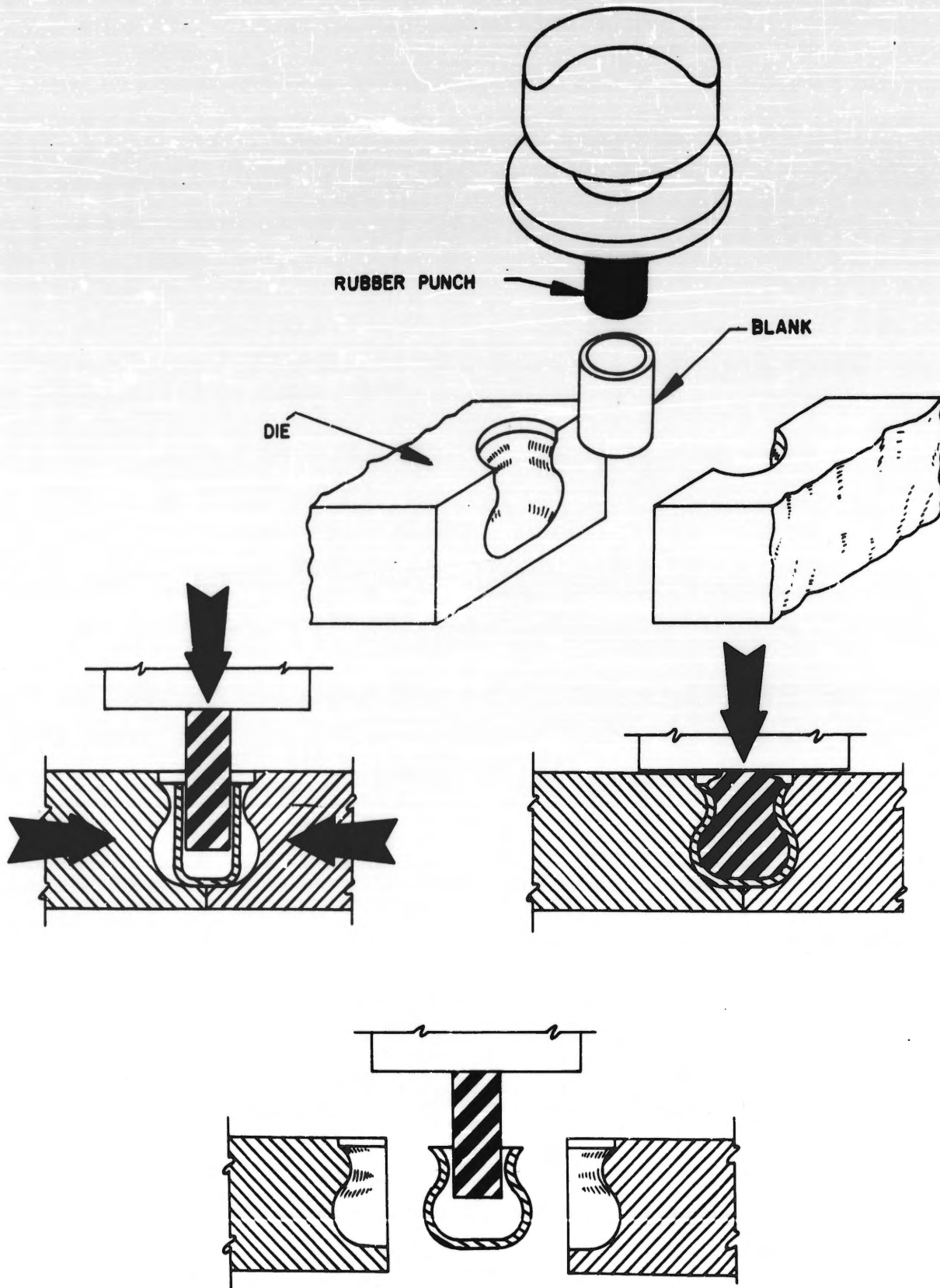


Figure 6.2 A Typical Bulging Operation Using Rubber Punch

The basic rubber forming processes are the Marform process, Hydroform process, Guerin process, and Verson-Wheelon process. Each of these processes and their advantages will be discussed separately.

The rubber itself has several factors that must be considered. The rubber must be capable of forming readily to the shape of the die. It must be hard enough to produce the necessary bending, forming, or shearing action required. It must not be too hard to flow freely into the die or punch cavities prior to the application of maximum pressure. The rubber should also have good wear qualities, resistance to cutting action of burred edges, and resistance to heat.

### Marform Process

The Marform process, as shown in Figure 6.3, is a method of deep drawing where the rubber pad is, in effect, a universal die which shapes itself to the form of the punch as the drawing operation proceeds and pressure is applied. The rubber pad in the top container is fairly hard and thus a considerable pressure is needed to cause the rubber to flow and conform to the punch contour. The pressure in rubber forming is always applied by a hydraulic press since this type of press offers the required pressures and speed control.

An advantage to this process is that a rubber pad and hydraulic unit can be fitted to any ordinary single-action hydraulic press of sufficient power. Economically, the tools required are inexpensive and easy to manufacture, a punch and pressure ring being all that is required. For products of the same internal size and form, but of different gauges of material, only one punch and ring are required as the rubber automatically compensates for the thicker and thinner materials. Since the units which were attached to the standard presses proved so successful, certain manufacturers started producing self-contained machines where the controls, hydraulic unit, and rubber pad are all integrated into one machine.

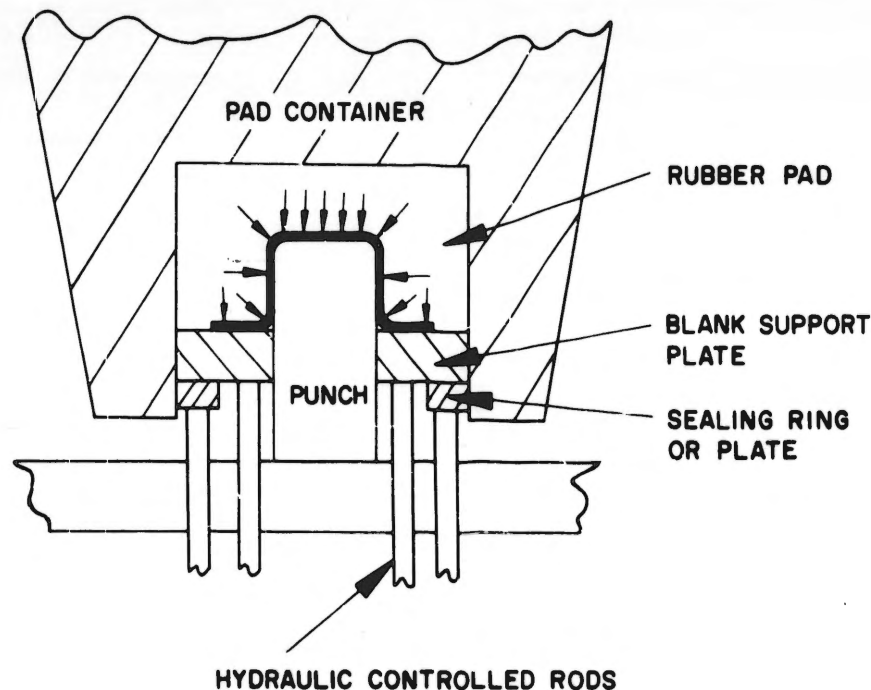


Figure 6.3 The Marform Process

**Advantages.** Marform process advantages include the following:

- (1) deep drawing of one or more different or identical parts is possible during a single press cycle.
- (2) simplified tooling substantially reduces costs as compared to matched steel die
- (3) inexpensive tooling and quick changeover make short runs both economical and practical.
- (4) complex and unusual parts are readily formed thus eliminating the need for complicated dies.
- (5) tapered shapes can be drawn with greater slope and depth than is possible with conventional dies.
- (6) controlled pressure during press cycle results in more uniform wall thickness of the drawn part.
- (7) formed parts require little or no hand work when removed from press.
- (8) since fewer draws are required to complete the part, possible annealing operations are eliminated.

**Hydroform Process**

Hydroforming, as shown in Figure 6.4, is a recent innovation in sheet metal forming, being introduced in 1951. The name is adopted from the fact that the solid rubber pad is replaced by a rubber diaphragm backed up by hydraulic pressure. The diaphragm is sealed to withstand the high pressures (up to 15,000 psi) created by the hydraulic fluid.

The extremely high pressures are not required for all materials or shapes of product; therefore, by using the appropriate pump control, the pressure most suitable for any given part or material can be chosen. The backup pressure naturally cannot be constant or the diaphragm would burst when not in contact with the workpiece.

**Advantages of Hydroforming.** An advantage of Hydroforming is that there is very little, if any, thinning of the metal being worked. This is because as the pressure builds up in the cavity, the metal blank is gripped very tightly between the punch and the diaphragm and a frictional effect is set up which prevents slide. This locking effect of the metal to the punch also gives the advantage of bigger reductions per draw. One or two Hydroforming operations will usually perform the same work that would require four or five draws. Of course, the greatest advantage of the Hydroform process is the same advantage that applied to the Marform process--the fact that only two parts are needed for the tool.

Other advantages include the following:

- (1) both simple and intricate shapes can often be drawn in a single operation.
- (2) universal function of the upper die member eliminates need of a matching die.
- (3) male dies or punches are easily produced and handled on the press.
- (4) more than one blank can be formed on the same die in one press cycle.
- (5) surface finishes are not marred or blemished when formed under fluid pressure.
- (6) tool mounting is simple and setups and changeovers can be rapidly made.
- (7) punches can be easily reworked or corrected if faulty.
- (8) springback is reduced to a minimum.
- (9) parts can usually be produced faster.

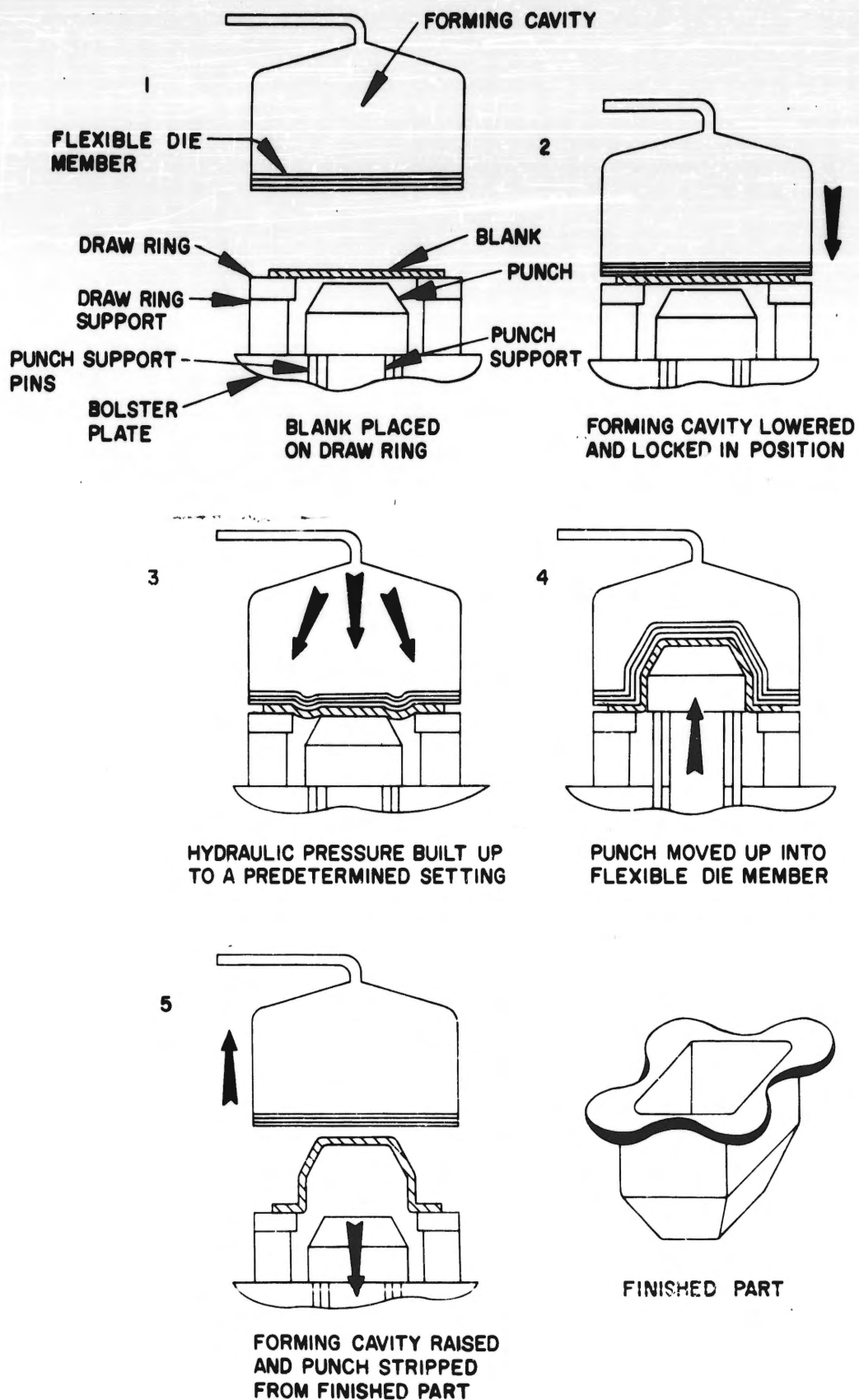


Figure 6.4 The Hydroform Process

## Guerin Process

The Guerin process, as shown in Figure 6.5, is used in the forming of shallow parts in rubber dies rather than metal dies. Several thin rubber layers are confined in a container which is mounted to a ram. The ram is lowered and the compressive forces from the rubber form the part by forcing the metal blank to assume the shape of the form block.

Advantages of the Guerin Process. The Guerin process produces lower pressures and shallower draws than the Marform process. Pins are usually used to prevent slippage of the blank when forming is taking place. The advantages and design considerations of the Guerin process are approximately those of the Marform process. The difference between the processes is only the lesser pressures and draw depths experienced in the Guerin process.

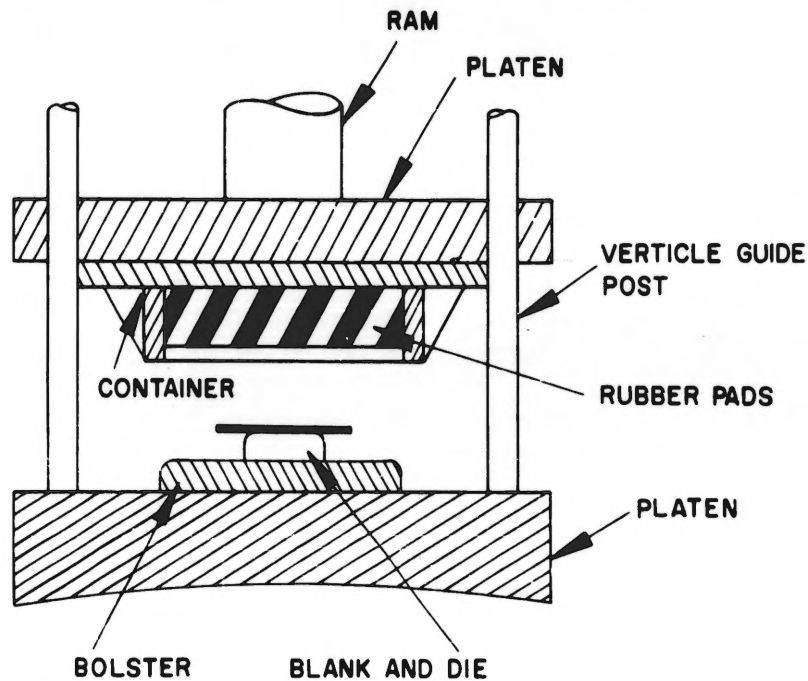


Figure 6.5 The Guerin Process

### Verson-Wheelon Process

The Verson-Wheelon process, as shown in Figure 6.6, differs from the other rubber forming processes in that no mechanical force is used in forming the part. This process employs a flexible neoprene bag or fluid cell which can be filled with hydraulic fluid causing it to expand or contract. The operation is performed on a Verson-Wheelon press. The entire forming operation is performed within a cylindrical steel housing. The work blank is put on the forming die and covered with a rubber pad. The collapsed bag is above the pad. As hydraulic fluid is introduced, the bag expands and causes the rubber to form the blank below it to the shape of the forming die. Since the flexible bag inflates equally at all points, the pressure is uniform across the rubber pad. The uniformity of pressure is much greater with this process than with those using a piston arrangement. Naturally there is very little unbalance in the press due to the equal pressure distribution. The Verson-Wheelon press can form a variety of shapes and sections. Some typical work produced on these presses are straight bends, channel sections, curved flanges, lightening holes, beads, ribs, offsets, contouring and bending of rolled formed sections and extrusions.

Advantages. Verson-Wheelon process advantages are as follows:

- (1) tooling is simple. Male form blocks are easy and inexpensive to make and simple to rework.
- (2) no bolting or balancing of male form block is necessary.
- (3) high forming pressures tend to eliminate wrinkling. Hand working after forming is almost entirely eliminated.
- (4) assist-tooling which is often required on conventional hydraulic presses is almost entirely eliminated on the Verson-Wheelon press.
- (5) higher working pressures can be anticipated without resorting to large and cumbersome press members.

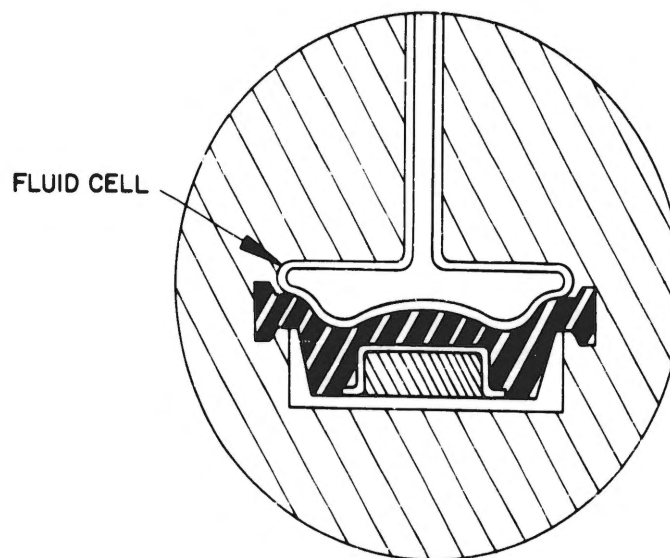


Figure 6.6 The Verson-Wheelon Process

## DESIGN CONSIDERATIONS

### General

Some general design features to consider in rubber forming are listed below:

- (1) the hardness of the sheet should be between that of soft aluminum and that of half-hard stainless steel.
- (2) the maximum allowable flange width can be calculated by use of the following formula:

$$F = \frac{RE}{1 + E - \cos X} \quad \text{where}$$

R = radius of flange in bend, inches.

E = permissible elongation, %. (see note)

F = flange width, inches.

X = flange angle, degrees.

Note: elongation should be computed at approximately 50% of maximum value to allow for normal rough edges on the material.

- (3) the normal flange angle tolerance is plus or minus 1 degree for soft material and plus or minus 5 degrees for harder materials.
- (4) the mold line tolerance, as shown in Figure 6.7, is plus or minus 0.015 inch for soft material and plus or minus 0.020 inch for harder materials.

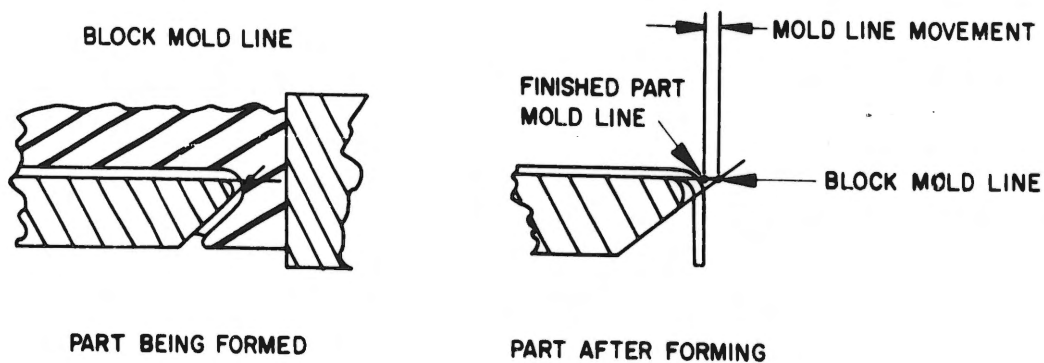


Figure 6.7 Mold Line Tolerance in Rubber Forming

The elastic recovery of the material causes flange springback. If the material is forced into complete contact with the die block, the springback is governed by the material characteristics and not by the pressure. A condition similar to that in Figure 6.8 occurs.

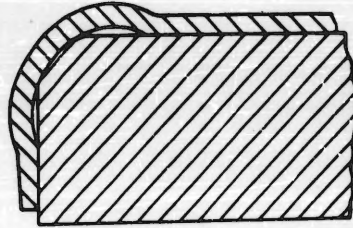


Figure 6.8 An Example of Springback

It is in the transition region between the bend radius and the block that the greatest recovery occurs and, since the higher pressures insure more intimate contact, the springback is actually less at high pressures than at low pressures.

Employment of a minimum bend radius, rather than a generous bend radius, will keep the springback problem at a minimum. Soft tempers and hot forming operations minimize springback.

To compensate for the angular recovery, blocks are usually undercut from 1 to 3 degrees so that the part will result in the correct bevel angle as shown in Figure 6.9.

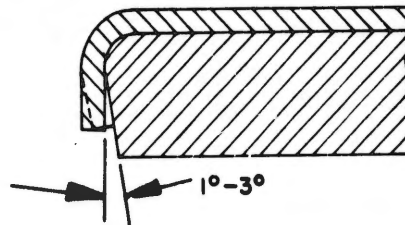


Figure 6.9 A Typical Method of Reducing Flange Springback

If a flat surface is required, it may be advisable to dish or compensate the face of the die so the recovery will be flat as shown in Figure 6.10.

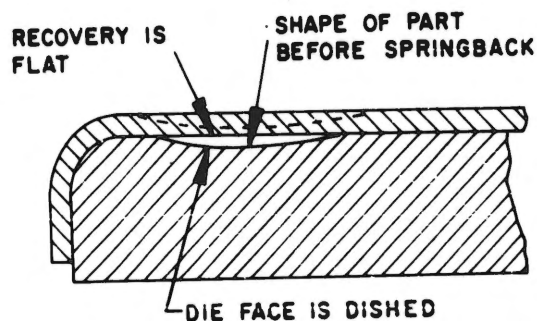


Figure 6.10 A Typical Method of Attaining Flat Surfaces in Rubber Forming

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**CHAPTER 7**  
**STRETCH FORMING**

**PROCESS**

**General**

The term "stretch forming" is applied to the process of forming wrought metal by applying tensile loads to a material in such a way as to cause permanent strain in varying degrees necessary to produce the required shape. This is done by stretching the material over a tool or stretch block. The material is gripped by the stretch forming machine and a load is applied to strain the material beyond its elastic limit. As the load is gradually released, the material loses some of its elastic strain and will contract uniformly around the contour of the stretch block.

In stretch forming, all fibers in the cross-section are stretched in tension beyond the elastic limit, while in the bending method, some fibers are compressed and some are stretched (see Figure 7.1). Thus, in stretching, a permanent set in the metal is accomplished with a minimum of springback.

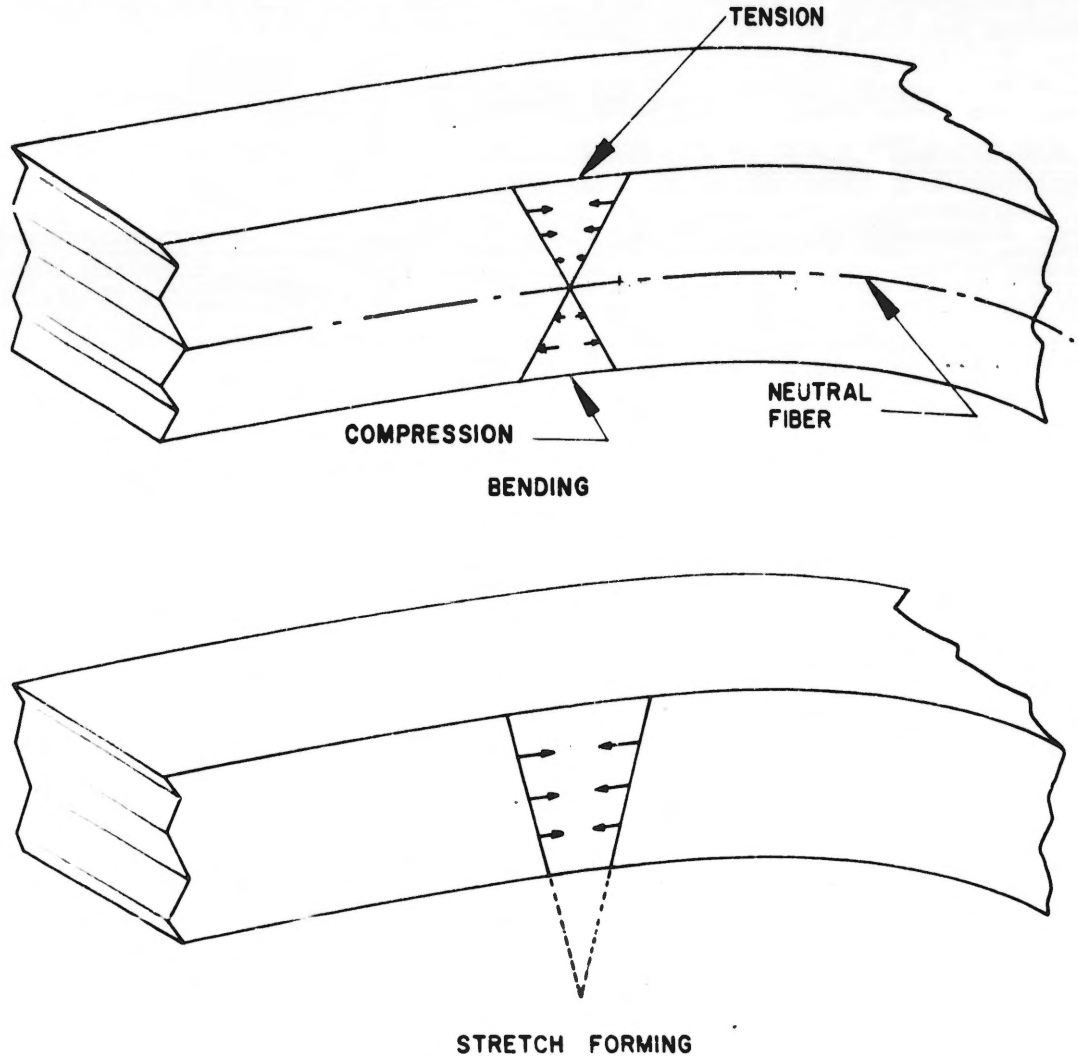


Figure 7.1 Theory of Stretch Forming

There are seven basic methods of stretching materials:

- (1) Stretch forming (see Figure 7.2)
- (2) Stretch wrap forming (see Figure 7.3)
- (3) Contour forming (see Figure 7.4)
- (4) Rotary forming (see Figure 7.5)
- (5) Stretch wipe forming (see Figure 7.6)
- (6) Combined compression and stretch forming (see Figure 7.7)
- (7) Tangent bending (see Figure 7.8)

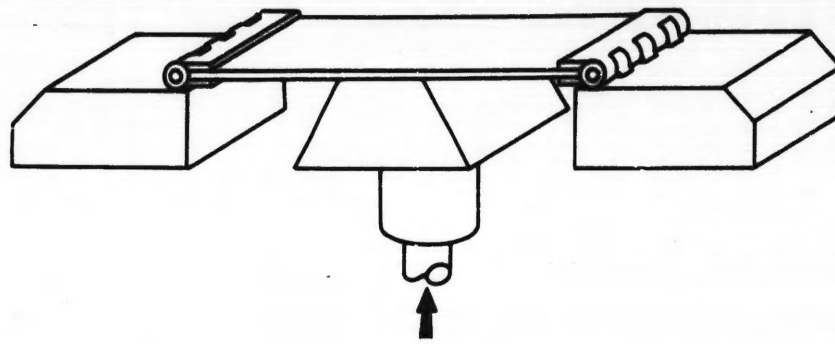


Figure 7.2 Stretch Forming

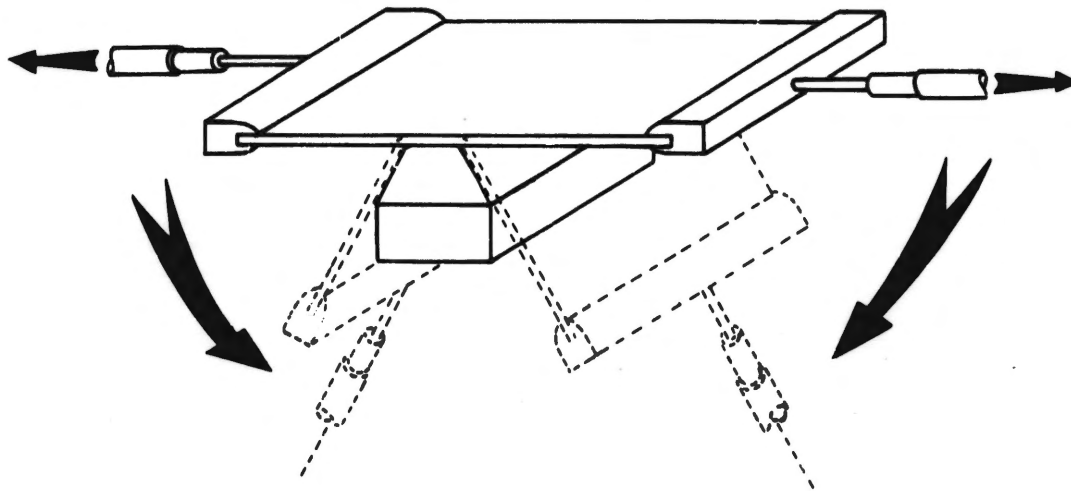


Figure 7.3 Stretch Wrap Forming

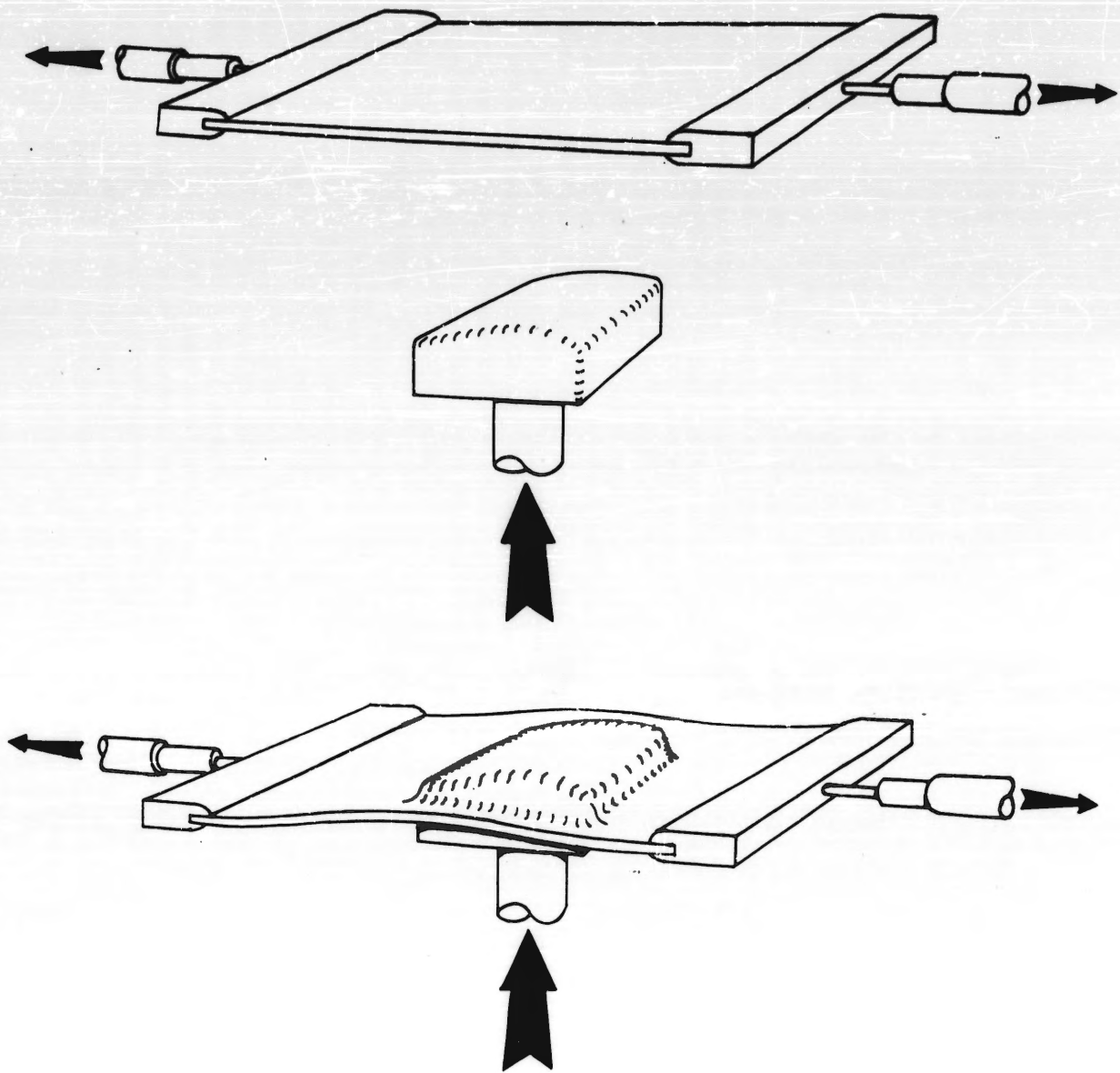
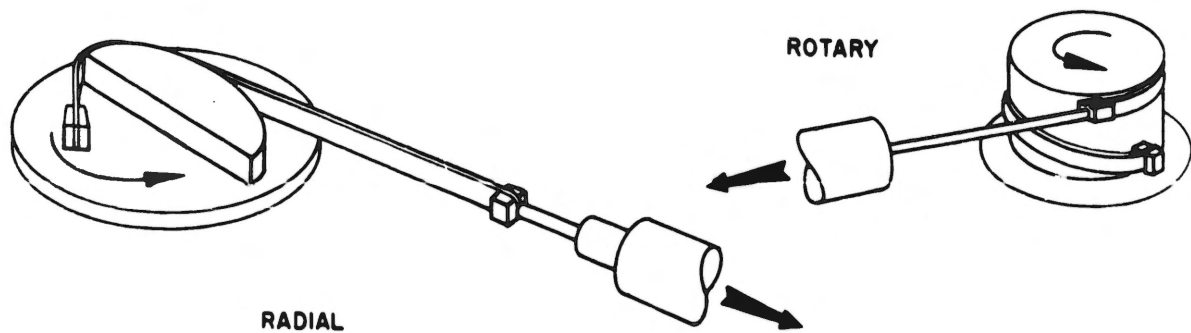


Figure 7.4 Contour Forming



RADIAL

ROTARY

Figure 7.5 Rotary Forming

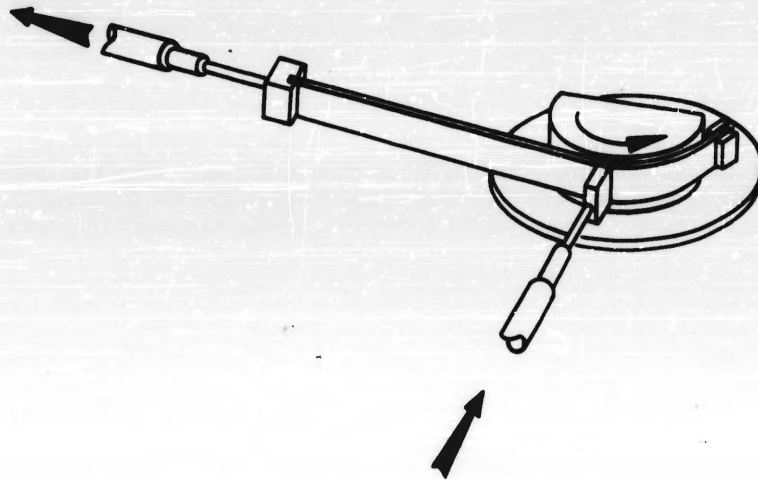


Figure 7.6 Stretch Wipe Forming

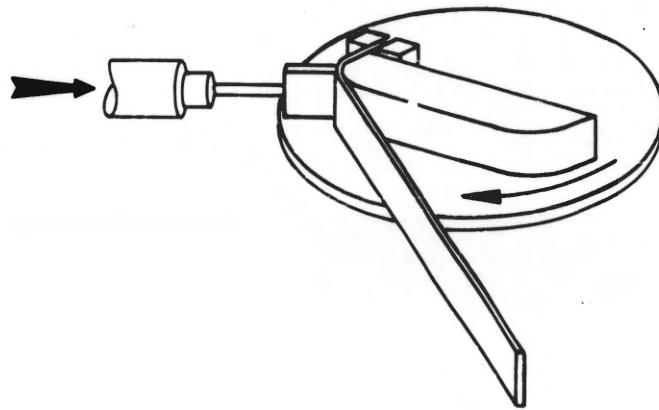


Figure 7.7 Combined Compression and Stretch Forming

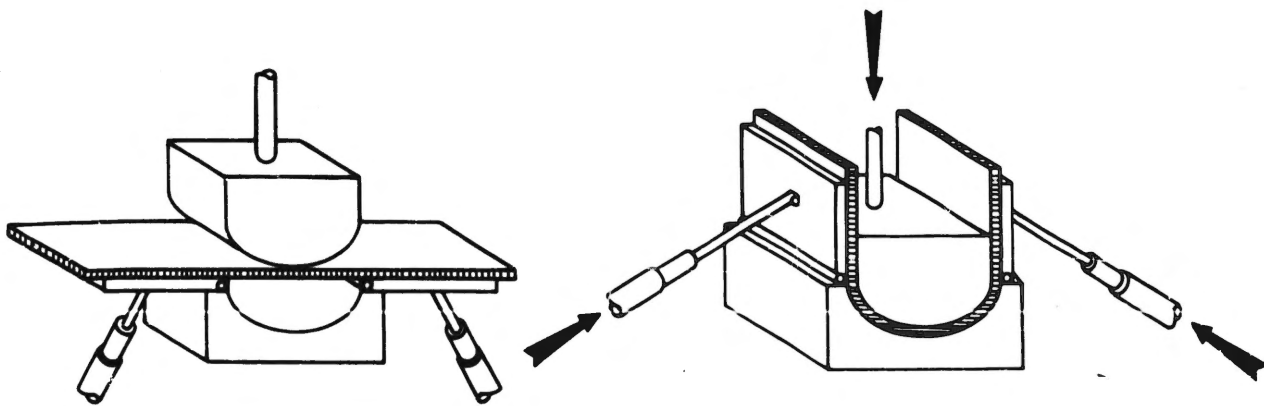


Figure 7.8 Tangent Bending

## Shapes

Not all parts can be produced by stretch forming. The ability of a part to be stretch formed depends on several factors, the most important one being contour. A positive contour is one which presents a convex surface. There must always be a positive contour in at least one orientation in a stretch formed part. Parts may be classified by contour as follows:

- (1) universal positive symmetrical (sphere or ellipsoid)
- (2) biaxial positive symmetrical (side of football)
- (3) biaxial positive asymmetrical (usual aircraft skin)
- (4) uniaxial positive (straight leading edge skin)
- (5) uniaxial positive-negative (saddleback)
- (6) combinations of (1) and (2) (curved "S"-sections)

## Materials

Any ductile material can be stretch formed since the mechanical principle involved is the same for all materials. The non-ferrous materials most commonly stretch formed are the heat-treatable aluminum alloys, which are stretch formed cold in various tempers. Titanium and its alloys are stretch formed either hot or cold. Magnesium alloys can be stretch formed but only at elevated temperatures.

## Equipment

The equipment which produces the stretch formed part is known as a stretch press. Some commercial stretch presses have become widely adopted in the aircraft industry and these will be discussed briefly below.

Erco Stretch Press. This machine is used to produce relatively symmetrical, smooth contoured parts. The steel ways on the bed have two electronically positioned holding clamp beams. Each beam has a self-energized clamping jaw unit attached to it. These jaw units grip the material and hold it over the forming die which is mounted on a movable center guide table. The table is positioned and the die raises gradually forcing the material to assume the shape of the die.

Sheridan-Gray Stretch Press. This is a transverse type stretch wrap machine which has a principle of operation similar to the Erco Stretch Press. The material is slowly raised and is formed over a stationary die until the desired elongation is reached.

800-Ton Verson Press. A heavy duty Verson forming machine has been developed to stretch form long narrow sheet stock such as wing and tail skins. The part is clamped in the jaws which pivot on the bed plate of the machine. The die is mounted on the upper ram of the machine. The part is formed by lowering the die into the material with sufficient pressure to elongate the material approximately 5%.

Hufford Stretch Press. The form blocks on this press are mounted in a stationary position between movable grippers which hold the blank in tension. Parts that can be produced on this press range from shallow single contours up to 180°. This is used for forming flat sheets and rolled or brake formed sheet metal shapes.

Stretch Leveling. This process is used in flattening metal sheets by stretching. A stretch leveler consists primarily of a set of stationary jaws to hold one end of a sheet and a set of movable jaws, actuated by a hydraulic piston, to hold the other end of the sheet. By means of hydraulic pressure the sheet is stretched past its elastic limit. This gradual stretching removes all waves and buckles from the sheet and makes it very taut and flat. Stretching beyond the elastic limit, to 1 to 2% elongation assures that the sheet will not spring back to its original shape but will spring back uniformly across the entire sheet thus re-

remaining flat. Stretch leveling is used in operations where the finished product must be perfectly flat.

**Special Equipment.** An expansion forming technique has been developed for producing large sheet metal parts such as external wing tanks. The machine in this case uses huge expanding mandrels which can exert very high radial forces. The sheets are rolled into conical shapes and welded together by heliarc welding machines. These sections are then placed over the expanding mandrel and are stretched to precise shape with a very close dimensional control. The advantages of this method of forming are no warpage, no thinning of the metal, no flash formation, close dimensional control, and economy of tooling.

When no specially designed stretch presses are available, double-action hydraulic presses can be adapted to stretch forming. In the process the die is attached to the main ram of the press. The sheet is held at both ends between heavy flat rails and holddown plates. The stock must be draped between the clamps and made long enough so that the die, as it descends, will stretch the metal sufficiently to produce a permanent set, but not enough to rupture it. The required length can be determined by trial or calculation, and should be kept the same for all sheets to obtain uniform results. Then to form the part, the die should be well lubricated and lowered to stretch the metal in much the same manner as with a regular stretch press.

#### Equipment Accessories

Certain accessories are used in stretch forming and information on these is provided mainly to give the designer a knowledge of the terminology used and the setup methods used in the shop. Some of these accessories are joggle blocks, drill jigs, scribe blocks, and snakes.

Joggle blocks are used with dies to make formed depressions or "joggles" in the workpiece at desired points. The blocks are constructed from the same materials as the dies with which they are used. After the part is formed and setting pressure applied, the joggle blocks are inserted into their proper location and forced against the workpiece by means of hand pressure, suspended squeeze presses, or auxiliary hydraulic cylinders. Dies for use with joggle blocks must have recesses machined out to permit deformation of the part under pressure from the block.

Drill jigs are used with dies to insure uniformity of hole positions in relation to contour and trim lines of the part. The accurate location of holes are useful as tooling holes in the subsequent assembly operations.

Scribe blocks furnish a true edge for scribing trim lines on a part while it is still on the die. The marking operation is performed manually with a sharply pointed scriber. The part is scribed while still on the die since this saves time as well as insures accuracy of the marking.

Snakes are flexible filler pieces which support the work during forming when certain light sections have a tendency to collapse or deform. The profile of the snake usually conforms to the shape of the part, thus offering the greatest possible support. Snakes are made from many different materials such as hardwood, fibre, lead, steel, masonite, kirksite, and others. Naturally the choice of material depends on the number of parts to be produced and the material from which these parts are to be manufactured.

If heat treatment of a part is required, the stretch forming should be done after the heat treatment and prior to aging. This will eliminate distortion which would occur if heat treating was done after forming. Another alternative may be to preform the part, heat treat it, then finish form.

## ADVANTAGES AND LIMITATIONS

Advantages of stretch forming can be summarized as follows:

- (1) difficulties due to springback are reduced.
- (2) sections once fabricated as two or more separate parts can be stretch formed as integral units.
- (3) almost any cross-sectional shape can be stretch formed.
- (4) stretched extrusions are more uniform than the parts that would normally be formed with press, hammer or roll equipment.
- (5) angles between legs of a given section can be varied with a stretch die, thus eliminating the need for considerable handwork.
- (6) tensile and yield strengths are increased, while elongation is decreased, by stretch forming extrusions or formed sections.
- (7) uniform distribution of work hardening and the elimination of localized strains is attained. This occurs because 100% stretching of the work piece insures uniform pressure at all points of the die contact during the forming.
- (8) due to stretching from both ends, physical property changes occur uniformly over the entire length of the material as it is being stretched to the desired shape.
- (9) changes in cross-sectional dimensions are likely to be uniform over the entire length of the piece rather than locally as in many forming operations.
- (10) work hardening of the material to a higher strength occurs. This work hardening is uniform throughout the part, and is not localized, as in the case of drop hammered parts. It takes place with a minimum reduction in thickness and not just on the surface of the part, as in many roll formed parts.
- (11) increase in mechanical properties, due to work hardening, allows the designer to receive even better properties from the material than existed in its condition before forming.
- (12) local thinning of a part to a point of failure is eliminated, rarely exceeding 1 to 2%. This is an important factor in stressed skin design as used in aircraft engineering..
- (13) an operator with relatively short experience can form parts with an accuracy that would require longer training for roll forming or hand finishing.
- (14) only one die is required in stretch forming, while two are used in drop hammer forming and double and single acting presses. In addition, ability to make the die with little or no springback compensation greatly reduces the labor cost. Also die material cost is reduced.
- (15) material may be formed in the heat treated or cold worked condition.
- (16) a common failure of materials formed in compression is wrinkling and buckling (compression type failures); as stretch formed parts are formed by holding the part under tension, a failure of this kind is very rare.
- (17) heat treat distortion is eliminated.

Disadvantages of stretch forming are as follows:

- (1) in the forming of sheet stock around a double curvature die, an excessive length of material must be left between the die and the jaw. This is done to minimize the stress in the sheet, caused by the changing from a curve to a straight line. This material loss may be considerable; however, the recent introduction of gripper jaws which curve to the contour of the shape reduce the material losses considerably.
- (2) the forming of a section, such as a channel around a minimum curvature die can sometimes cause an excessive amount of stretch in the outer fibers of the part. If the part fails, due to this excessive elongation, the stretching force may be reduced and the part bent around the die. As some springback will be apparent in this type of forming, it is sometimes called the "springback method."
- (3) the work is held under tension by jaws gripping both ends of a part. Therefore any local recesses between the jaws must be made through the use of a jogger or auxiliary ram.

## DESIGN CONSIDERATIONS

### General Desirable Design Practices

- (1) Type A parts (shown in Figure 7.9) are more desirable than Type B when there is a shallow bend normal to the direction of stretching, since Type A shapes tend to eliminate buckling.
- (2) Sheet material (except magnesium) should be stretched parallel to the grain to utilize maximum elongation.
- (3) If possible, several parts should be produced from a single stretched sheet, since this is more economical (see Figure 7.10).

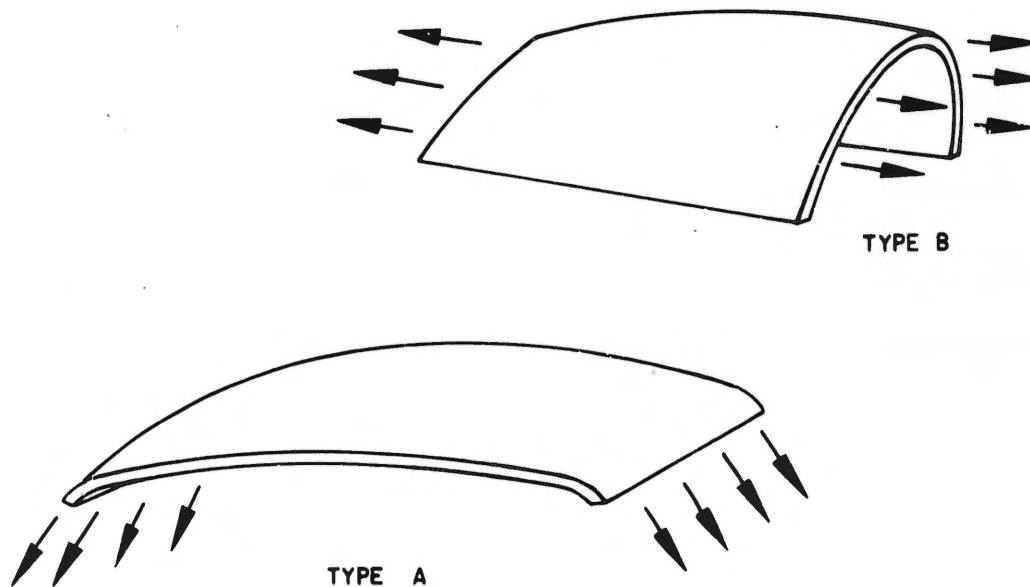


Figure 7.9 Desirable Contours for Stretch Forming

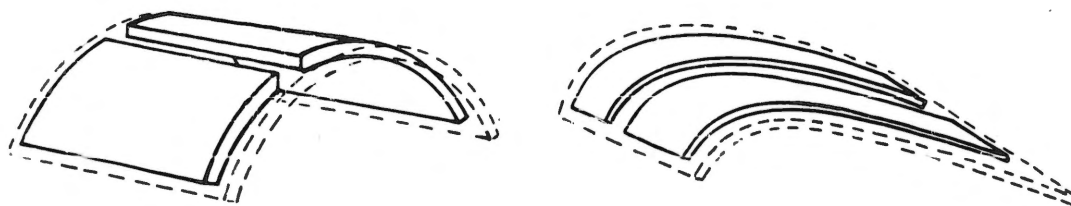


Figure 7.10 Production of More than One Part From a Single Stretched Sheet

- (4) If parts are designed with crowns and ridges, the rise must be low enough to permit the sheet to form within the plastic range of the material.
- (5) The radius must be large enough to permit the formation of curved sections up to angles of  $180^{\circ}$ .
- (6) For parts that must be formed simultaneously in two planes, the parts should be smoothly contoured.
- (7) Webs should be inside the curves.
- (8) Parts should have constant thickness throughout their length.
- (9) Parts of bent up shapes should be formed with outstanding legs on the inside of the bend where they can be supported, as shown in Figure 7.11. Inside compression flanges are not subject to rupturing as stretch flanges are.

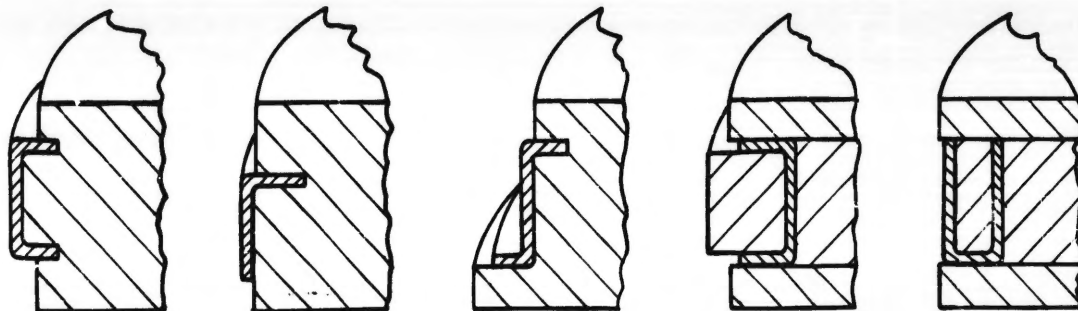


Figure 7.11 Stretch Forming Parts With Outstanding Legs

#### General Undesirable Design Practices

- (1) Reverse curvatures can be obtained in stretched sheets, but only under limited conditions.
- (2) Joggles, lumps, and blisters in blanks will prevent successful stretching operations, and such parts require drop hammer forging at increased cost.
- (3) Contours with radii over  $180^{\circ}$  should be avoided since they require the use of die adapters. However, with adapters, arcs up to  $240^{\circ}$  are possible.
- (4) Parts such as angles, channels, and hat sections are difficult to stretch form.
- (5) Compound curves can be produced, but only if there are no abrupt curvature changes and sharp reversals.
- (6) Sharp angular bends of structural type sections cannot be changed appreciably during stretch forming, therefore variable flange angles must be preformed in straight sections.
- (7) Sharp or reverse curves, abrupt changes in curvature, and curves in several planes should be avoided when possible.

- (8) Parts with low spots and contours below the stretch forming plane (see Figure 7.12) cannot be formed on certain type presses.

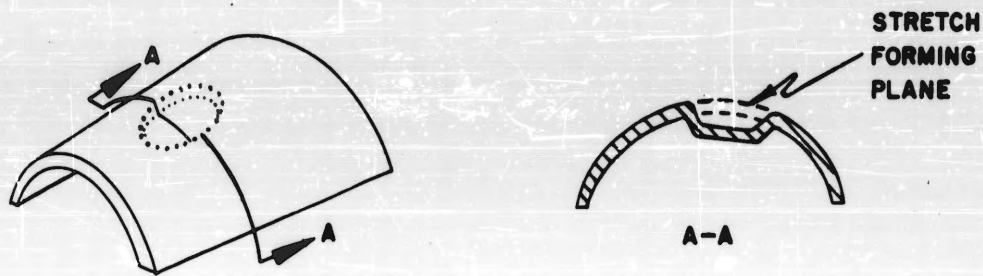


Figure 7.12 Avoid Contours Below Stretch Forming Plane

- (9) Twisted parts can be formed only when section can be completely supported by the die and retained by it, as shown in Figure 7.13).

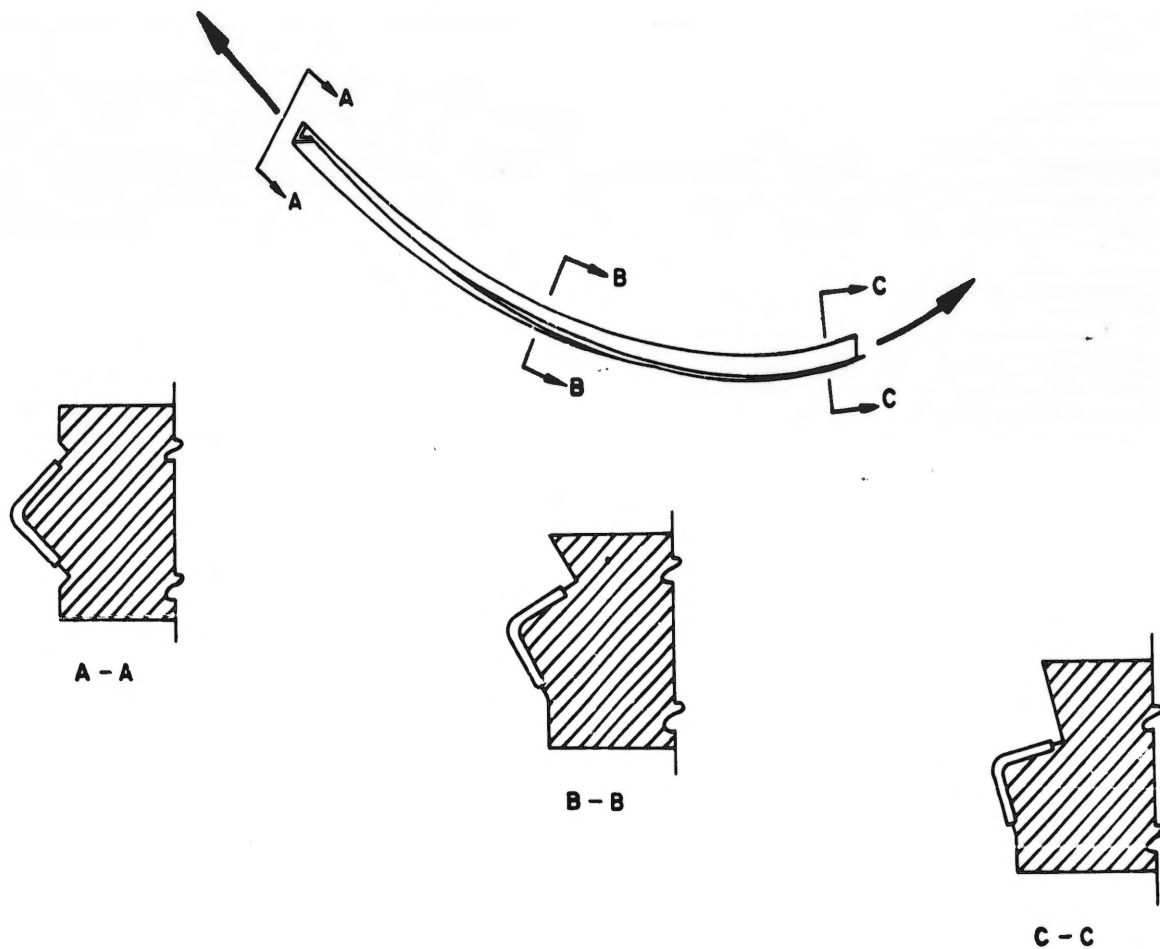


Figure 7.13 Stretch Forming Twisted Parts

**Special Considerations for Forming Preformed Shapes**

- (1) Reentrant curves should be avoided, since they are not readily adaptable to stretch forming. However, reentrant curves can be obtained at the cost of special tooling and manufacturing operations. Some such shapes may be accomplished in successive forming operations of the machine which requires elaborate tooling, as shown in Figure 7.14.

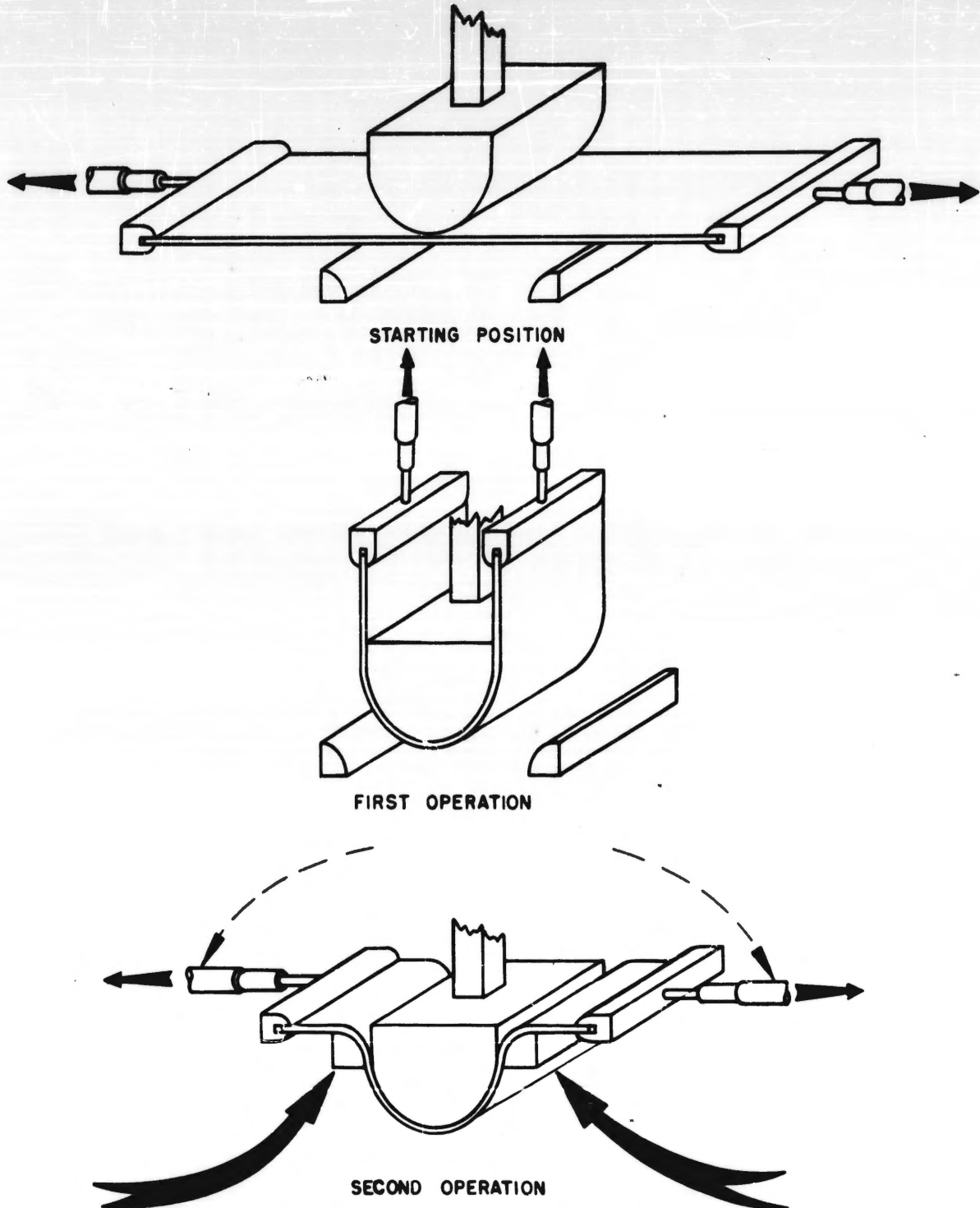


Figure 7.14 A Method of Stretch Forming Reentrant Contours

- (2) Joggles should be avoided, although they can be formed if the part is soft enough to be partly fabricated by means of a mallet and fibre block while the part is in tension on a stretch die.
- (3) Tapered sections are not satisfactorily adapted to stretch forming.
- (4) S-type curves occurring along axis of tension are undesirable in stretched parts.
- (5) Flange angles should be constant. Variable angles must be preformed before stretching; if necessary, part should be so designed that the angle varies at a uniform rate as shown in Figure 7.15).
- (6) Lightening holes, notches and other cutouts must be made after stretching uniform-width material as shown in Figure 7.16).

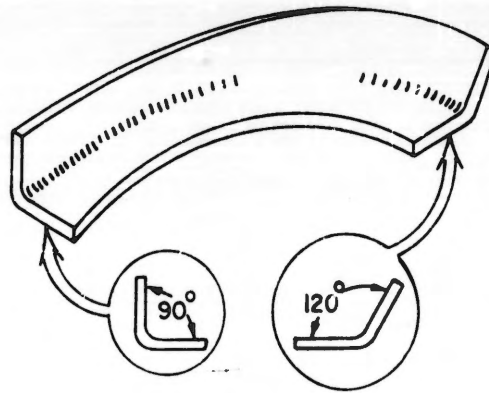


Figure 7.15 Stretch Forming Variable Flange Angles

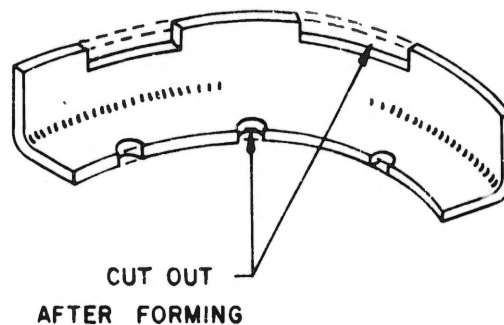


Figure 7.16 Notching Stretch Formed Parts

- (7) On parts requiring flange angle changes, legs should be designed parallel to the bend radii, in order to eliminate interferences with the stretcher forms, as shown in Figure 7.17).

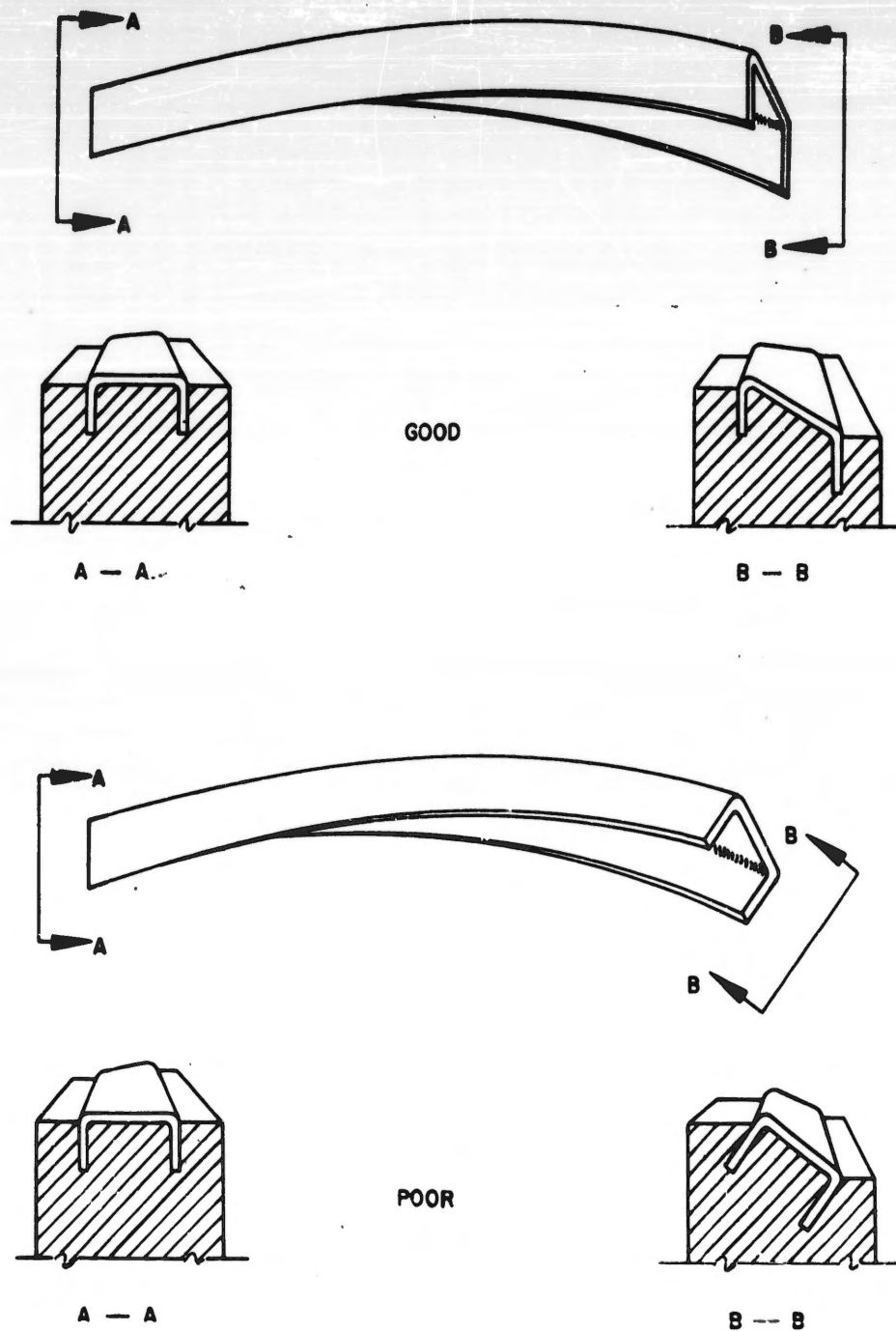


Figure 7.17 Avoid Interference With Stretching Die

- (8) Some radial shrinkage occurs in all stretch formed parts and should be considered a factor in design.
- (9) When a part requires more than one bend radius, smallest radius should be used to determine the maximum radial shrink, as shown in Figure 7.18).

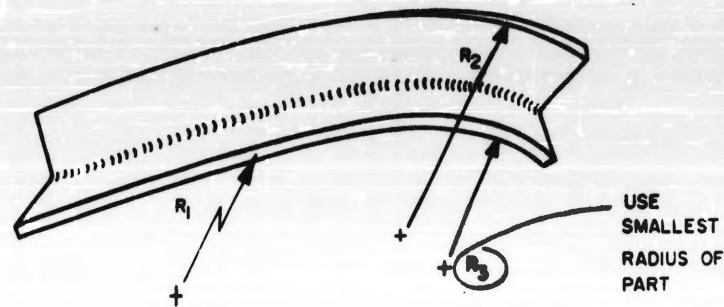


Figure 7.18 Stretch Forming Bend Radii

- (10) Radial shrink need not be considered for angle or tee sections where the leg is inside because of the support given the leg during forming as shown in Figure 7.19).

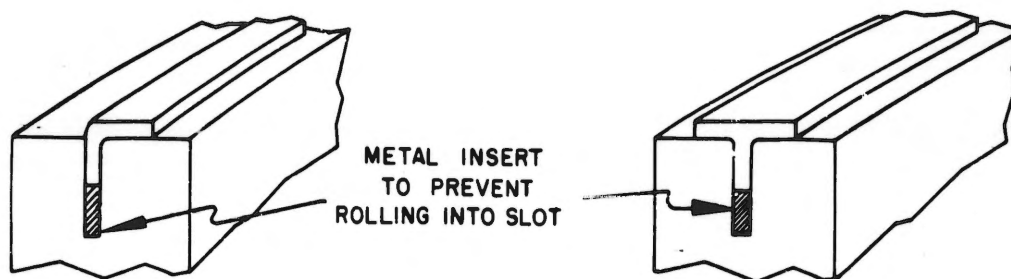


Figure 7.19 A Method of Reducing Radial Shrink in Stretch Forming

- (11) All holes should be located from the surface of the part most rigidly supported by the stretcher form to insure that proper edge distance is maintained.
- (12) The optimum desirable shape for section contour forming is a hat section, either extruded or formed, because of its stability after forming. When released from the die the hat will twist least of any due to unbalanced springback.
- (13) "L" and "Z" sections will "corkscrew" to some extent dependent on the temper of the material. It is necessary to add material to one leg of a Z to prevent this as shown in Figure 7.20).

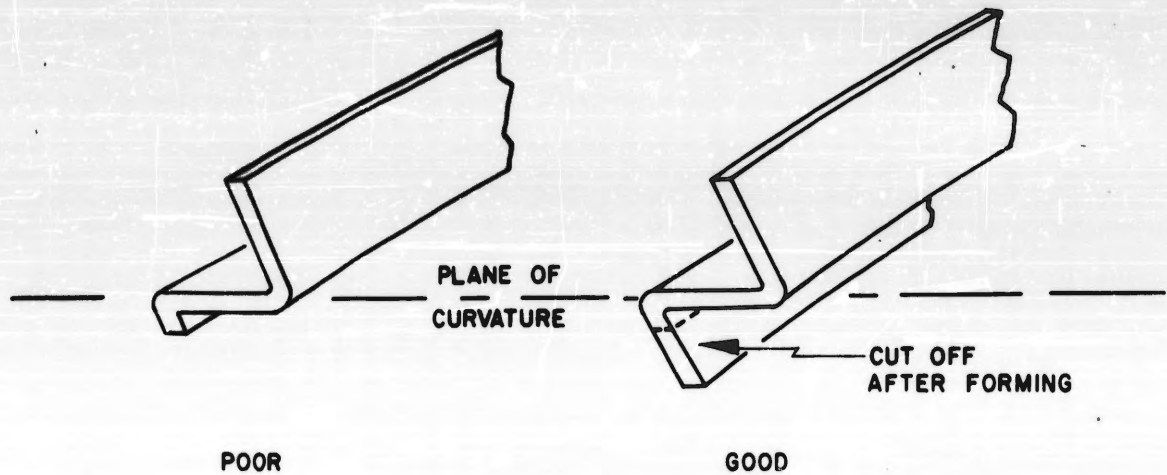


Figure 7.20 Designing for Stretching "Z" Sections

- (14) During section contour forming, the angle between the legs of the section may be changed by the stretch die, either opening or closing the angles, provided this does not result in an overall twist of the section. Extreme cases of such twist cause actual displacement of the bend radii in sheet metal formed hat sections. An example is a section made from 2024S-O, as shown in Figure 7.21).

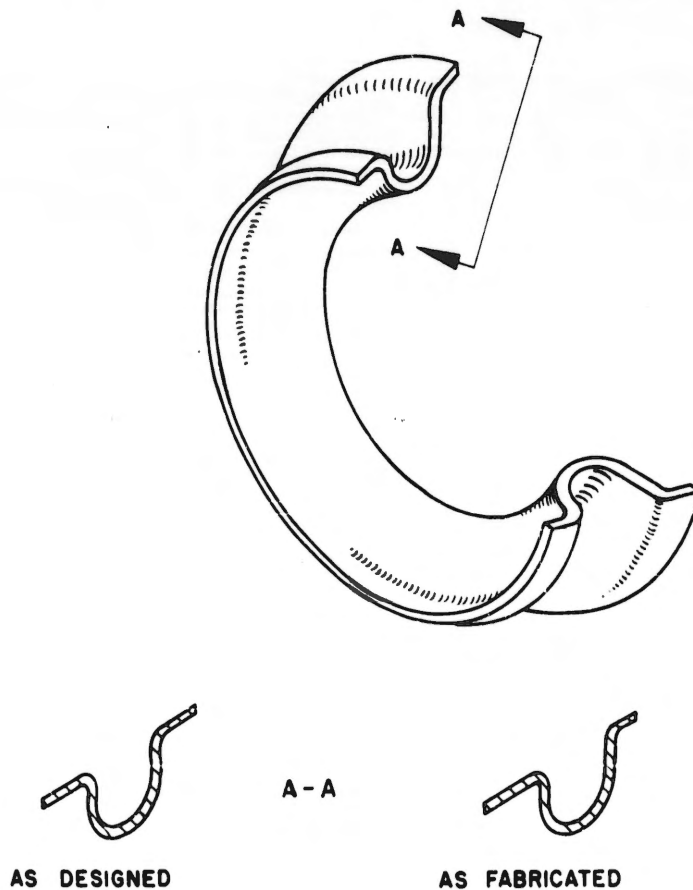


Figure 7.21 Extreme Twist Causing Displacement of Metal in Stretch Forming

- (15) Extrusions cannot be "bent to the heel" while on the stretch dies, as shown in Figure 7.22)

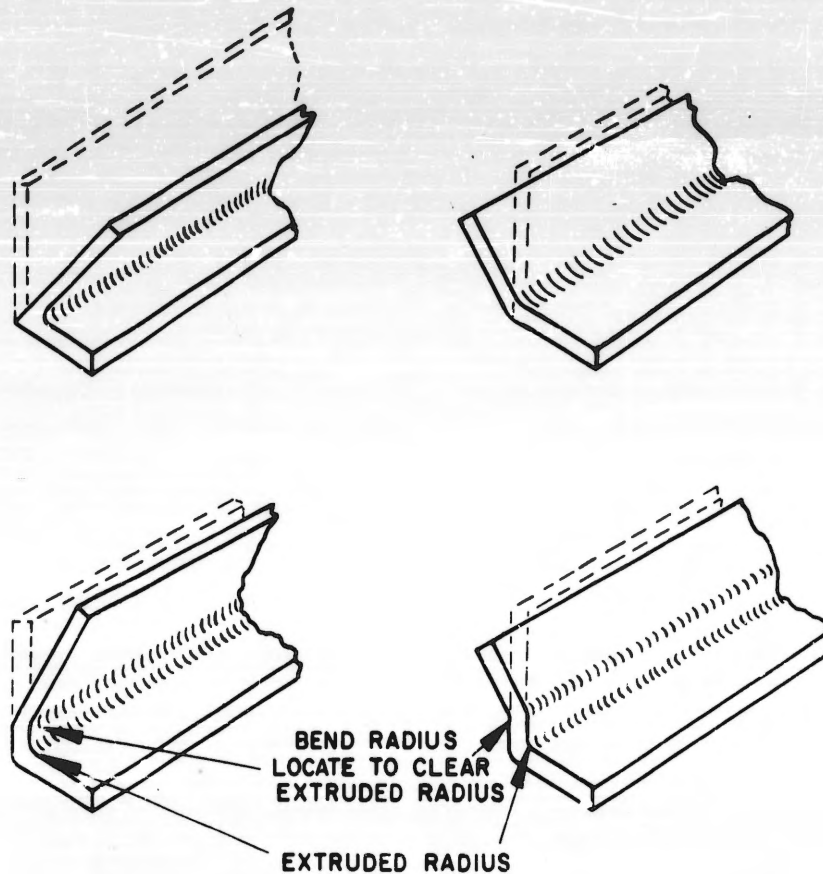


Figure 7.22 Design Considerations for Stretch Forming Extruded Sections

- (16) Direction of flanges with respect to the radius of contour affects the maximum elongation induced by stretching due to notch effect. L-sections with the heel on the inside of the turn may be stretched less than when the heel is on the outside by about 1/3.
- (17) Reverse curves can be made provided their radii do not exceed several inches. They are made by pulling the press arms around the die for the major curve, then adding suitable blocks to the die and reversing the direction of the press.

### Special Considerations for Combined Compression and Stretch Forming

- (1) General forming limitations are given in Table 7.1.

Table 7.1 Combined Compression and Stretch Forming Limitations

	Preformed Shapes	Skins
Max. Blank Size (inches)	12 x 240	72 x 360
Max. Length (inches)	240	360
Max. Width (inches)	12	72
Max. Thickness (inches)	--	0.090
Max. Flange Width (inches)	--	--
Min. Length (inches)	20	24
Max. Contour (inches)	180°	180°
Min. Dia. Half Circle (inches)	24	24
Max. Dia. Half Circle (inches)	150	150

- (2) Material may be formed to 360° and beyond.  
(3) The maximum size part which can be formed to 360° is a part of 16" radius.  
(4) The length of parts which can be formed to 330° or beyond is limited by and equal to the stroke of the machine.  
(5) Parts formed above 230° must be formed in spiral shapes to provide clearance for the working arms of the machine and then sprung into a flat plane.

#### Other Special Design Considerations

Stretch forming results in section reduction; therefore, it is of importance to furnish engineering and planning departments with the magnitude of section reduction. A formula has been developed to be used as a guide for allowing production tolerances on stretch formed 2024 and 7075 aluminum extrusions.

The method used for computing reductions in stretch formed aluminum parts, based on calculations of width and thickness reductions compared with actual test results is as follows:

Multiply the percent of elongation by the constant 0.4 for height and width reductions.

Multiply the percentage of elongation by the constant 0.64 for thickness reductions.

The answers obtained by this method are expressed in percent of reduction of the original part. The constants given above may be applied to any percent of elongation at any place on the part.

This method can be utilized to approximately determine the dimensional changes in

cross-section through the use of the chart, Figure 7.23, and the procedure outlined below. The method applies to most of the common extruded or sheet metal sections.

To find the percent of thinning by the chart in Figure 7.23, refer to the section of Figure 7.24.

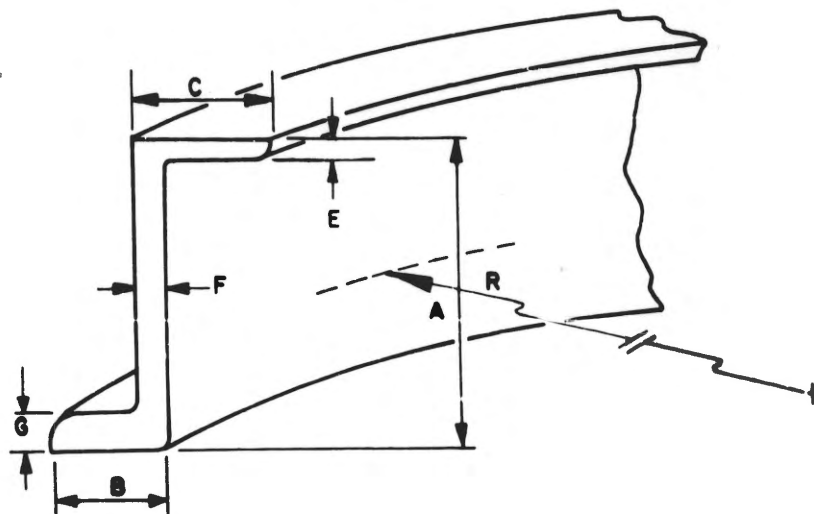
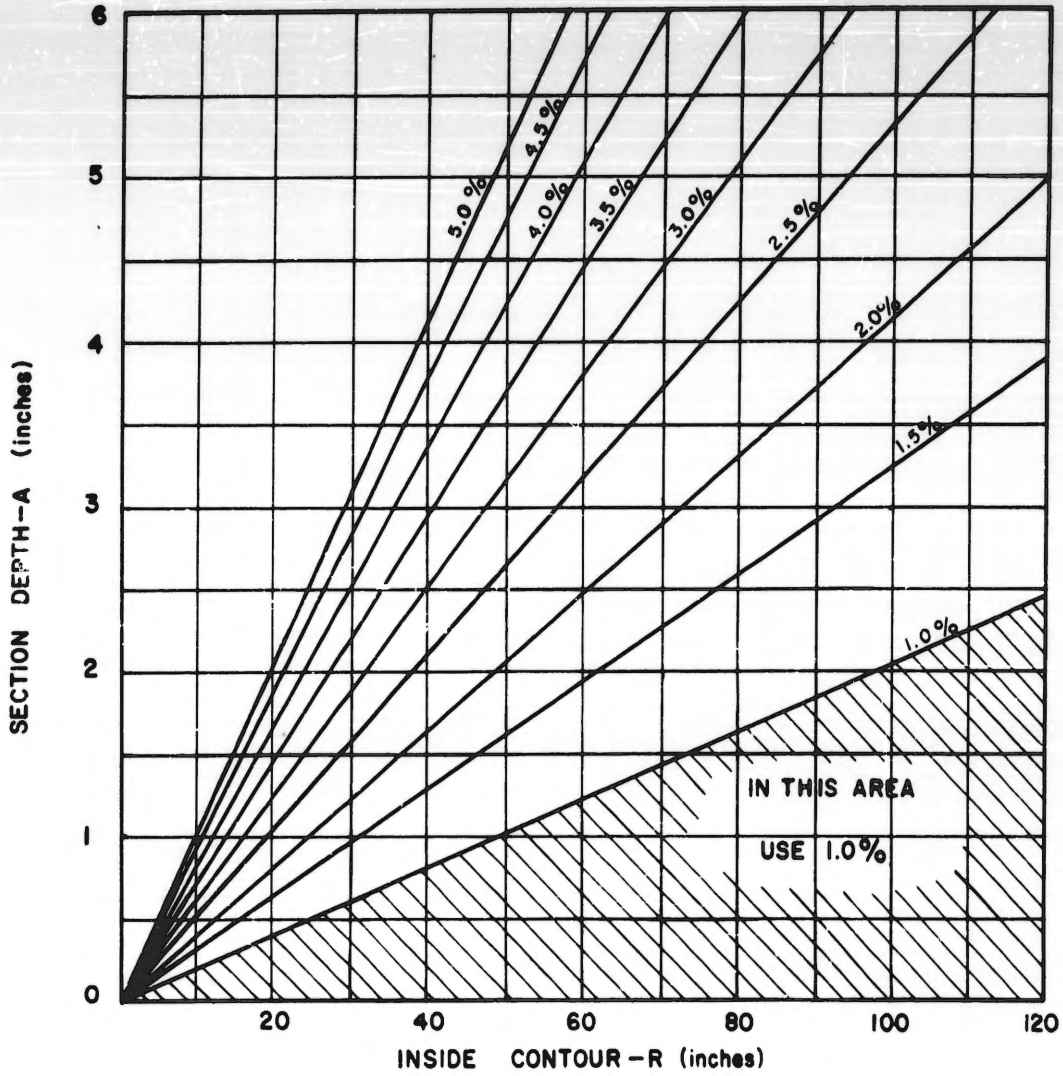


Figure 7.23 Dimensional Changes During Stretch Forming

- (1) use the nominal dimension for calculating the decrease. Subtract the decrease from the original minimum dimension to obtain the minimum dimension to obtain the minimum after forming.
- (2) do not use less than 1% reduction for any dimension.
- (3) the percent of decrease for dimensions C, E, and F, is read directly from the chart to the nearest 1/2%.
- (4) the percent of decrease for A is half that for C.
- (5) the decrease for B and G is 1%.

The following example is typical:

When  $A = 3.000$  and  $R = 40$  the chart of Figure 7.23 shows a reduction of 3.5%.  
Therefore,

$$C_{\min} = 1.238 - (.035)(1.250) = 1.194$$

$$E_{\min} = .094 - (.035)(.100) = .090$$

$$F_{\min} = .072 - (.035)(.078) = .069$$

$$A_{\min} = 2.976 - \frac{(.035)(3.000)}{2} = 2.923$$

$$B_{\min} = 1.484 - (.01)(1.500) = 1.469$$

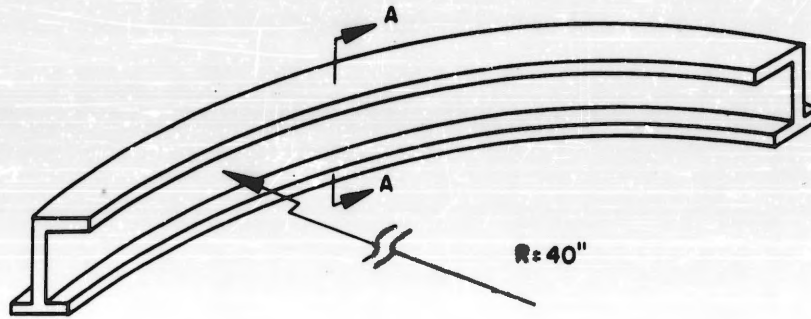
$$G_{\min} = .094 - (.01)(.100) = .093$$

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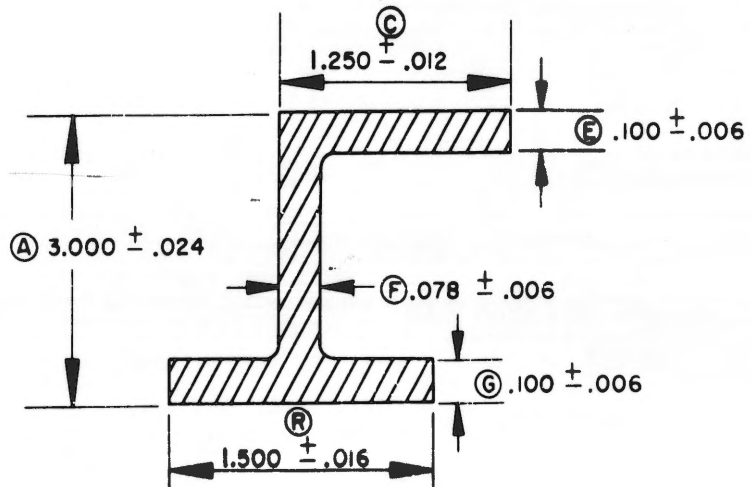
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ASME Metals Engineering, Processes

PART AS FORMED



SECTION A-A  
BEFORE FORMING



SECTION A-A  
AFTER FORMING

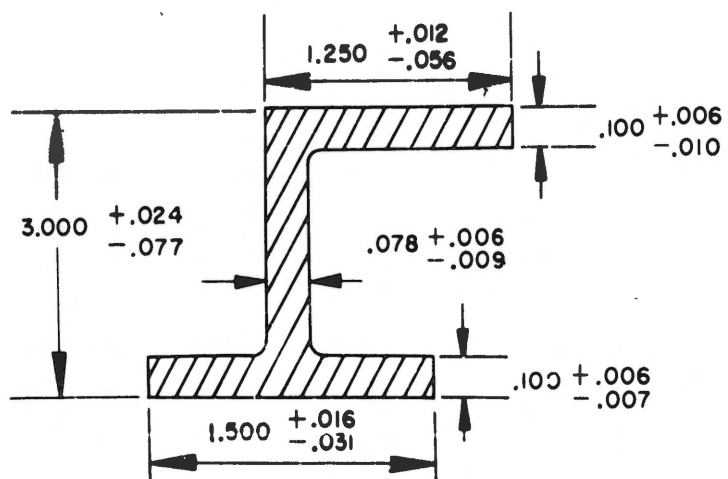


Figure 7.24 Typical Example of Dimensional Changes During Stretch Forming

## CHAPTER 8

### STAMPING

#### PROCESS

##### General

Metal stamping processes can be divided into two separate classifications; cutting and forming. Although both of these can be performed by the same tool, the operations are basically distinct as shown in Figure 8.1.

##### Cutting

Cutting operations are those in which the metal is sheared or cut by stressing it beyond its ultimate strength. There are several separate operations which can be classified as cutting.

- (1) Blanking is cutting out a piece of metal of the shape and size of the final part (see Figure 8.2). The only limitation on blanking is the ability of the cutting tool to withstand the applied forces. Blanking is usually performed on single-action presses.

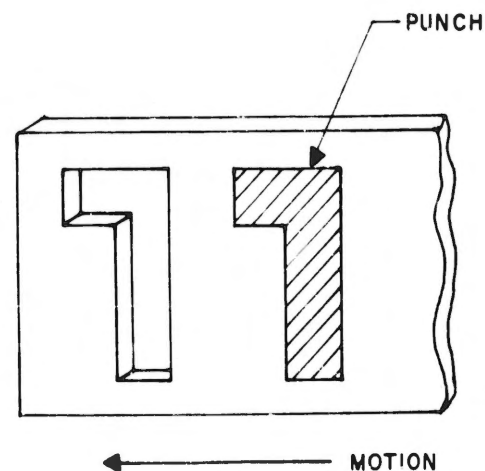
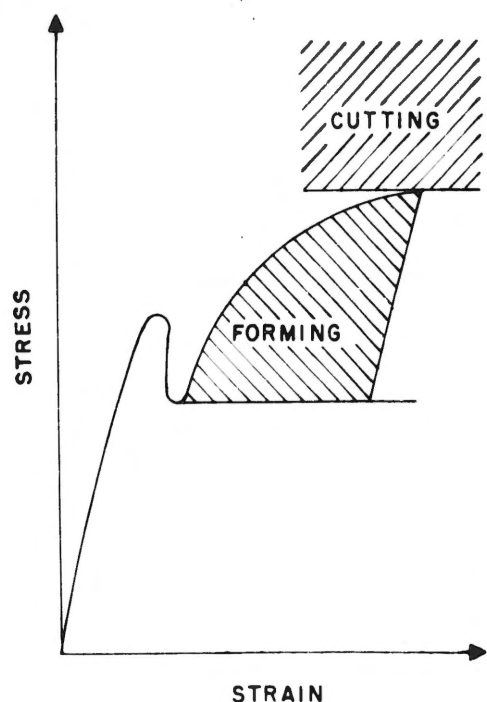


Figure 8.2 Blanking Operation

Figure 8.1 Diagram of Stamping

- (2) **Punching is a process of partial blanking. It is usually used in progressive or follow dies (see Figure 8.3). Each stage of the operation cuts a major portion of the blank but leaves a small connection with the stock for transferring the part between stages. Progressive die work is not only efficient, but is also economical since it minimizes the amount of scrap.**

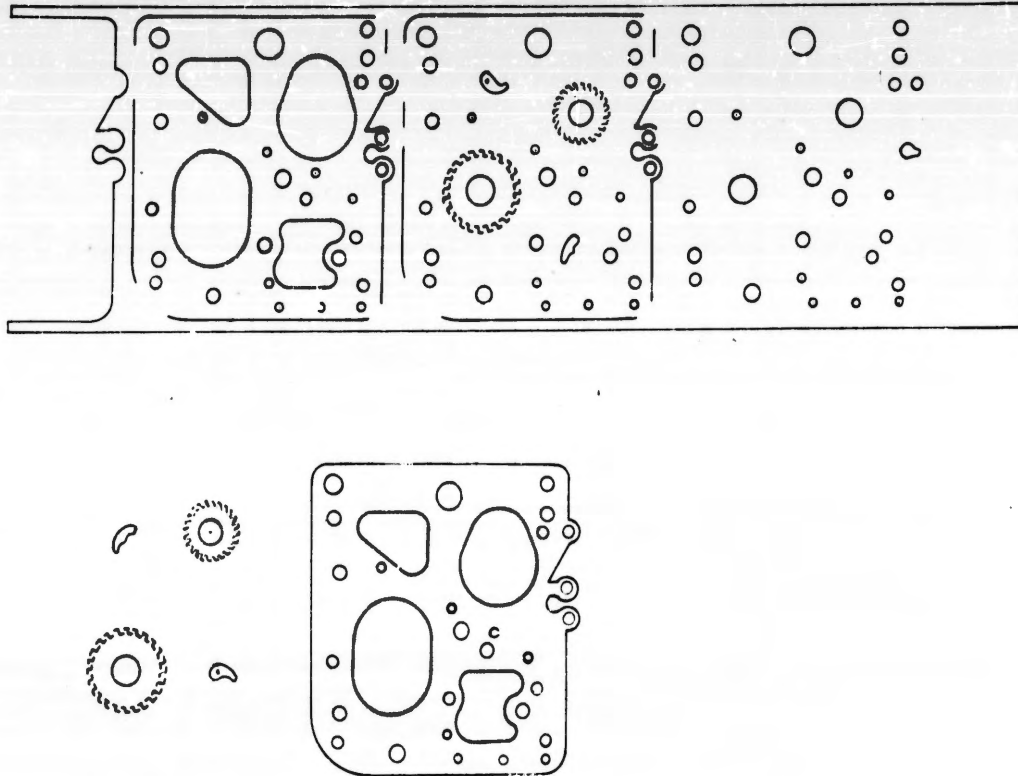


Figure 8.3 Punching Operation on Progressive Dies

- (3) **Piercing is the name applied to the hole-cutting process. It is used for cutting any shaped hole for which the punch and die can be machined.**
- (4) **Perforating is multiple piercing. The holes are usually of very close proximity.**

- (5) Notching is the operation of cutting notches in either a curved or a straight edge (see Figure 8.4). Notching cannot be a continuous process since the operation sets up unbalanced lateral forces which make it difficult to control dimensions.

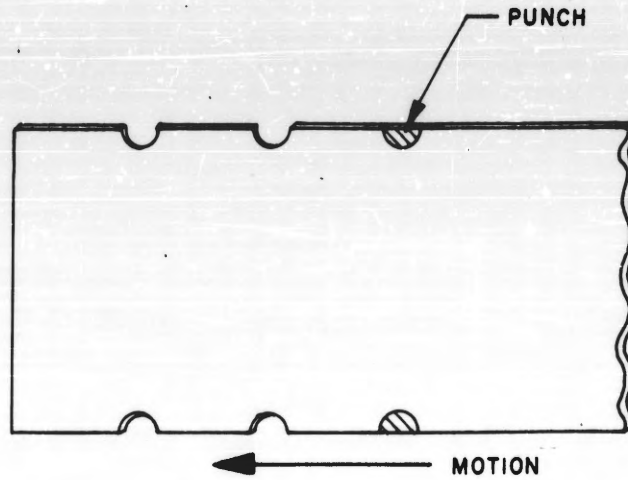


Figure 8.4 Notching Operation

- (6) Slitting is similar to shearing except that slitting does not separate the parts completely (see Figure 8.5). The slitting process is usually used as a preliminary process to bending a tab.
- (7) Lancing is a combined cutting and forming operation (see Figure 8.6); the cut usually being a straight line. The application of lancing is rather limited.

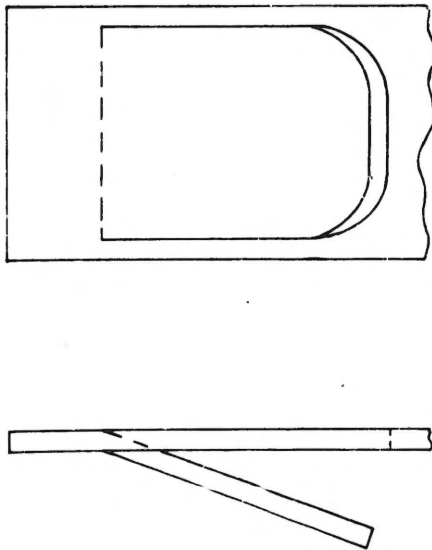


Figure 8.5 Slitting Operation

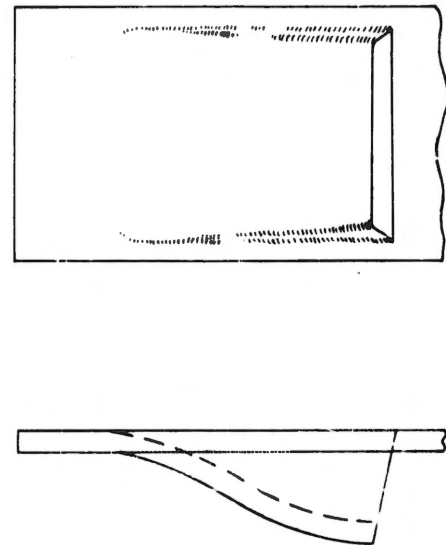


Figure 8.6 Lancing Operation

- (8) Parting and shearing are both for separating a part from the stock (see Figures 8.7 and 8.8). The shearing process produces no scrap while the parting process produces a small amount of scrap. In parting, the lateral forces are in balance thus allowing closer control of dimensions than in shearing.

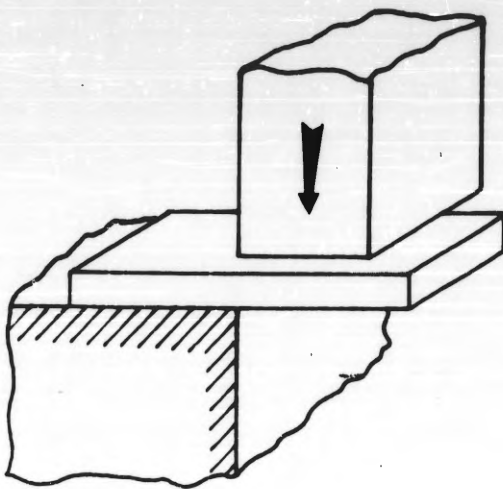


Figure 8.7 Shearing Operation

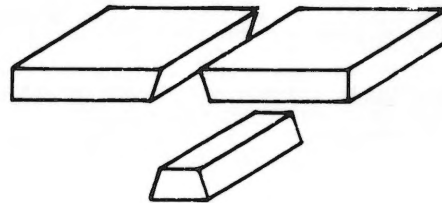
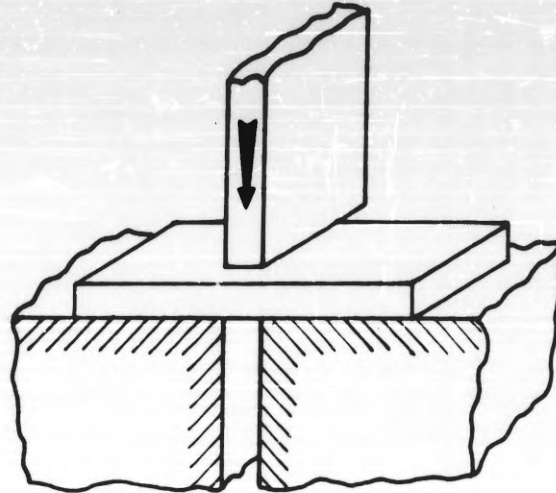


Figure 8.8 Parting Operation

- (9) Trimming is the operation used in removing the excess stock after forming. In most forming operations it is often difficult to predict the exact extent and direction of metal flow, thus excess stock must be provided. Three variations of the trimming operation are conventional trimming, pinch trimming, and cam or lateral trimming. These are merely different operations for removing a flange which may remain after forming.
- (10) Dinking is the blanking or shearing operation used with non-metallic materials such as paper, leather, and plastics. Dinking is similar to the process of cookie cutting, that is the lower half of the die is a flat plate and the upper part cuts out the desired shape.

## Forming

Forming operations are those in which sheet metal is strained beyond its yield point to achieve a permanent set and retain a new shape. Care must be taken in the forming process to be sure that the part is not stressed beyond its ultimate strength thus causing rupture to take place.

The process of drawing is similar to forming, the difference being that forming involves local plastic deformation and drawing involves general plastic deformation. The subject of drawing was discussed earlier in Chapter 4.

There are several separate operations which are a part of forming.

- (1) Bending is the name applied to the process of forming the metal about a straight-line axis. The purpose of bending is to form angles in a blank of sheet metal. Bending can be accomplished with bar folders, sheet brakes, or bending dies.
- (2) Curling is an operation used to produce a rim at the open end of a drawn part. It is used mainly to protect or reinforce the end of the part. Sometimes a part is curled around a wire ring for greater strength. This is known as "wiring." Curling differs from bending in that the axis of bend is a curved line (see Figure 8.9).
- (3) Beading (sometimes called stamping) is a shallow forming operation used to produce beads, lettering, and decorative configurations (see Figure 8.10).

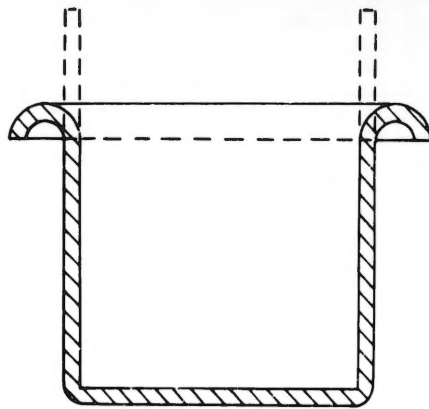


Figure 8.9 Curling Operation

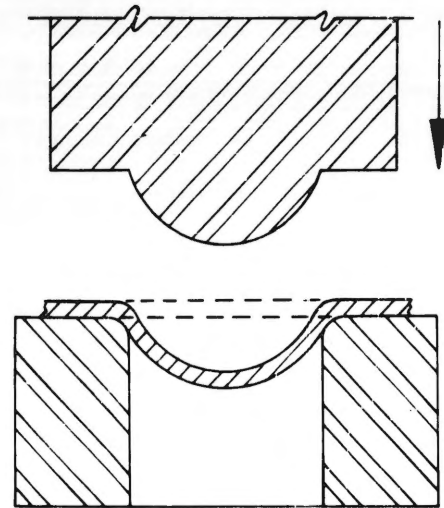


Figure 8.10 Beading Operation

## Equipment

The equipment for stamping operations is usually chosen for the characteristics that make it adaptable for a certain purpose. The basic types of stamping machines are hammers, hydraulic presses, and mechanical presses.

Hammers were the earliest type of equipment used in metal stamping. They were used extensively in the development of the metal stamping operation but have been largely replaced today by presses. Rope-lift and air hammers are still used occasionally in the aircraft industry.

The size of hydraulic presses varies from 3/4 ton bench press to the 15,000 ton, four-post press. Hydraulic presses offer certain advantages over mechanical presses in that they offer longer operating strokes and also full rated capacity over the entire length of stroke. Hydraulic presses are usually slow-moving because of the limitations of the pumping equipment to handle the large quantities of oil necessary to fill the large cylinders. Hydraulic presses are used extensively in the aircraft industry in the rubber die process (described in Chapter 6).

Mechanical presses may be classified as to construction of the frame, the mechanism for providing the ram motion, and whether or not it has automatic press auxiliaries provided. The frame construction can be gap or C-frame, arch type, straight side, and pillar type frame. Mechanical presses can be classed as single-action, double-action, or triple-action presses, depending on the number of moving slides or rams. Motion of the ram can be provided by cranks, eccentrics, cams, toggles, screws, and knuckle joints.

### Dies

Dies in stamping operations can be classified as simple, compound, combination, progressive, transfer, and special. Since the type of operations that can be performed depend greatly upon the type of die used, each of these dies will be discussed separately.

Simple Dies. These are dies that are intended to perform only one operation. The operation can be either the cutting or forming type. As the name implies, this die is usually the simplest possible arrangement and construction consistent with the life of the die and quality of the product. The quality of these dies varies from very simple cheap dies for small production runs to very elaborate expensive dies for continuous production.

Compound and Combination Dies. These are single-stage dies for performing two or more operations of the same general type. The operations may be performed simultaneously or in sequence. The main characteristic of these dies is that all the operations are performed on the part in one location. Consequently, stamped parts can be produced within relatively close limits since the dimensions between component elements are controlled by the degree of precision achieved during construction of the die. The principal disadvantage in the use of dies of these types is that the die elements are often crowded together and thus require slower operating speeds and greater maintenance because of their delicacy.

Progressive Dies. These are multiple-stage dies in which two or more operations are performed during the same stroke of the press but at several different work stations. The work is fed through several stations and one or more operations may be performed at each stage. The primary objective of a progressive-die arrangement is to achieve greater rigidity and simplicity than can be obtained by use of compound and combination dies, consequently permitting increased operating speeds in addition to reducing maintenance and construction costs.

Transfer Dies. These are similar to progressive dies since they both contain multiple stages. However, some parts cannot be processed in progressive dies because complexity of large size doesn't permit them to be fed from one stage to the next. Transfer dies can handle these parts because they incorporate a transfer mechanism for moving the part between stage. Transfer dies are usually more expensive than progressive dies because of their larger size and the additional cost of the transfer mechanism. They are only used for large-quantity continuous production. Compared to simple, compound, and combination dies, transfer dies will operate at higher production rates with lower maintenance cost and longer life.

Special Dies. These are dies whose design and function are so radical that they possess none of the dominant characteristics of the more general classes of dies. Special dies include lateral trimming dies, standard or universal dies, and rubber dies.

Lateral trim dies are used for unorthodox trimming operations. They incorporate a sequence of lateral motions. The Brehm die is a common commercial lateral trim die.

Standard or universal dies are those which possess certain universal characteristics which permit them to be used for a range of sizes or different types of operations. These dies are basically simple dies intended to perform single operations, but they are designed so that the punch and die elements can be quickly adjusted or replaced with different sizes. This type of die makes it economical to use stamping for producing as few as thirty to fifty parts.

Rubber dies can be used in blanking, piercing, bending, and shallow forming operations. For cutting operations, a hardened tool steel template or punch is mounted above the bed of the press; one or more rubber blankets are fastened to the ram of the press, and the sheet metal is placed over the tool steel template. The ram is lowered, applying pressure through the rubber to the sheet metal until sufficient stress is set up at the edges of the template to shear the metal. The resulting sheared edge is ragged but the process is so good that it is used extensively in production of airframe parts. The rubber die process also has the advantage of having dies that can be made up very quickly. This is often important for low production rush jobs.

#### ADVANTAGES AND LIMITATIONS

The stamping process has the advantage of low cost for high production. Stampings also are lightweight, highly uniform, and surfaces are well adapted to receive finishes. Any metal which can be prefabricated as sheet or strip can be processed by some type of stamping operations.

#### DESIGN CONSIDERATIONS

The basic design considerations in stamping are illustrated in Figure 8.11.

#### REFERENCES

Kent's Mechanical Engineers Handbook, Design and Production Volume, 12th Edition, Section 20

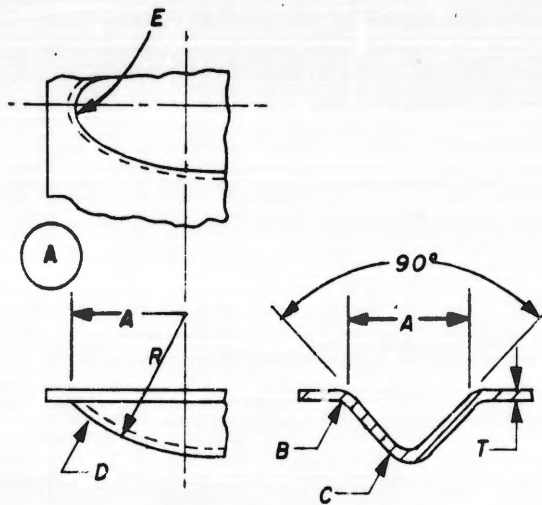
ASME Metals Engineering, Processes

Bolz, Production Processes, Volume One

Tool Engineers Handbook

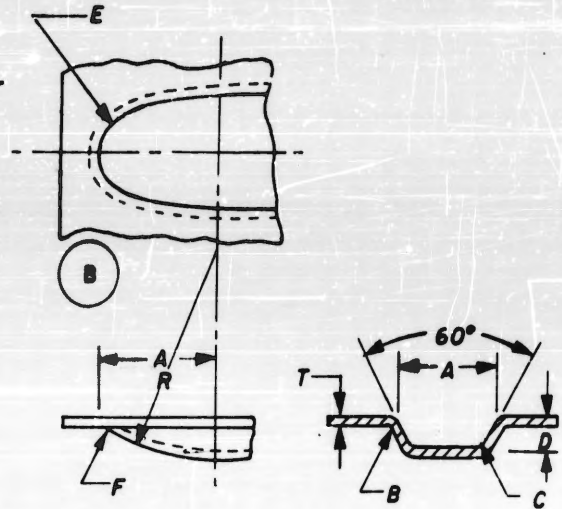
New American Machinists Handbook

THE RADII ARE DETERMINED BY SUBSTITUTING THE METAL THICKNESS FOR "T," AND MULTIPLES OF "T," IN EACH INSTANCE, A RADIUS LESS THAN RECOMMENDED CAUSES TEARING AT THE BEAD.



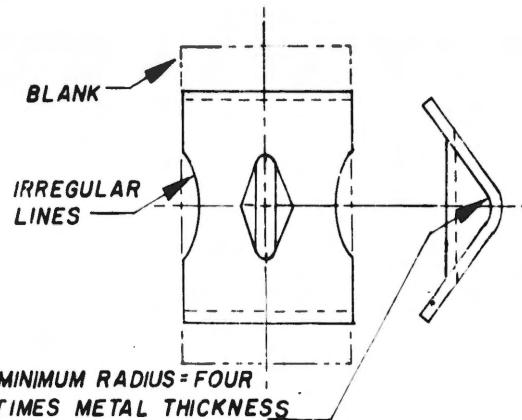
A	B RADIUS	C RADIUS	D RADIUS	E RADIUS
0.25	2T	2T	4T	T
0.38	2T	2T	4T	T
0.50	2T	2T	4T	2T
0.62	4T	4T	4T	2T
0.75	5T	5T	4T	3T
1.00	5T	5T	4T	3T

THE BEADS SHOWN IN (A) AND (B) ARE TYPICAL AND RECOMMENDED FOR USE IN ALL POSSIBLE APPLICATIONS. THESE HAVE BEEN DESIGNED SO THAT THE ANGLE OF THE SIDES WILL NORMALLY ALLOW THEIR USE ON FLAT, ANGULAR AND CURVED SURFACES WITHOUT PRODUCING BACKDRAFT. CHART INFORMATION IS GIVEN FOR DEPRESSED OR INTERNAL BEADS.



A	B RADIUS	C RADIUS	D	E RADIUS	F RADIUS
1.00	3T	2T	0.25	4T	4T
1.50	3T	2T	0.31	4T	4T

#### RIBS

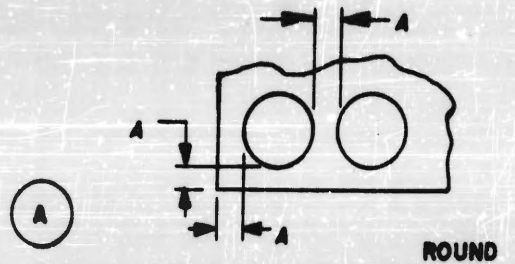


MINIMUM RADIUS = FOUR TIMES METAL THICKNESS  
 PROPERLY DESIGNED RIBS ADD RIGIDITY TO ANGLES AND FLANGES. IRREGULAR SIDES ALLOW FOR RIB WHEN PART IS MADE FROM STRIP STOCK. A RADIUS OF LESS THAN FOUR TIMES METAL THICKNESS WILL USUALLY TEAR AND CAUSE PART FAILURE.

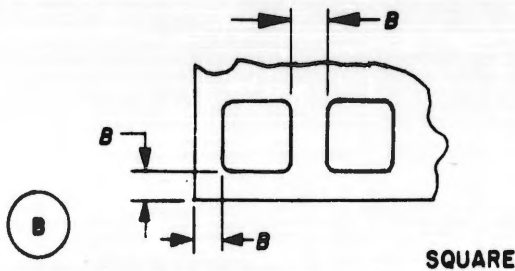
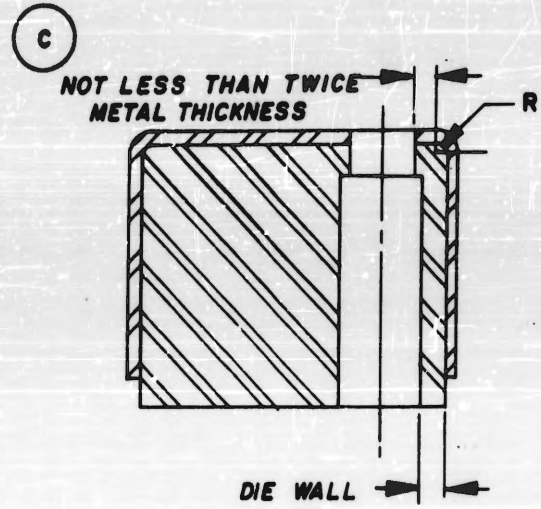
#### DESIGN OF STRENGTHENING BEADS AND RIBS

Figure 8.11 Design Considerations for Stamping<sup>(1)</sup>

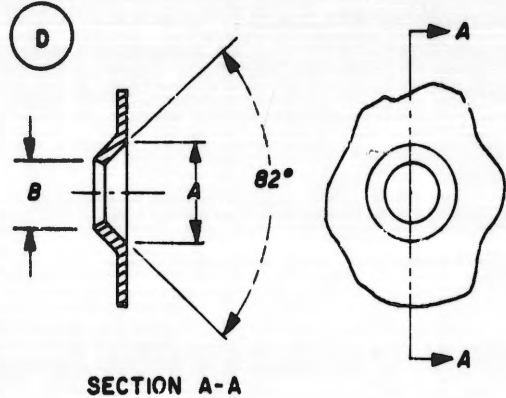
(1) By permission from The New American Machinist's Handbook by Rupert LeGrand. Copyright, 1955. McGraw-Hill Book Company, Inc.



METAL THICKNESS, INCHES	DISTANCE "A" MIN. INCHES
UP TO 0.062	0.12
OVER 0.062	TWICE METAL THICKNESS



METAL THICKNESS, INCHES	DISTANCE "B" MIN. INCHES
UP TO 0.090	0.18
OVER 0.090	TWICE METAL THICKNESS

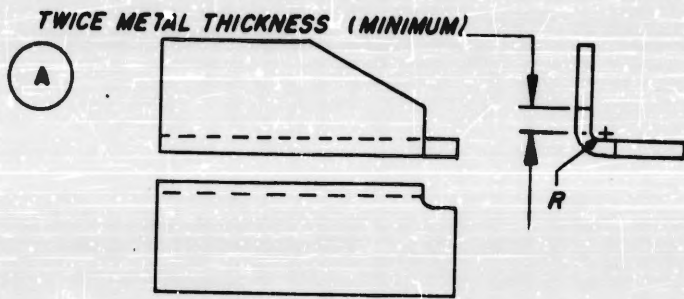


SCREW SIZE	DIAMETER COUNTERPUNCH, INCHES	DIAMETER HOLE IN.
NO. 4	0.24	0.14
NO. 5	0.26	0.15
NO. 6	0.29	0.17
NO. 7	0.32	0.18
NO. 8	0.34	0.19
NO. 9	0.37	0.21
NO. 10	0.40	0.22
NO. 12	0.45	0.25
NO. 14	0.50	0.27
1/4 "	0.52	0.28
5/16 "	0.65	0.34
3/8 "	0.77	0.40
7/16 "	0.90	0.46
1/2 "	1.03	0.53

(A.) AND (B.) THE DISTANCE BETWEEN HOLES OR BETWEEN A HOLE AND A TRIMMED EDGE IS GOVERNED BY STOCK THICKNESS, HOLE SIZE, PUNCH SHANK SIZE, TYPE OF HOLE, AND DIE-STEEL STRENGTH. (C.) HOLE EDGES SHOULD BE SEPARATED FROM A LINE NORMAL TO THE METAL FACE AND THROUGH THE CENTER OF THE RADIUS AT A BEND BY AN AMOUNT EQUAL TO AT LEAST TWICE METAL THICKNESS. (D.) STANDARD SIZES FOR COUNTERPUNCH AND HOLE DIAMETERS. THE CHARTED DIMENSIONS ARE FOR SCREW HEADS ONLY; WHEN A LOCK WASHER IS USED, ALLOWANCE MUST BE MADE FOR THE WASHER.

DESIGN LIMITATIONS FOR HOLES

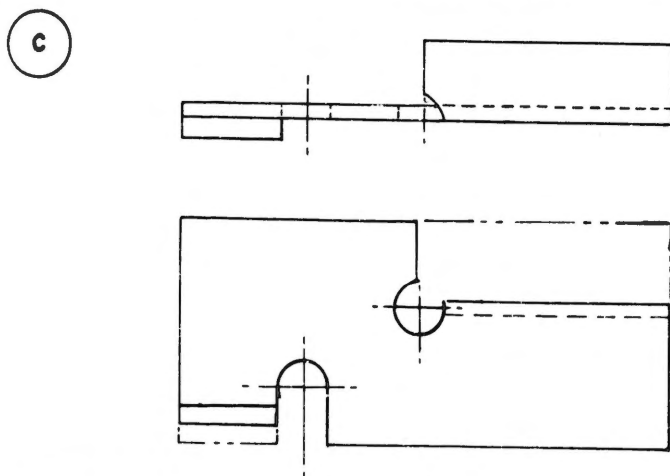
Figure 8.11 (contd)



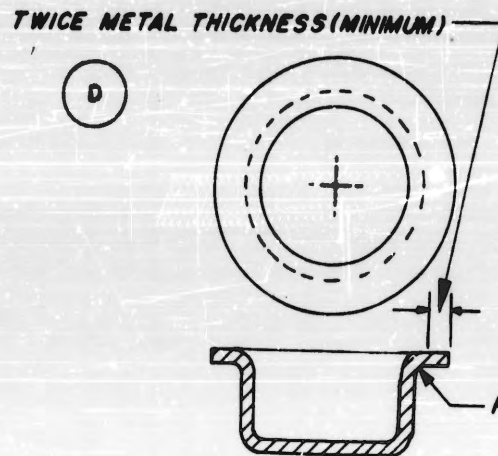
**(A)** TAPERED FLANGES SHOULD NOT TAPER TO THE END OF THE BLANK BUT SHOULD BE CUT OFF SO THAT THE NARROWEST SECTION WILL BE AT LEAST TWICE METAL THICKNESS MEASURED FROM THE RADIUS CENTER.



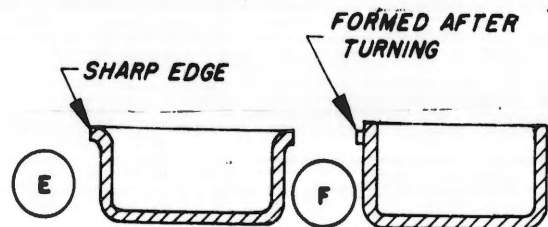
**(B)** OUTSIDE FLANGES AND FLANGES AROUND OPENINGS SHOULD HAVE A HEIGHT OF AT LEAST TWICE THE METAL THICKNESS MEASURED FROM THE RADIUS CENTER. THIS SERVES TWO PURPOSES: (1) EASES THE FORMING OF THE LIP, AND (2) PROVIDES A SURFACE FOR ATTACHING COVERS AND OTHER MEMBERS.



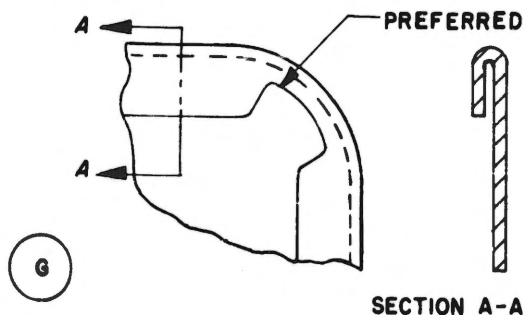
**(C)** WHERE FLANGES EXTEND OVER ONLY A PORTION OF A PART, IT IS DESIRABLE TO PUNCH A NOTCH OR HOLE AT THE END OF THE FLANGE TO ELIMINATE TEARING OF THE METAL. THIS IS ALSO A METHOD OF REDUCING STRESS-CONCENTRATION FACTORS AT THE INTERSECTION OF THE TWO SURFACES.



**(D)** FLANGES LEFT BY TRIMMING SHOULD HAVE A WIDTH OF AT LEAST TWICE THE METAL THICKNESS FROM THE RADIUS CENTER.



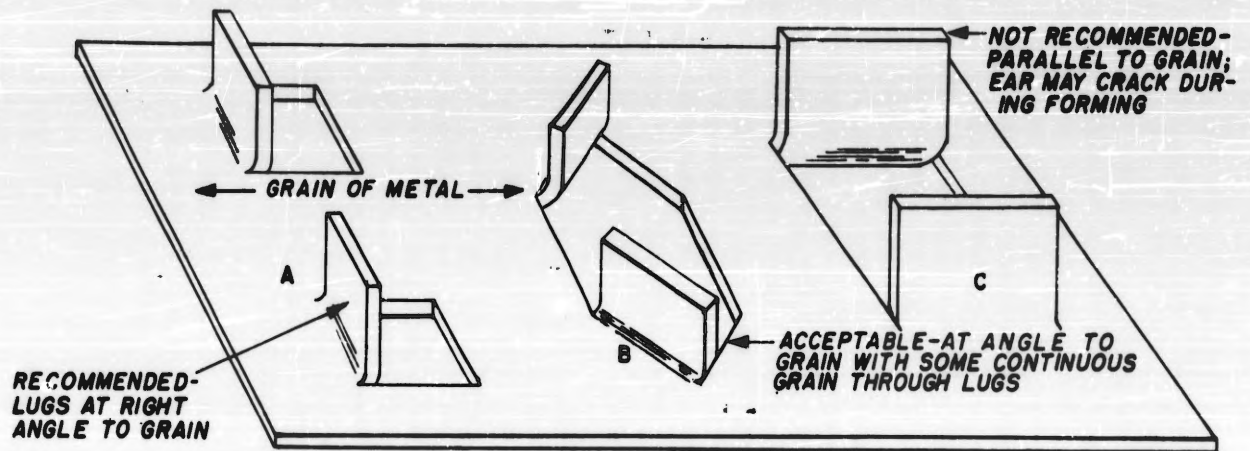
**(E)** WHERE A SHARP EDGE IS NOT OBJECTIONABLE ON A DRAWN PART, THE FLANGE MAY BE TRIMMED CLOSE. **(F)** FLANGES CAN BE ELIMINATED ON SOME DRAWN PARTS BY ADDING AN OPERATION TO FORM THEM UP AFTER TRIMMING.



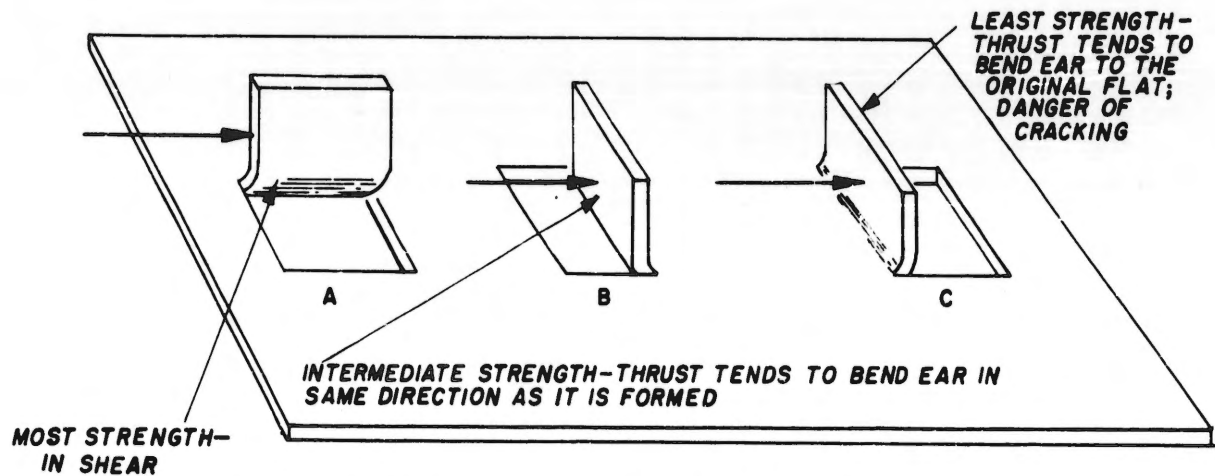
**(G)** NOTCH THE CORNER OF A HEMMED EDGE TO ELIMINATE GATHERING OF THE METAL IN THE FLANGING OPERATION.

#### DESIGN OF FLANGES

Figure 8.11 (contd)  
8-10



WHEN LUGS ARE USED, THEY SHOULD BE FORMED AT RIGHT ANGLES TO THE GRAIN OF THE METAL AS IN "A". IF THIS IS NOT PRACTICAL, THEN "B" IS PERMISSIBLE. "C" IS NOT RECOMMENDED AND MAY NECESSITATE THE USE OF PREMIUM GRADE STEEL.

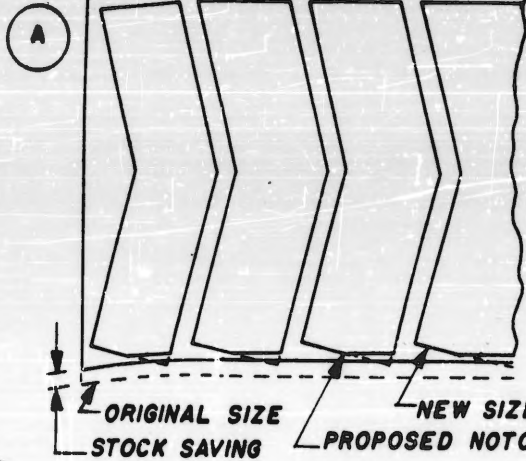


DIRECTION OF LOAD ON LUG IS A FACTOR IN POSITIONING THE LUG. LOADING AS IN "A" IS RECOMMENDED BECAUSE THE STRENGTH IN SHEAR EXCEEDS THAT IN BENDING. IF "B" AND "C" ARE ONLY POSSIBILITIES, RIBS OR GUSSETS CAN BE USED AS REINFORCEMENTS.

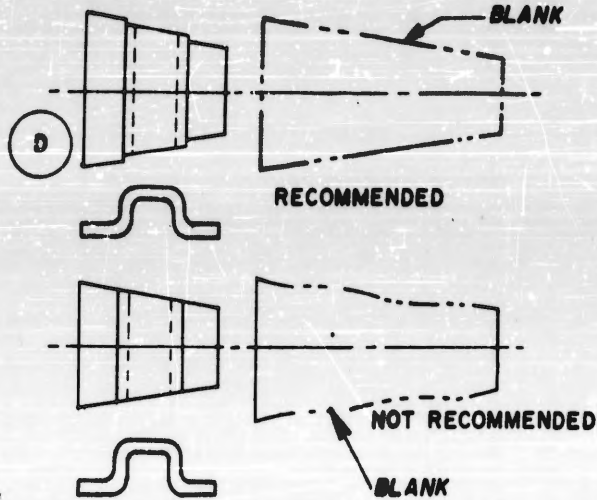
#### DESIGN OF LANCED LUGS

Figure 8.11 (contd)

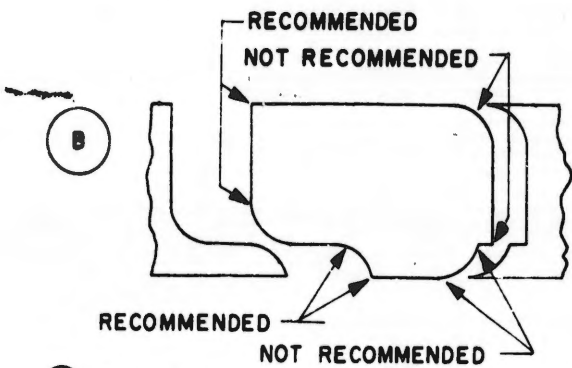
**EDGES**



(A) PARTS SHOULD BE STUDIED FOR PROJECTING CORNERS OR FLANGES THAT CAN BE CUT OFF WITHOUT SACRIFICING STRENGTH OR WELDING SURFACE.

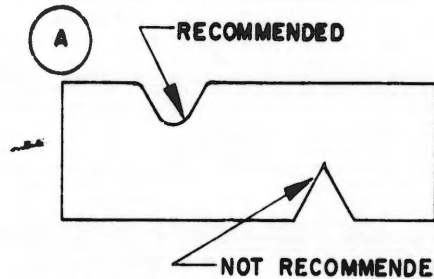


(D) TO REDUCE COST OF BLANKING DIES, PARTS SHOULD BE DESIGNED SO THAT STRAIGHT EDGES CAN BE MAINTAINED ON THE FLAT BLANKS.

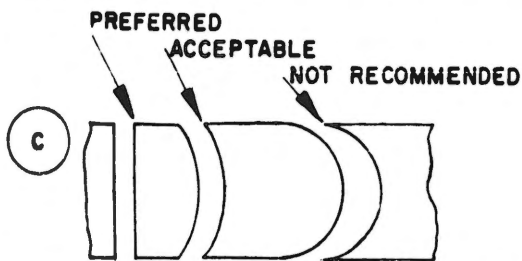


(B) PARTS CUT FROM STRIP STOCK SHOULD HAVE CORNERS WHICH ARE PARTLY FORMED BY THE EDGE OF THE STOCK, SHARP AND APPROXIMATELY 90°; CORNERS NOT PARTLY FORMED BY THE EDGE SHOULD BE ROUND, WHEREVER POSSIBLE.

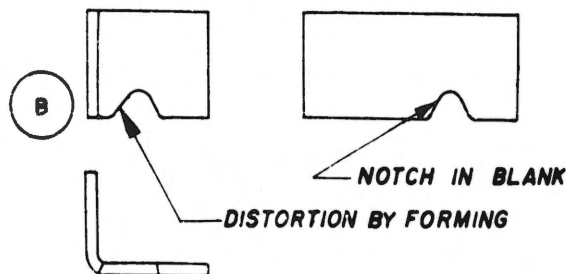
**NOTCHES**



(A) THE RADIUS OF THE VERTEX OF A NOTCH SHOULD BE AS LARGE AS POSSIBLE TO PREVENT TEARING; A MINIMUM OF TWICE METAL THICKNESS AND A 60° ANGLE NOTCH IS RECOMMENDED. NOTCHES WITH A SHARP "V" AT THE VERTEX ARE NOT RECOMMENDED AS THIS IS WHERE TEARING USUALLY STARTS.



(C) FEATHER EDGES SHOULD BE AVOIDED TO MINIMIZE DIE MAINTENANCE. THESE EDGES ARE DIFFICULT TO MAINTAIN AS THEY TEND TO BREAK OFF IN THE DIE AND THUS INCREASE COST AND MAINTENANCE.



(B) IF A NOTCH IS TO BE PUT IN A BLANK REQUIRING SUBSEQUENT FORMING IN THE VICINITY OF THE NOTCH, ALLOWANCE SHOULD BE MADE IN THE DESIGN FOR DISTORTION THAT MIGHT BE CAUSED BY THE FORMING OPERATION.

**DESIGN OF BLANK EDGES AND NOTCHES**

Figure 8.11 (contd)

## CHAPTER 9

### ROLLING

#### PROCESS

Cold roll forming is a process in which a flat strip of metal is progressively formed into its final desired shape by passing it through a series of rolls. No heat treatment of the metal is required before, during, or after the forming. The process is extremely rapid and parts are produced to close tolerances. A vast variety of shapes are available by use of this process and, as is illustrated in Figure 9.1, almost any desired configuration is possible.

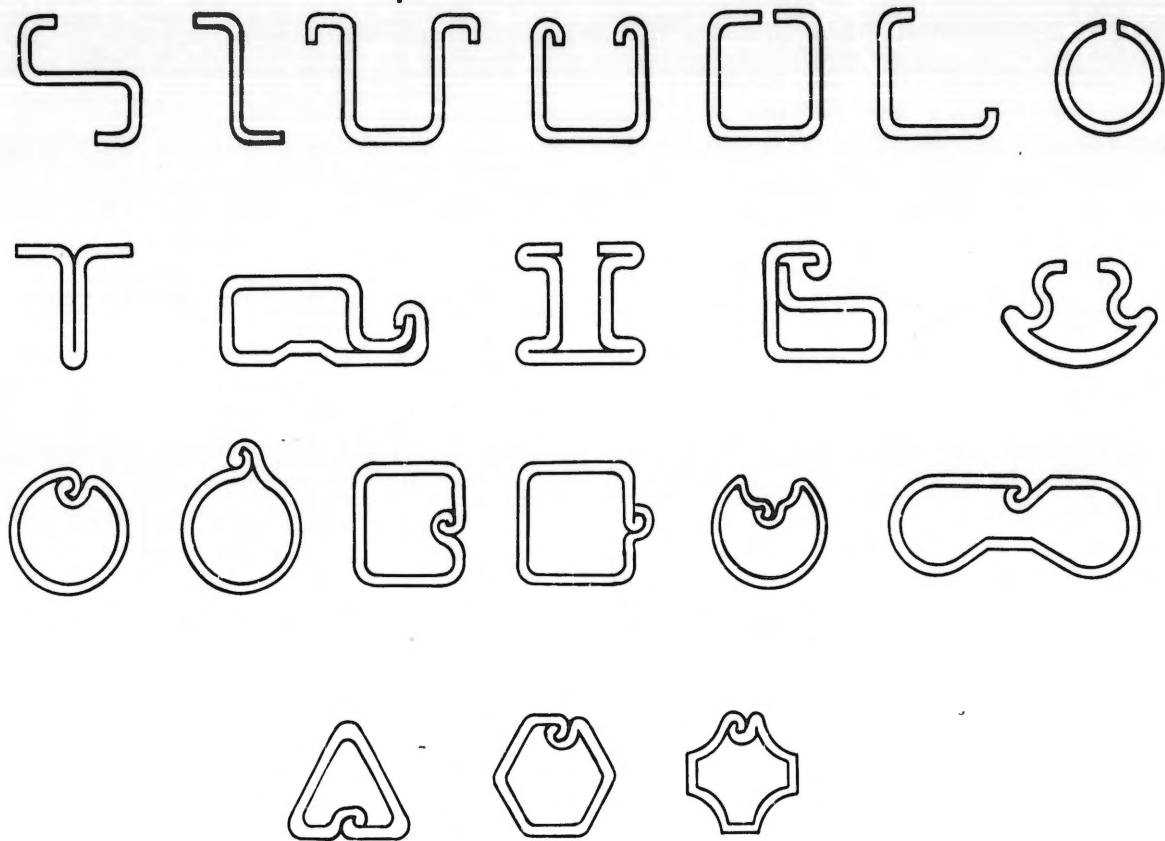


Figure 9.1 Typical Rolled Shapes

#### Materials

Cold rolled steel is the easiest and most commonly used material for roll formed parts. It offers a limited amount of springback and can be rolled without the use of a lubricant. Hot rolled steel can be roll formed satisfactorily but large amounts of lubricant must be used to flush away the scale which loosens from the steel during forming. Aluminum, copper, brass, bronze, and zinc sheets can all be roll formed readily but usually, special rolls are required for each different type of material.

A great many precoated materials can be roll formed without causing any damage to the coating. The bend radii on such parts must be kept large enough to avoid cracking of the coating at the bends. Precoated materials are usually rolled with lubricant on highly polished or chromium plated rolls.

Stainless steels can be roll formed but since they work harden during forming, they require about twice the forming capacity as is required by steel. Austenitic and ferritic stainless steels are commonly roll formed where the desirability of elaborate shapes or continuous lengths warrants the increase in tooling costs. Martensitic stainless steels are almost never roll formed.

Certain materials which cannot be roll formed cold are now being used in producing parts at elevated temperatures. Titanium alloys and magnesium alloys do not have the ductility required for roll forming at room temperature. Thus they are heated by induction coils placed between the sets of rolls until sufficient temperatures are reached to allow for forming of parts by the rolls.

### Equipment

The roll forming machines are usually classified into two types, inboard and outboard, depending on the arrangement of spindle supports or housings. An outboard machine has overhung spindles while an inboard machine has the spindles supported at both ends. Certain units are double-housing machines; that is, they can be converted from inboard to outboard depending on the type of work to be done.

The outboard machine is used primarily for forming small shapes from light-gage metal. This machine has the advantage of lower initial cost and faster setup time. The inboard machine is used more extensively than the outboard machine since the spindle deflection is reduced greatly. Much heavier forming work can be done on the inboard machine.

The majority of stock that is to be roll formed comes in coils, therefore, the parts must be cut as they come out of the machine in one continuous stream. There are three types of cut-off machines in use, namely, the flying shear, the circular saw, and the rotary type machine. By far the most common of these machines are the flying shear machines. On these, the stock passes under a blade and proceeds along the run-out table until it contacts a trigger. This trigger releases a set of compressed springs which actuates the blade. After the section is severed, the flying shear automatically reloads. The circular saw machine cuts off the part by a saw blade as the section moves along. The rotary type cut-off machine cuts the sections by means of a blade on a rotating drum. This is usually used for cutting heavy sections.

### Shapes

There are three types of curved shapes that can be produced by roll forming. These may be classified as follows:

- (1) straight sections, or parts with parallel bendlines.
- (2) straight flanged parts, or parts consisting of large flat portions or webs and non-parallel bendlines.
- (3) smoothly contoured parts, or parts possessing large radii and only minor flat portions or webs.

The variety of shapes that can be produced by roll forming includes channels, angles, "Z"s (as shown in Figure 9.2), piping, and tubing. The parts produced can be notched, pierced, coiled, printed, or embossed with little if any additional time being involved. Many aircraft structural parts can be and are being produced by the roll forming process.

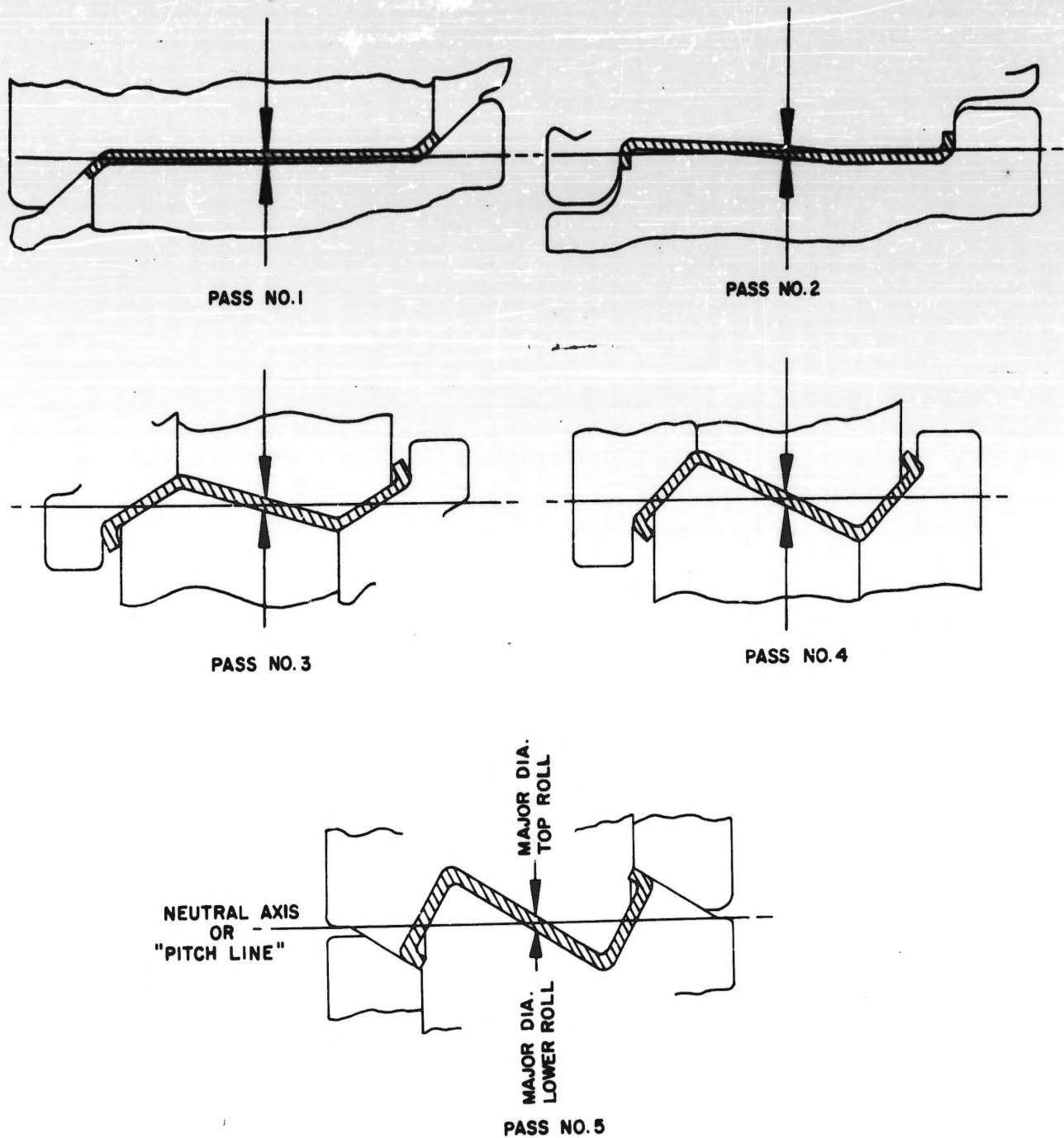


Figure 9.2 Rolling a "Z" Section

#### ADVANTAGES AND LIMITATIONS

Some of the advantages of roll forming include the following:

- (1) high strength to weight ratio in parts produced by this method.
- (2) a wide range of shapes and sizes are producible.
- (3) parts produced have good surface finish.
- (4) heat-treatment is eliminated for most materials.
- (5) close tolerances can be maintained.

- (6) a large variety of materials can be formed by this method.
- (7) the operation is both simple and high speed.
- (8) simultaneous operations can be performed while the part is being roll formed.

Some of the limitations in roll forming include the following:

- (1) high cost of tooling involved which cannot be absorbed by low production rates.
- (2) size limitations imposed by existing equipment.
- (3) bend radii are limited in some materials, especially coated materials.

### DESIGN CONSIDERATIONS

Some of the general design considerations in roll forming are included in the following rules:

- (1) extreme section depths should be avoided.
- (2) side walls should be formed with a slight angle to reduce roll wear and metal scoring.
- (3) avoid blind corners or blind radii.
- (4) outside radii should be at least equal to metal thickness. The inside radius depends on the metal being formed, an untempered part being formable with zero radius while tempered parts require a greater radius to prevent cracking.
- (5) the metal sheet thickness should lie within the range of 0.005 to 0.750 inches.
- (6) Tolerances of roll-formed sections -

Angles - plus or minus 1° up to 0.064 inch stock

plus or minus 2° up to 0.125 inch stock

Straightness - 1/8 inch in 12-foot lengths

Piece Length - plus or minus 1/16 inch using automatic cut-off

Twist - not to exceed 1/2° per foot. a maximum 5° twist is allowable

Dimensions - plus or minus 1/32 inch on fractional dimensions.

plus or minus 0.015 inch on decimal dimensions

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## CHAPTER 10

### CASTING

#### PROCESS IN GENERAL

All casting processes are basically similar in that the metal being formed is in a liquid or a highly viscous state and is poured or injected into a cavity of desired shape. The casting processes fall into the general categories of sand mold casting, permanent mold casting, die casting, investment casting, and centrifugal casting, and each is discussed separately with its own advantages, limitations and design considerations. Depending on the material, quantity, degree of precision, and strength characteristic of the piece, one or several casting methods will be applicable. Table 10.1 relates all the general characteristics of the casting processes, rating each with regard to various design characteristics desired (1 being the best). This table acts, therefore, as a preliminary guide for selecting any casting method and details may be found in the discussion section of each.

Table 10.1 Comparison of Casting Processes<sup>(1)</sup>

	Sand Casting	Plaster Mold Casting	Centrifugal Casting		Permanent Mold Casting	Die Casting
	Mold Material					
	Sand	Plaster	Sand	Metal	Metal	Metal
Porosity	6	4	2	1	3	5
Surface	6	1	5	3	4	2
Tolerances	6	2	5	3	4	1
Strength of solid metal	5	5	4	2	3	1
Thin section	6	1	5	3	4	2
Speed of production (small runs)	1	5	4	2	3	6
Speed of production (large runs)	5	6	4	2	3	1
Possibility to save machining	5	6	4	2	3	1
Cost per piece	5	6	4	2	3	1
Tool cost	1	3	2	4	4	5

#### SAND CASTING

##### Process

Sand casting involves pouring molten metal into a cavity of desired shape made from sand. Depending on the material to be cast, various grades of sand, sometimes including a clay binder, are packed around a pattern of the designed part. There are several classes of pattern equipment and each will be discussed briefly. Most castings require cores of some type to control the cavity contour. Thus, most classes of pattern equipment require core boxes in which the cores needed for each mold can be made. Many of the cores for production runs need to be baked in core driers before they are ready for use. Core driers are cast iron, aluminum, or magnesium forms in which the green sand cores rest while they are being baked in the core oven.

(1) By permission from Tool Engineers Handbook by American Society of Tool Engineers. Copyright, 1949. McGraw-Hill Book Company, Inc.

Among the classes of pattern equipment are the following:

- (1) single, loose, wood patterns - These patterns are relatively low in cost but are only applicable for limited production since they are easily warped by moisture and easily damaged in handling. They are of particular use in manufacture of prototype equipment where only one or two castings are required.
- (2) single, loose, metal patterns - These patterns are recommended for low cost, low production runs. Both wood and metal patterns have the disadvantage that the gates and risers must be cut by hand; this requires more time and causes quality variation due to the variation in gate dimensions.
- (3) gated, wood or metal patterns - Gated patterns may be used for the same uses as listed above. They have the same general drawbacks of shrinkage and warpage; however, the presence of the gates eliminates the disadvantage of hand-forming the gates.
- (4) metal match-plate patterns - These are used for production of large quantities of small castings and they give rapid and accurate reproduction. Naturally, the initial equipment cost is much greater with match-plates than with single patterns, but the increased cost is compensated for by increased production.
- (5) cope and drag patterns - Separate cope and drag patterns, made of either wood or metal, permit good production on medium to large castings. Metal cope and drag pattern equipment is particularly applicable for large production of heavy castings and for gang molding on machines.

#### Materials

Materials applicable to sand casting include cast iron, low and high carbon alloy steels, copper, aluminum, magnesium, zinc, and their alloys.

#### Advantages and Limitations

Sand casting has the advantage of low pattern cost and a wide range of available tolerances. This is a very flexible process and can handle almost any size or shape of casting as well as a variety of alloys. The process is among the most rapid of the casting processes.

The possible disadvantages inherent with sand casting are poor surface finish, possibility of porosity, and internal shrinks. The strength-to-weight ratio is lower with sand casting than with other casting processes.

#### Design Considerations

Casting Allowances. There must be allowances on a pattern if the part produced is to be the correct size; these allowances are for shrinkage, distortion, and machine finish.

Shrinkage allowance for patterns is the correction for the change in dimension as the solidified casting cools in the mold from freezing temperature to room temperature. This shrinkage or contraction is compensated for by making the pattern larger by the amount of shrinkage characteristic of the particular metal being used. This allowance is provided by the pattern maker rather than the designer.

Distortion allowance is used with certain types of castings where the part to be produced has a large flat area or a U-shape. The pattern is purposely distorted in these cases to make the resulting casting straight.

Machine finish allowance must be provided for castings which are to have subsequent machining operations. By this allowance, excess stock is provided at points where machining is to be performed.

Other Design Considerations. Other general points a designer must consider in sand casting are:

**Draft** - The minimum draft angle in green sand molding is  $1^{\circ}$ . The usual draft angle is  $2^{\circ}$  to  $3^{\circ}$ .

**Core Prints** - The length of a core print should be at least equal to its width or diameter. Vertical print surfaces should have at least  $2^{\circ}$  taper to facilitate core setting.

**Parting Lines** - Parting lines should be regular whenever possible. An irregular parting line never produces as satisfactory a casting as a regular one.

**Locating Points** - Locating points should be specified on the drawing so measurements will always be made from the same points. Whenever possible the locating points should be on the same side of the parting line.

**Tolerances, Section Thickness, Machine Finish Allowances** - See Table 10.2.

Table 10.2 Typical Sand Casting Tolerances, Section Thickness, and Machine Finish Allowances

	Typical Tolerances for 1000 pounds or greater castings  (inches)	Normal Minimum Section Thickness  (inches)	Minimum Machine Finish Allowances (up to 24" Pattern Size)  (inches)
Cast Iron	1/16	1/8	1/8
Malleable Iron	5/32	3/32	1/8
Cast Steel	5/32	3/16	5/16 *
Aluminum Alloys	5/64	1/8	1/8
Magnesium Alloys	11/64		
Brass	3/32	3/32	1/8
Bronze	1/8	3/32	1/8

\* Cast Steel up to 36" Pattern Size

## PLASTER MOLD CASTING

### Process

This process is ideally suited to the casting of small intricately shaped pieces of nonferrous metals; however, pieces as large as 2200 pounds have been consistently produced. The mold is made of plaster in much the same way as a sand mold and some of the plaster is reclaimed for further use. The cast piece is very close to dimension and has a smooth surface. The process involves rather elaborate equipment and the cost runs slightly higher than sand casting, but not as high as investment casting. Plaster mold casting allows for uniform hardness and prevents stress concentration since the insulating properties of the plaster mold allow slow cooling of the casting.

### Advantages

The plaster-mold process can produce castings with extremely thin sections and knife edges. Small holes for tapping can be cast to size. Hole locations can be spotted in the pattern, eliminating a drill jig. Complex cored castings can be readily produced as well as undercuts and intricate passages. Reproduction of fine detail is excellent, such as name plates and control knobs with markings and numerals. The smooth surface obtainable is outstanding.

### Design Considerations

General design considerations for plaster-mold casting are as follows:

- (1) tolerances of plus or minus 0.005 inch per inch can be held, unless the dimension crosses the mold parting line, where plus or minus 0.010 inch is advisable,
- (2) draft angles range from 1/2 to 1 degree,
- (3) cored holes can be cast to plus or minus 0.005 inch,
- (4) flatness can be held within 0.005 inch in areas of about 4 square inches, larger surfaces required 0.005 inch to 0.015 inch,
- (5) surface roughness can be better than  $30\mu$  -inches rms.,
- (6) overall size is usually limited by the standard mold size of 10 x 18 x 2-7/8 inches, the casting should not be more than 1-7/16 inches above the parting line.

## DIE CASTING

### Process

This process is commonly applicable to the nonferrous alloys (usually copper, zinc, magnesium, and aluminum). It involves forcing the metal in a highly viscous state under air or hydraulic pressure into a closed metal die. The combinations of high pressure, rapid casting, and precision of the metal die, allow for a high rate of production with good precision and surface finish.

### Equipment

The die casting machine consists of three main elements, (1) the frame which supports the weight of the dies and guides and supports the tie bars; (2) the die actuating mechanism for opening and closing the dies. This includes the linkage mechanism and the core setting and pulling equipment; and (3) the apparatus for injecting the molten metal into the die.

There are three basic types of die-casting machines.

The piston machine (see Figure 10.1) forces the shot of molten metal into the die by action of a plunger operated by an air or hydraulic cylinder. Pressures up to 5000 psi can be obtained by use of this machine. It is used primarily for lead, tin, and zinc-base alloys.

The cold-chamber machine (see Figure 10.2) has the molten metal hand-ladled into the pouring well. As the molten metal pours into the sleeve, a piston actuated by a hydraulic cylinder forces the shot into the die under pressure sometimes as high as 50,000 psi. This very high pressure produces castings with a higher density than a gooseneck machine is capable of producing. This machine is used primarily for making aluminum, magnesium, and brass castings.

The gooseneck machine (see Figure 10.3) gathers the shot of molten metal in the cast-iron gooseneck and then injects the metal out of the gooseneck into the die. Limited pressures (700 psi max) must be used to keep from bursting the gooseneck. The molten metal is sprayed into the die in a finely divided stream, thus causing the entrainment of air in the casting. This is one of the undesirable features of the gooseneck machine. The machine is used primarily for aluminum-base alloys.

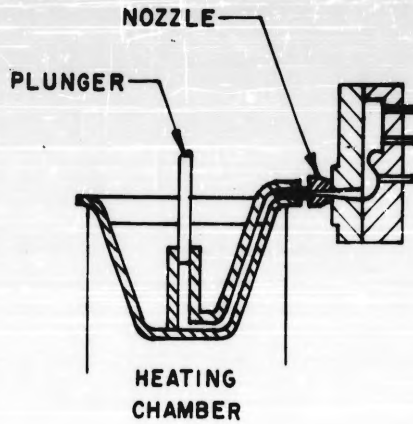


Figure 10.1 A Piston - Type Casting Machine

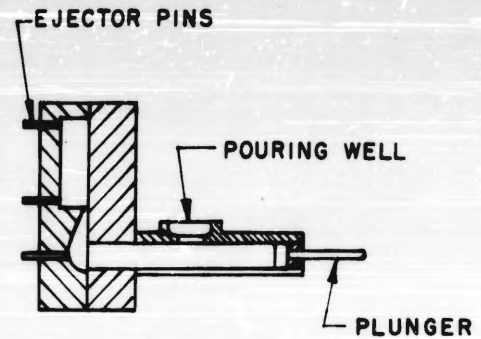


Figure 10.2 A Cold - Chamber Casting Machine

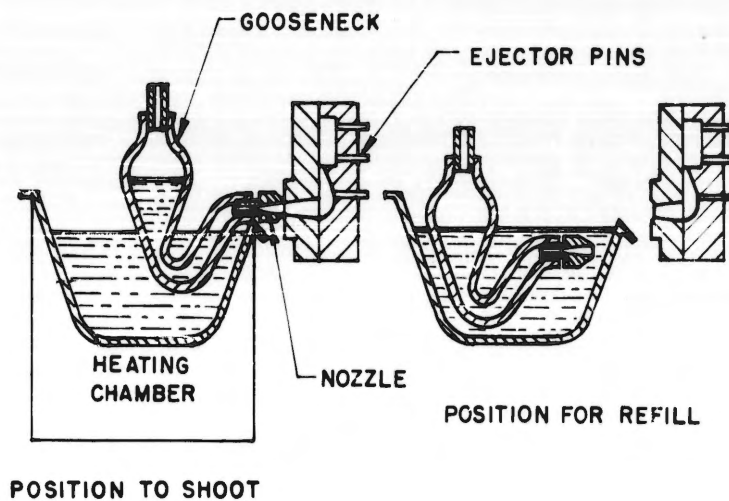


Figure 10.3 A Gooseneck Casting Machine

#### Advantages and Limitations

Die casting produces high strength castings of excellent dimensional stability. It is an extremely valuable process for high production runs. It produces a good surface finish and very often a die cast part needs no finishing or machining operations. Die casting is an excellent method for producing thin-walled sections.

Some of the limitations of this process are porosity and a high tool cost. The process is far too expensive for any low production runs.

#### Design Considerations

Table 10.3 lists some of the design considerations in die casting.

**Table 10.3 Approximate Dimensional and Weight Limits  
for Die Casting of Different Alloys**

Type of alloy (base metal)	Zinc	Aluminum	Magnesium
Maximum weight of casting (pounds)	35	20	10
Minimum wall thickness, large castings (inches)	0.050	0.080	0.080
Minimum wall thickness, small castings (inches)	0.015	0.050	0.050
Minimum variation from drawing dimensions per inch diameter or length	0.001	0.0015	0.0015
Cast threads, maximum number per inch, external	24	24	16
Cast threads, maximum number per inch, internal	24	None	None
Minimum draft on cores, inches per inch of length of diameter	0.003	0.010	0.010
Minimum draft on side walls, inches per inch of length or diameter	0.005	0.010	0.008

**PERMANENT MOLD CASTING**

**Process**

Permanent molds are molds made of metal (iron, steel, or bronze) into which the molten metal is poured without pressure. The molds are heated above 300°F and sprayed with a refractory coating to prevent the casting from clinging to the mold. The refractory coating also retards chilling of the castings and prolongs the life of the mold. Coring is limited in permanent mold casting since the mold must be separated from the casting as soon as it has set. Sand cores may be used when necessary; however, this semi-permanent type of mold casting is more costly. This process is used primarily for smaller nonferrous castings.

A special type of casting zinc alloy is known as "slush" casting. Molten zinc alloy is poured into a bronze die and after a certain period of time, the outer section of the metal adjacent to wall sets up. Then the die is inverted and the liquid metal remaining in the center is allowed to run out. The result is a hollow casting with a wall thickness dependent strictly on the length of time that elapses before inversion of the die.

**Advantages**

General advantages of permanent mold casting include such facts as high production rate per mold, uniformity of pieces, better surface finish, and reasonably close tolerances.

## Design Considerations

General design considerations for permanent mold casting are itemized in Table 10.4.

Table 10.4 Design Considerations for Permanent Mold Casting

Material	Tolerance (plus or minus)		Min. Wall Thickness (inch)	Min. Cored Hole Diameter (inch)	Min. Draft Per Side (inch per inch)
	Max. (inch)	Min. (inch)			
Aluminum	0.0015	0.010	1/8	1/4	0.015
Magnesium	0.0015	0.010	5/32	1/4	0.015
Copper Alloy	0.005	0.010	1/8	3/8	0.025
Iron	0.015	0.025	3/16		

## SHELL MOLDING

### Process

The shell mold casting process derives its name from the thickness of the mold (approximately 5/16 inch). The shell of fine sand and a plastic binder is manufactured on a shell making machine and then cured in a high temperature oven for a period of approximately one minute. The cope and drag are then glued together under pressure and the mold is ready for pouring.

The molten metal is poured into the mold and allowed to set; then the castings are easily shaken out since the high temperature has burned away the resin bond in the shell mold. Thus the sand does not adhere to the casting surface as it often does in green sand casting.

Since the shell molds can be made ahead of time and easily stored, the production rate can be fairly high.

### Advantages

Some of the general advantages of shell casting are accuracy of casting dimensions, smooth surface finishes, clarity of detail, improved physical properties, and reduction of chill and hard skin. In addition, since the shell can be made ahead of time and easily stored, the production rate is high.

### Design Considerations

- (1) Tolerances plus or minus 0.003 to 0.005 inches per inch parallel to parting line; plus or minus 0.010 to 0.015 inches across parting line.
- (2) Weight to 100 pounds and thickness of 3 to 4 inches.
- (3) Surface finish 100-120  $\mu$  -in. rms. special cases to 60  $\mu$  -in. rms.
- (4) Hole depth to diameter ratio of 8:1.
- (5) Zero draft angles.
- (6) External and internal threads - Class I tolerances.
- (7) Tolerances of cored holes plus or minus 0.001 inches.
- (8) Section thickness of 0.060 inch (minimum).

## INVESTMENT CASTING

### Process

The investment casting process involves making a wax, plastic, or even frozen mercury pattern either by hand or from a die, surrounding (investing) it with a wet refractory material, melting or burning out the pattern after the investment material has dried and set, and finally pouring molten metal usually under air or centrifugal pressure into the cavity. The investment is then broken away from the cast piece. For small pieces, numerous wax patterns may be cut off. Usually high cost alloys are used in this process since it is so expensive.

### Advantages

Advantages of particular importance of investment casting are:

- (1) it is adaptable to almost all metals,
- (2) complex shapes are attained, eliminating costly machining,
- (3) it is one of the most economical means of making pieces in pilot production before building costly forging or casting dies, or automatic tooling,
- (4) its use can be often justified for small-quantity runs,
- (5) cast parts not castable by any other process are available.

### Design Considerations

General design considerations for investment casting include the following:

- (1) tolerances from plus or minus 0.002 inch per inch for low temperature alloys to plus or minus 0.005 inches per inch for steel depending on section thickness. Across parting or gate lines tolerances must be increased,
- (2) minimum wall thickness of 0.4 inch unless sufficient taper is allowed for feeding in which event 0.02 inch has been attained,
- (3) thin edges limited to minimum of 0.012 to 0.015 inch,
- (4) maximum thread class is Class I,
- (5) serration peaks with minimum radius of 0.005 inch,
- (6) minimum fillets of 1/32 inch (1/16 to 1/8 inch is most desirable),
- (7) allow from 0.010 to 0.025 inch for required finishing stock,
- (8) minimum surface finishes from 60 to 90  $\mu$  -inch rms.

## CENTRIFUGAL CASTING

### Process

Centrifugal casting is not a separate process itself but is a method of forcing molten metal into a mold or die adaptable to almost any of the previously described casting processes. Molten metal is introduced into the spinning mold and is thrown to the mold wall where it is held under centrifugal force until it has solidified.

In the sand mold process this method is used mostly for casting iron pipe and other circular items such as wheels and gears.

For sand mold and the other casting processes, odd shaped parts are also centrifuge cast by spacing one or more molds on the periphery of a spinning table. The metal is then introduced at the center axis and led to the mold cavities by radial sprues.

### Advantages and Limitations

Predominant advantages to centrifugal casting include economy by eliminating center cores in the mold, elimination of gas holes and non-metallic inclusions due to tremendous centrifugal pressures, and the ability to better fill intricate and thin-walled sections also due to casting pressures.

The basic limitations when compared with static casting include restrictions as to size and shape plus expensive machinery.

### Design Considerations

The most that should be said regarding tolerances, surface finish, and other design considerations is that, depending on the die material, they are similar to those of each casting process previously discussed. Size of casting is limited mostly by what the spinning table can handle, and in the case of casting tubular products, about 50% more tolerance should be added for the inside diameter since this dimension will rely mostly on the volume of molten metal introduced.

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## CHAPTER 11

### POWDER METALLURGY

#### PROCESS

Powder metallurgy is the technique by which finely divided or powdered metals and alloys are compressed into a finished product and the individual particles welded together by sintering.

The production of powdered metal parts is usually done by

- (1) choosing the proper powder,
- (2) wet or dry mixing of the powders,
- (3) pressing the part in the die,
- (4) presintering for a short time at a low temperature,
- (5) machining of the presintered part,
- (6) sintering the part to obtain the desired set of mechanical properties,
- (7) impregnating the low density parts,
- (8) and coining or sizing when it is necessary to get accurate dimensions.

#### Equipment

The presses used in powder metallurgy are either mechanical, hydraulic, or a combination of the two. The mechanical presses are usually used in manufacturing small parts that can be produced at low pressures. Mechanical presses are built with capacities up to 1500 tons. Hydraulic or mechanical-hydraulic presses are used for very large parts and for parts where uniform density is required. These presses are slow acting but have capacities running as high as 5000 tons.

#### Materials

There are three general classes of metal powders that are applicable to these forming processes as follows:

- (1) metallic powders are those in which the particles contain a melting constituent and fuse to one another upon contact.
- (2) nonmetallic powders are those where the powder itself is a melting medium used to bond together a high melting point constituent.
- (3) intermetallic powders are those containing both high and low melting point metals. Impregnation as well as fusing occurs.

The process is one of the only methods available for producing bars of refractory metals such as tungsten, molybdenum, tantalum, columbium, and zirconium.

Powder metallurgy is also well suited to the combination of layers of dissimilar metals (each one pressed, the combination then rolled together and sintered) and to the mixture combination of metals and nonmetals for such items as brake linings.

#### Types of Parts Produced by Powder Metallurgy

There are actually five different classes of parts produced by powder metallurgy as follows:

- (1) flat parallel faces,
- (2) parallel faces with holes,

- (3) external flanges,
- (4) internal flanges,
- (5) step flanges or double hubs.

Parts with flat parallel faces are the simplest parts to produce. This type of part is produced on flat face punches with pressure applied from above only or from both above and below. The double action pressure gives the parts uniform density. Another method of producing parts of uniform density is by using a floating upper die and stationary lower punch.

Parts that have two parallel faces with one or more holes through them parallel to the direction of pressing are produced by pressing the powder around stationary core rods. The powder is inserted in the mold, the core rod raised, and compression pressure is applied to form the part. Then the pressure is released, the core rod withdrawn, and the finished part is ejected.

Parts with an external flange are produced with a shouldered die and with or without a core rod, depending on whether a hole is required. The flange is produced by the upper punch pressing the powder against the die shoulder while the lower punch forms the body of the piece. The punches are usually spring loaded to provide extra compression. Figure 11.1 shows an example of producing a part with an external flange.

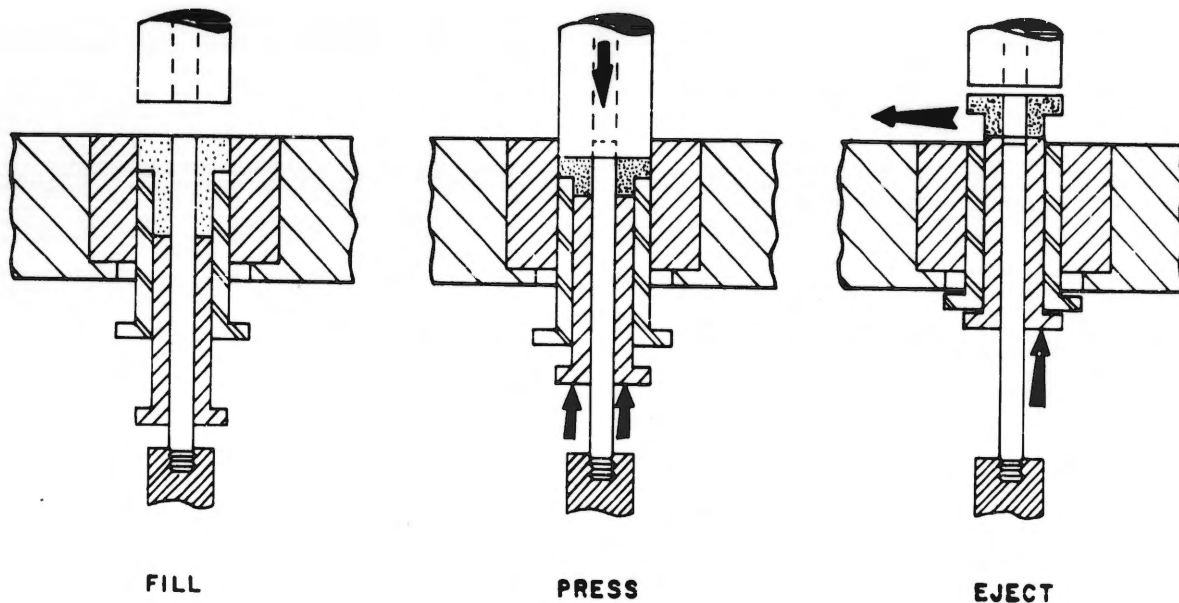


Figure 11.1 A Typical Powder Metallurgy Process

Parts with an internal flange are produced with a shouldered core rod. The punches are often spring loaded for extra compression and the parts are often produced using non-simultaneous motion; that is, pressure is applied from the top first and at some later time in the cycle, the spring loaded lower punch is released.

Parts with different pressing levels such as step flanges or double hubs are produced by use of telescopic punches which are usually spring loaded. Naturally these parts are the most difficult to produce and non-simultaneous motion is usually used to achieve the desired configuration.

## ADVANTAGES AND LIMITATIONS

Some of the general advantages of powder metallurgy are as follows:

- (1) it is the chief method of producing parts from refractory materials that melt at such high temperatures that they cannot be produced commercially in furnaces.
- (2) precision dimension parts that are so hard and brittle that they cannot be produced by any other method, can be readily produced by powder metallurgy.
- (3) porosity is controlled.
- (4) parts with extremely high density can be produced.
- (5) laminated parts can be produced that have intimate bonding.
- (6) machining operations are virtually eliminated.
- (7) parts can be produced from several different materials which do not combine in the molten state but which can be pressed together to give excellent properties.
- (8) the saving of metal can run as high as 50%.

Some limitations of powder metallurgy are as follows:

- (1) there is no lateral flow of material thus limiting the shapes that can be produced.
- (2) the process is expensive due to the high cost of both the metal powder and the die.

## DESIGN CONSIDERATIONS

Table 11.1 shows some tolerances applicable to powder metallurgy. Tolerances on length, flange diameter, flange thickness, and concentricity are given. Table 11.2 shows typical wall thickness for length and diameter sizes. Figure 11.2 shows some desirable design features that should be considered in designing a part for the powder metallurgy process. Figure 11.3 shows the way certain features should be redesigned to make them applicable to the powder metallurgy process.

Table 11.1 General Tolerances (plus and minus) for Powdered Metal Parts

Length (inches)	Length Tolerance (inches)	Diameter Tolerance (inches)	Flange Diameter	
			Diameter (inches)	Tolerance (inches)
Up to 1	0.005	0.0015	Up to 1	0.004
1 -1 1/2	0.010	0.002	1 -1 1/2	0.006
1 1/2-2	0.015	0.003	1 1/2-2	0.008
2 -2 1/2	0.020	0.004	2 -2 1/2	0.010
2 1/2-3	0.025		2 1/2-3	0.014
			3 -4	0.016
Flange thickness			Concentricity tolerance	
Thickness (inches)	Tolerance (inches)	Diameter (inches)	Total indicator reading (inches)	
Up to 1/4	0.004	Up to 1	0.003	
1/4 - 3/8	0.006	1 -1 1/2	0.004	
3/8 - 1/2	0.008	1 1/2-2	0.005	
		2 -2 1/2	0.006	

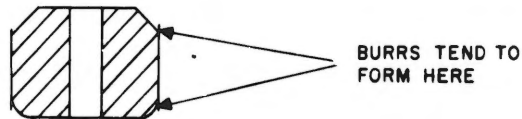
Table 11.2 Ratio of Wall Thickness to Length and Diameter

Minimum wall thickness (inches)	Maximum over-all length (inches)	Maximum outside diameter (inches)
0.032	1/2	1/2
0.040	5/8	3/4
0.045	3/4	1
0.050	7/8	1 1/8
0.055	1	1 1/4
0.060	1 1/4	1 1/2
0.070	1 3/8	1 5/8
0.075	1 1/2	1 3/4
0.080	1 5/8	1 7/8
0.085	1 3/4	2

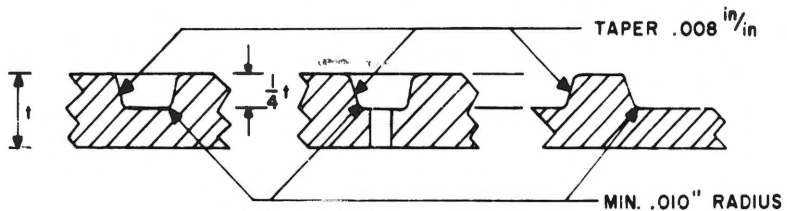
AVOID DESIGN OF PARTS WITH IRREGULAR WALL SECTIONS



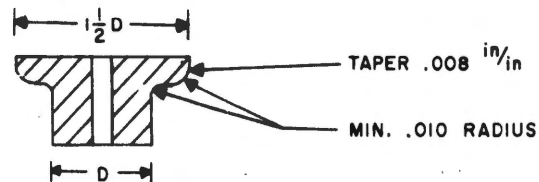
KEEP BEVELS AND RADII SMALL TO AVOID BURRS



LIMITATIONS ON DEPRESSIONS, COUNTERBORES, AND BOSSES



LIMITATIONS ON FLANGES



LIMITATIONS ON SHOULDER DESIGN

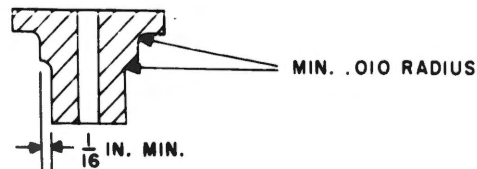


Figure 11.2 General Design Considerations for Powder Metallurgy



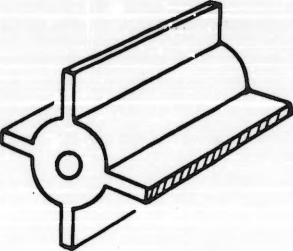
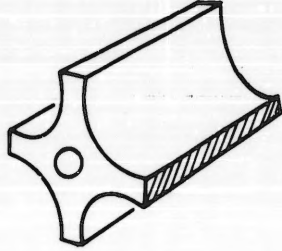
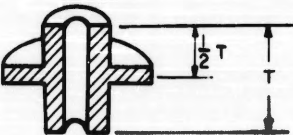
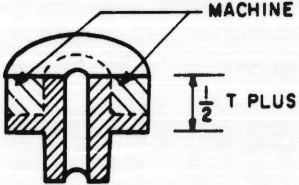


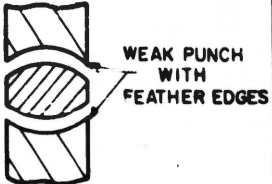
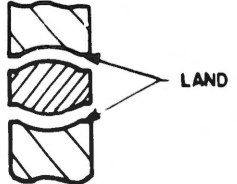
DESIGN FEATURE	ORIGINAL	REDESIGNED
TAPER DESIGN DETAILS TO PREVENT CORE ROD DAMAGE		
AVOID INCOMPLETE DIE FILLING		
		
AVOID REENTRANT ANGLES AND CURVES		
AVOID CERTAIN CURVATURES AT EDGES		

Figure 11.3 Examples of Redesign of Parts for Powder Metallurgy




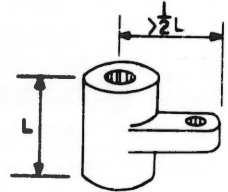
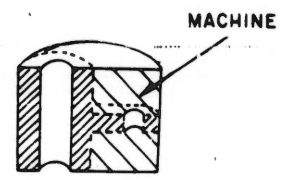

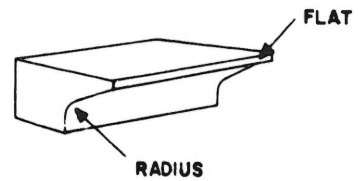

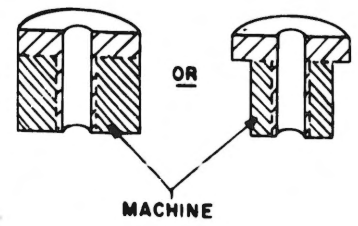
DESIGN FEATURE	ORIGINAL	REDESIGNED
		
<p>AVOID AXIAL VARIATIONS GREATER THAN <math>\frac{1}{2}</math> PART LENGTH</p>		
<p>AVOID SHARP CORNERS</p>		
<p>AVOID THIN SECTIONS</p>		

Figure 11.3 Examples of Redesign of Parts for Powder Metallurgy (contd)

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## CHAPTER 12

### HEAT TREATMENT

#### GENERAL

After a piece has been shaped by one of the methods described in the previous portions of this handbook, there are often some additional requirements imposed on the strength, ductility, toughness, wear resistance, freedom from internal stresses, etc.; of the material of the piece. These additional requirements are normally met by using one or several methods of heat treatment or surface preparation; the latter is discussed in the next part, and includes the requirements of cleaning, polishing, corrosion protection, etc., This part will consider methods of meeting requirements of internal and surface stress relief, surface and through-hardening, and annealing for machinability or ductility.

#### HEAT TREATMENT OF FERROUS MATERIALS

##### Process

The heat treatment of steels is performed in order to improve machinability, restore ductility for forming and extrusion, obtain toughness, or obtain a hardened case around a piece for wear resistance. The process involves basically raising the temperature of the piece to a required level and then cooling it at a slow, medium, or rapid rate in order to obtain the desired mechanical properties.

There are six basic types of heat treatments further grouped into categories of quenching and non-quenching as follows:

##### Non-quenching types

- stress relieving
- annealing
- normalizing

##### Quenching types

- case hardening (carburizing, carbonitriding, cyaniding, and nitriding)
- surface hardening (flame and induction)
- through hardening (water, oil, and air quench)

The non-quenching types of heat treatment are used usually, but not always, as preliminary steps in conditioning steels for further processing and heat-treating.

In order to better illustrate the following terms and definitions of heat treating, refer to the iron-carbon diagram of Figure 12.1.

**Stress Relieving.** This is a process which is used to reduce the residual stresses caused in a part which has been cold worked, machined, or welded. The steel is heated to a point somewhere below the lower critical temperature (the usual stress relieving range is 1100 - 1200°F), held at this temperature one hour or more per inch of thickness, and then slowly air or furnace cooled. This process is often used before or after heat treatment to reduce distortion.

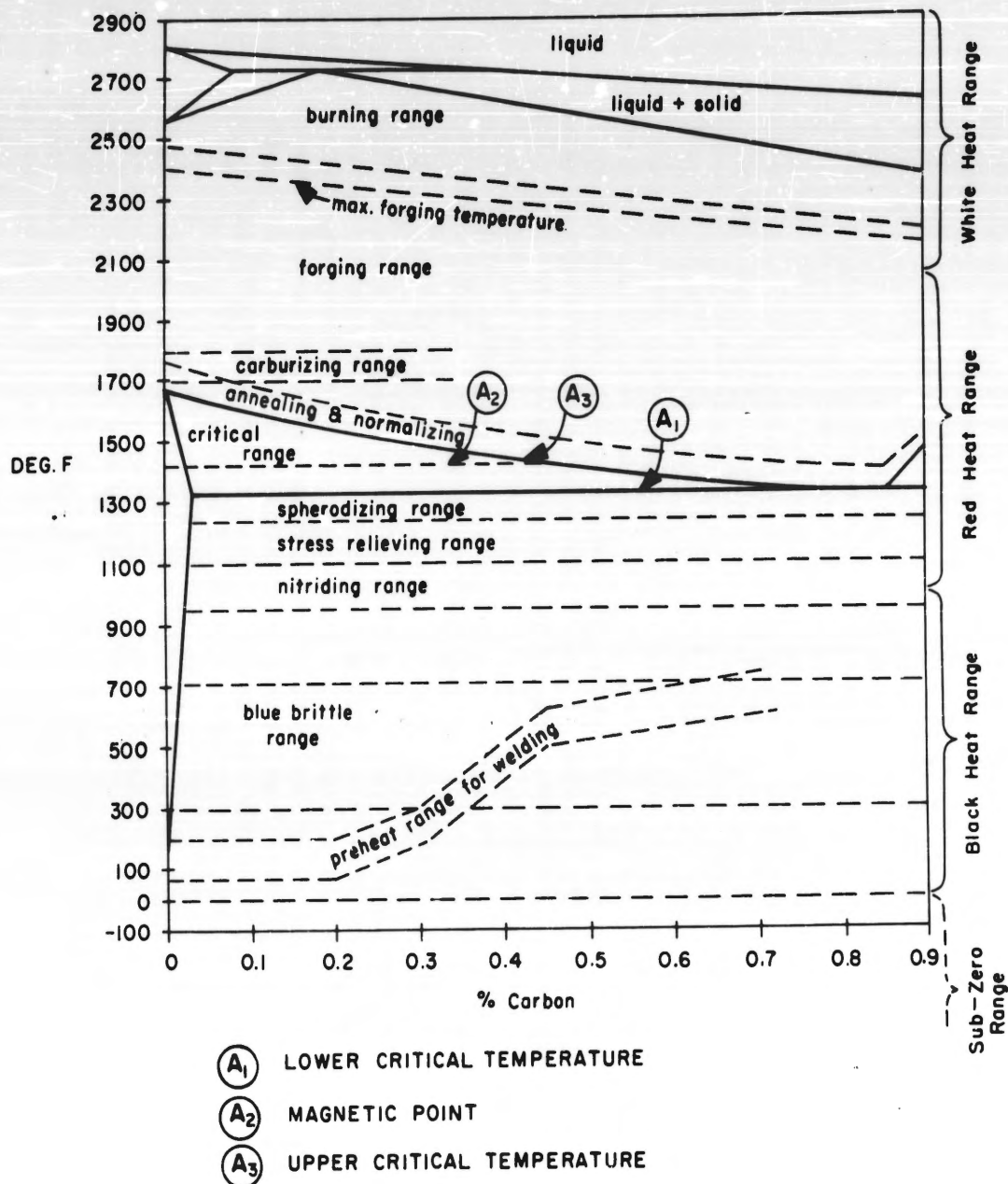


Figure 12.1 Iron Carbon Diagram

**Tempering.** This process is usually performed to improve the properties of a part that has been previously quenched. The steel is heated to a predetermined temperature below the transformation range and slowly cooled in a furnace or still air. Since the internal stresses are eliminated by this process, the toughness and impact resistance increase. As the tempering temperature is increased, the ductility increases and the hardness and tensile strength decrease.

**Normalizing.** In this process, the part is heated to a temperature above the upper critical temperature and subsequently is cooled in still air down to room temperature. The purpose

of normalizing is to refine the grain structure and improve the machinability. When the part is cooled, the austenitic grain structure transforms giving an increase in strength and hardness and a decrease in ductility.

**Annealing.** Annealing is performed by heating a part to a temperature above the upper critical temperature, holding it there until austenite forms, and then cooling very slowly in a furnace to a point below the lower critical temperature. During the cooling, the austenite turns to ferrite and pearlite producing a smaller grain size, which exhibits softness and good ductility.

**Case Hardening.** The "case" or outer shell of a part may be a varying depth depending on the way it is produced and the use to which it is to be put. Case depths are classified as follows:

**Shallow Cases (less than 0.02 inch)** - These are used where good surface condition after heat treating is desired but where the part won't be subjected to high stresses.

**Medium Cases (0.02 to 0.04 inch)** - The case thickness on these parts is sufficient to permit light grinding.

**Medium-to-deep Cases (0.04 to 0.06 inch)** - This presents a good surface where friction or abrasion wear may be present.

**Extra-deep Cases (more than 0.06 inch)** - These cases are highly wear resistant and also resistant to damage from shock and impact loads.

Methods used to produce these cases are listed below and typical case thicknesses and applications are shown in Figure 12.2.

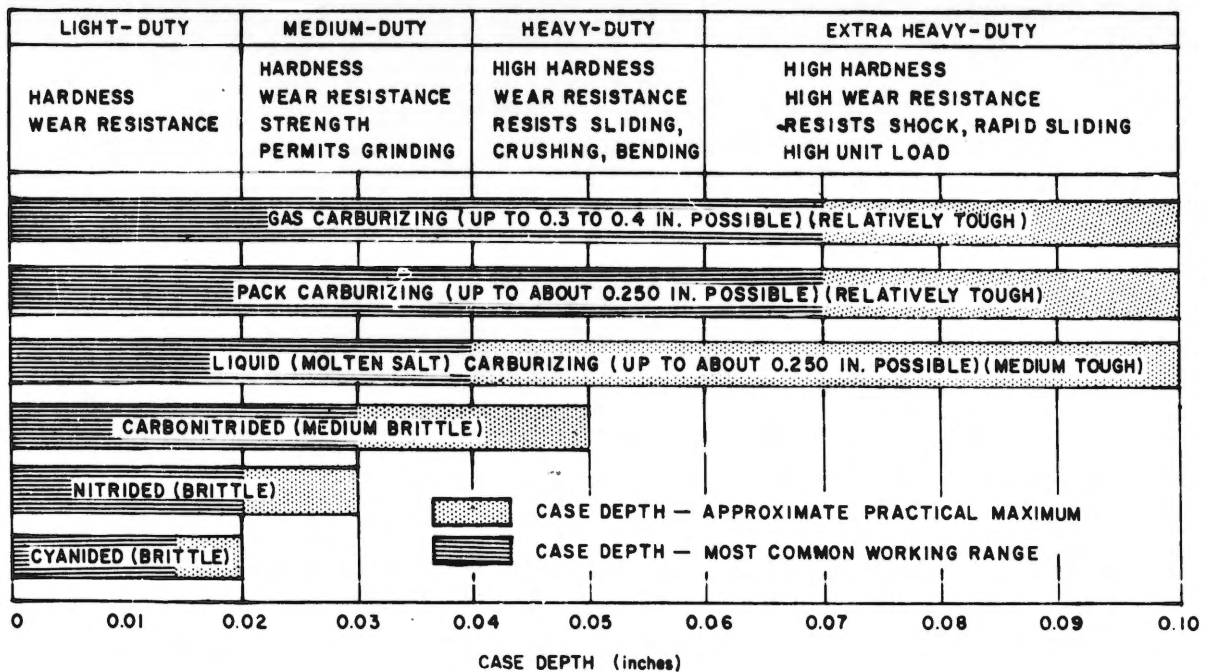


Figure 12.2 Case Hardening Thickness<sup>(1)</sup>

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- (1) **Carburizing** - Carburizing is an impregnation method in which the surface of the steel is subjected to a shallow coating of carbon. There are three types of carburizing that are generally employed to case harden parts, liquid, gas, and pack.

The method of liquid carburizing consists of immersing the part in a hot salt bath, composed basically of cyanide compounds, and leaving the part immersed until a case of 0.02 to 0.03 inch is formed.

Gas carburizing employs a furnace in which steels are subjected to an atmosphere of high carbon gases. Such steels are usually hardened to a depth of 0.01 to 0.04 inch.

In pack carburizing, the parts to be carburized are buried in a container of dry carbonaceous materials and the container is placed in a furnace. Deep cases can be obtained by this method.

- (2) **Carbonitriding** - This is a process of introducing carbon and nitrogen simultaneously to the surface of a steel that has been heated in a controlled atmosphere. Case thickness produced in this case is about 0.03 inch maximum. This method creates less distortion than carburizing.
- (3) **Cyaniding** - The process involves heating the parts in a molten cyanide salt bath and then quenching. The immersion period is usually short, not more than one hour. This process provides the part with high hardness and good wear resistance.
- (4) **Nitriding** - In this process, the parts are placed in a special airtight heating chamber where ammonia gas is introduced at high temperature and decomposed into nitrogen and hydrogen. The nitrogen enters the steel surface and combines with the elements of the steel to form nitrides. The nitrides give an extreme hardness to the surface. The properties of wear resistance, endurance limit, and high temperature hardness are all increased considerably by nitriding.

**Surface Hardening.** When only medium hard surfaces are required, it is often expedient to surface harden the part. The methods of flame hardening and induction hardening are used to obtain this characteristic. Flame hardening is a method of hardening by rapidly heating a surface with heat from an acetylene torch, and then quenching the heated surface. The flame is moved constantly to eliminate burning or hardening too deeply. The process is rapid and also tends to minimize distortion. Induction hardening involves the heating of a steel part by electrical induction current with frequencies between 1000 and 500,000 cps, followed by a quench. This is the fastest method of heat treatment and also produces a part free from distortion and residual stresses.

**Through Hardening.** Through hardening is normally used to obtain optimum mechanical properties throughout a part. Table 12.1 shows the hardenability and applications of some direct-hardening steels. Through hardened characteristics are obtained basically by the standard heating and quenching or interrupted quenching methods. The former method is shown in the upper-left diagram of Figure 12.3 and the latter method is shown by the remaining three diagrams of the same figure.

Table 12.1 Hardenability and Uses of Directly Hardenable Steels (AISI) (1)

Carbon (%)	Low Hardenability	Medium Hardenability	High Hardenability	Applications
0.30-0.37	1330, 1335, 4037, 4042, 4130, 5130, 5132, 8630	2330, 3130, 3135, 4137, 5135, 8632, 8635, 8637, 8735, 9437		For heat-treated parts requiring moderate strength and great toughness. Frequently used for water-quenched parts of moderate section size or oil-quenched parts of small size. Typical parts are connection rods, axles, shafts, studs, steering knuckles, etc.
0.40-0.42	1340, 4047, 5140, 9440	2340, 3140, 3141, 4053, 4063, 4140, 4640, 8640, 8641, 8642, 8740, 8742, 9442	4340, 9840	For heat-treated parts requiring higher strength and good toughness. Used for medium- and large-size parts, low- and medium-hardenability steels being generally employed for axle shafts and propeller shafts and high-hardenability steel for particularly large axles, shafts, and aircraft parts. Generally oil-quenched
0.45-0.50	5045, 5046, 5145, 9747, 9763	2345, 3145, 3150, 4145, 5147, 5150, 8645, 8647, 8650, 8745, 8747, 8750, 9445, 9845	4150, 9850	For heat-treated parts requiring fairly high hardness and strength along with moderate toughness. Parts are usually gears and similar stressed machine components
0.50-0.62		4068, 5150, 5152, 6150, 8650, 9254, 9255, 9260, 9261	8653, 8655, 8660, 9262	Used primarily for springs and tools
1.02	50100	51100, 52100		Used mainly for ball and roller bearings but also for other machine parts requiring high hardness and wear resistance

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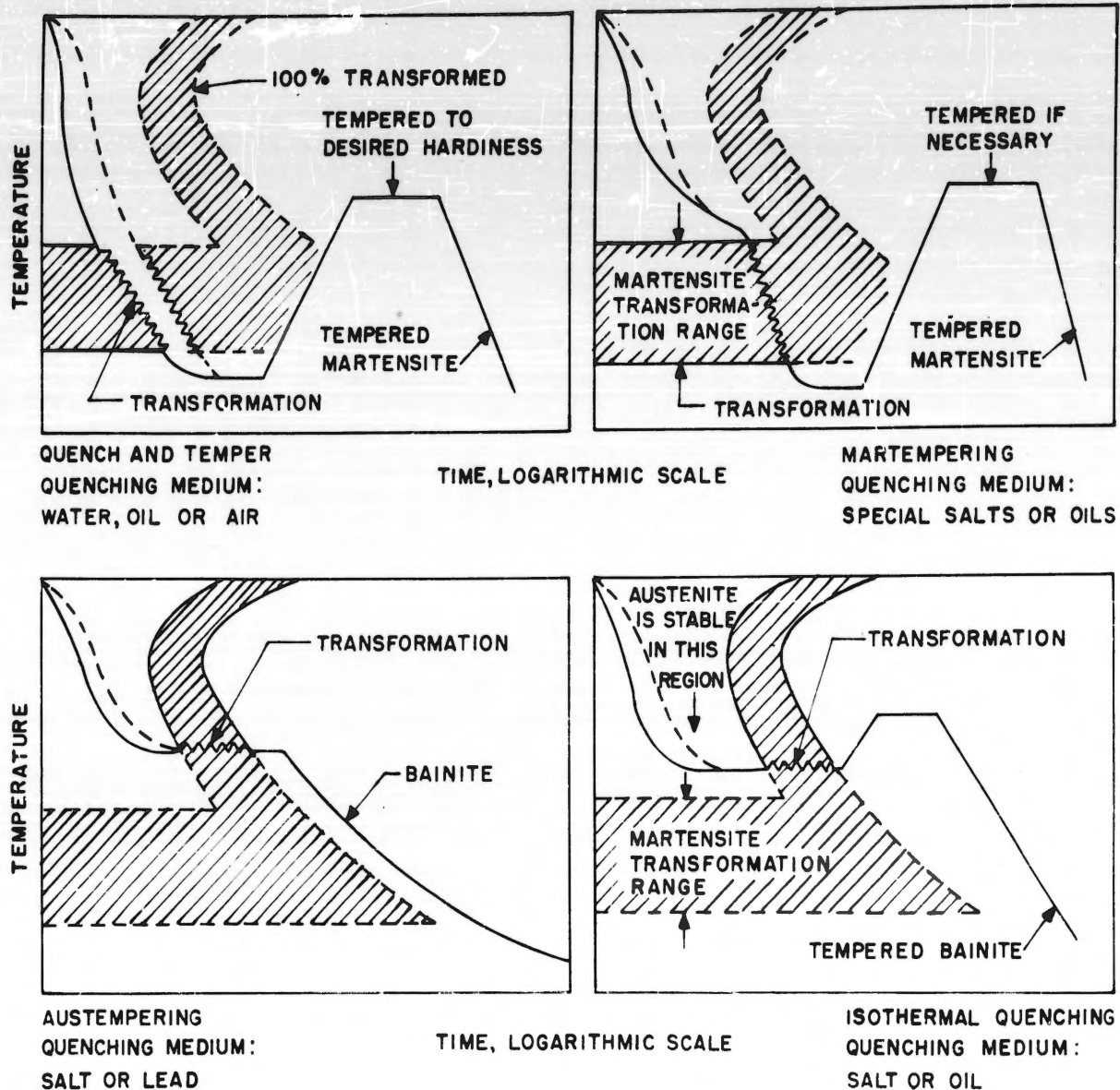


Figure 12.3 Methods of Through Hardening (1)

In the standard quenching method, three media are available for drawing away the heat from a treated part, namely, water, oil, or air. Fresh water is satisfactory only when used as a flush; still salt water avoids the bad effects of bubbles from dissolved gases. The water-quench is used mainly on plain carbon steels to attain high hardness through fast cooling. This media has the most severe cooling features.

Mineral oils, economical and chemically stable media, are used to harden alloy steels and produce less distortion than water. They are also the most commonly used.

Air is used with high alloy steels for which the critical cooling rate is decreased sufficiently to allow for low distortion.

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The interrupted quenching is used with medium and high carbon steels to lessen the tendency of a part to distort or crack while being cooled. The method is divided into the individual processes of martempering, austempering, and isothermal quenching. All processes are similar in that cooling rate is closely controlled. A particular advantages of martempering and austempering is that thin sections may be safely treated without attending problems of distortion. Isothermal quenching has an advantage in being able to handle large parts.

### Design Considerations

Basic design considerations to aid in meeting final physical and mechanical requirements after heat treating ferrous materials include the following:

- (1) design parts as symmetrical as possible,
- (2) use generous fillets at junctions of different sized sections,
- (3) use a balanced layout of holes, bosses, etc.; avoid clustering of openings,
- (4) design parts subject to fatigue as large as possible,
- (5) provide pads and enlarged shoulders for gear and wheel seatings,
- (6) avoid placing stamp works on parts subject to high stresses,
- (7) avoid rough surfaces and sharp corners,
- (8) long parts having stock finish on one side and machined finish on another will tend to warp; all surfaces should have similar surface characteristics.

Reference to Table 12.2 will aid the designer of proper heat-treatment to meet his design requirements. This Table appears on page 12-8.

## HEAT TREATMENT OF NONFERROUS MATERIALS <sup>(1)</sup>

### Aluminum

Heat treatment of aluminum alloys is essentially the same as for steel. The alloy is heated to a high temperature, rapidly cooled, and then hardened by being reheated again, but to a lower temperature. The metallurgist refers to these operations as a "solution anneal," followed by a "quench," and then by "artificial aging," respectively.

When alloys are added to aluminum, they can form new phases with increase in temperature such as solid solutions. Hence, a solution anneal consists of heating a heat-treatable alloy to about 950°F so that all the new phase material is in solution with the matrix. As the temperature of solution anneal is increased, this process becomes more rapid. The primary limitations to continued increase of temperature is avoidance of melting within the alloy, or "burning," which results in loss of ductility. In severe cases blisters are produced which reduce the alloy's strength. Too low a solution-anneal temperature either does not dissolve all the new phase or else takes too long.

To let the solution-heat-treated alloy cool slowly to room temperatures would allow the new phase just placed in solution to come out as relatively large particles. Large particles in the matrix would bring the alloy back to where it was prior to the solution anneal, and nothing would be gained. To "freeze" the atoms of the new material in solution with the aluminum, the material is cooled rapidly by quenching in cold water. The condition that now exists is one of supersaturation, and the alloy is striving to get out of solution.

A low temperature heat-treatment, or aging treatment, following the quency of the solution-annealed alloy, causes the new phase to come out of solution and precipitate, but at a controlled size in a controlled dispersion. Thus, the particles are no longer distributed

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Table 12.2 Steel Application and Heat-treating Guide<sup>(1)</sup>

Use or Part	Low-carbon		Medium-carbon			High-carbon	
	C 1020, 1117, etc.	A 2315, 3115, 4615, 5120, 8620, etc.	C 1040	A 3140, 4140, 5145, 8640, 8740, 6145, etc.	A 4340, 3250, etc.	Oil-hard. tool steel	Water-hard. tool steel
Arbors			N, T	T	T		
Armature shafts			T	T	T		
Axles	C	C	N, T, A	S, T		T	T
Ball races		C	S	T		T	T
Bolts and studs			T, A	T	T		
Bushings	C	C				T	
Cams		C				T	T
Camshafts	C	C		T	T		
Cant dogs							T
Chain links				T			
Chain pins	C	C					
Chuck jaws		C		T		T	
Chuck screws			N, A	T			
Clutches					T	T	
Collets						T	T
Connecting rods				T	T		
Crankshafts			N, S, A	S, T	S, T		
Drift pins			N	T			
Engine bolts	C	C	N, T	T			
Gears	C	C	N, S, T, A	S, T	S, T	T	
Guide pins						T	T
Mandrels	C	C		T		T	
Pinions	C	C	N, S, T	S, T	S, T	T	
Pins	C					T	T
Pistons		C				T	
Pump shafts			N, T, A	T			
Rollers	C	C					
Rolls	C	C	S	S, T	S, T	T	T
Lead screws			N, A	T			
Set screws			T	T			
Spindles	C	C	S, T, A	S, T	S, T	T	T
Stay bolts	N	A					
Thrust washers		C				T	
Turbine shafts			N, T, A	T			
Turnbuckles			T	T			
U bolts			T	T			
Universal-joint pins	C	C					
Universal-joint bodies			N, T, A	T	T		
Worms	C	C	S, T	S, T			

N = normalized  
 C = casehardened  
 S = surface-hardened  
 T = through hardened  
 A = as-rolled or natural condition

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randomly in large particle sizes but rather as very tiny platelets, evenly distributed throughout the matrix. This condition causes the alloy's hardness and strength to increase perceptively, and its ductility and corrosion resistance to decrease.

Some heat-treatable aluminum alloys do not require a low-temperature precipitation treatment. They start precipitating at room temperature. Thus alloys that are aged at a slightly elevated temperature, say 350° F for about 8 hours, are termed "artificially aged," while those which precipitate at room temperature are referred to as "naturally aged."

One of the best-known precipitation-hardened aluminum alloys is 2024. One very serious disadvantage of the precipitated 2024 alloy is its poor resistance to corrosion. During aging  $\text{CuAl}_2$  particles form at grain boundaries depleting the surrounding metal in copper, and they act as cathodic; the surrounding aluminum particles behave as anodes. Hence, when moisture is present, galvanic corrosion sets in. To avoid intergranular corrosion, cladding is done with a thin layer of pure aluminum, and the product is known as Alclad or Duraluminum.

The hardness of those alloys, which are not heat-treatable but which harden by cold work only, are designated 1/4 hard, 1/2 hard, or 3/4 hard. They develop their hardness when the sheet is cold-rolled. They can be annealed to dead soft but cannot be reheat-treated to restore physical properties.

General design considerations are similar to those for steel.

### Titanium

All the titanium alloys are potentially heat-treatable. The practicability of heat treatment is an entirely different matter. Titanium is a reactive metal and carbon, oxygen and nitrogen are absorbed readily. When temperatures exceed 600° F, hydrogen can be absorbed in large quantities. If final heat treatments are required on formed parts they would probably have to be done in an inert atmosphere. The same would apply to the quenching of parts to avoid contamination. These are some of the difficulties encountered in heat treatment of titanium, which at present is confined to forgings, extrusions, bar and other simple massive shapes.

General design considerations are also similar to those for steel.

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## CHAPTER 13

### SOLDERING

Soldering is a method of joining metals in similar or dissimilar metal combinations by means of a nonferrous filler metal, without fusion of the base metal, and is normally carried out at temperatures lower than 800°F.

#### GENERAL CAPABILITIES

Most metals and alloys can be joined by soldering to themselves or to other metals, as long as the joint meets the mechanical, corrosive, or other requirements of the service application. However, since soldering is done with a relatively low-melting-point alloy, soldered joints are inherently weaker than those produced by welding or brazing.

#### SOLDER COMPOSITIONS

In general, solders are lead-tin alloys with or without the addition of other elements. The more common alloys are listed in Table 13.1. For many joining operations, tin is the major alloying or wetting ingredient. In many cases the greater the tin content, the more rapid the wetting of the metal to be joined by solder and the more rapid the melting. Within certain limits the useful physical properties are also improved by increased tin content.

#### FLUXES

Fluxes are necessary to facilitate the removal of oxide films and to assist in the wetting and joining of the solder. Selection of the proper flux is very important, since there is no such thing as a universal flux. It is usually advisable to use the fluxes recommended by the manufacturer of the respective solder alloy. The choice of a flux depends upon (1) the type of solder used, (2) the type of base metal or alloy, (3) the design of the joint, (4) the soldering process, and (5) the ability to remove flux residues after the joint has been made.

Three major groups of fluxes are available as listed in Table 13.2.

#### MATERIALS

In the design of soldered joints, the metals to be joined must be considered. Table 13.3 includes the recommended materials to be used with the more common metals.

**Table 13.1 Characteristics of Major Commercial Tin-Lead Solder Alloys**

**Note:** The remaining composition of the solder alloy may be composed of varying percentages of Sb, Ag, As, and In.

Nominal Composition (%)		Melting Range (°F)		Application
Sn	Pb	Solidus	Liquidus	
100	0	450	450	Electrical parts, contact with certain foods, sweat soldering of copper tubing.
70	30	360	378	Tinning and metal coating.
60	40	360	372	Electrical parts and applications where temperature requirements are essential.
50	50			Most popular solder alloy.
45	55	360	440	Automobile radiators and roofing seams.
40	60	360	458	Radiator and heating units, wiping solders for lead pipes and cable sheaths.
35	65	360	475	General purpose and wiping solder.
30	70	360	489	Automatic and torch soldering.
15	85	440	550	Automobile body solder.
5	95	522	597	Coating and joining.
2	98			Can side seams.
0	100	620	620	Subfreezing temperature applications.

**Table 13.2 Fluxes for Soldering**

<b>Classification</b>	<b>Type</b>	<b>Remarks</b>
<b>Acid Fluxes</b>	<b>Zinc Chloride</b>	Used by itself or with small amounts of stannous chloride with lead-silver solder. It is a corrosive flux, so should be removed by a warm water rinse after soldering.
	<b>Zinc Chloride-ammonium chloride</b>	Perhaps the most common type for use with lead-tin solder for soldering galvanized iron or zinc-base alloys. Also preferred for cast iron or alloys containing large amounts of chromium or nickel.
<b>Rosin Fluxes</b>	<b>Nonactivated</b>	A noncorrosive flux used when removal of the flux after soldering is difficult. Is mixed with alcohol or petrolatum to form liquid or paste forms. Sometimes improved by addition of a wetting agent.
	<b>Activated</b>	Made by adding a small percentage of anine hydrochloride (primarily for electrical work) or an oleic or lactic acid, which results in a more active but mildly corrosive flux.
<b>Fluxes for Aluminum</b>	<b>Hydrazine compounds</b>	Show excellent promise, and may provide at least a partial answer to the problem of soldering aluminum.
	<b>Proprietary</b>	Many concerns are producing solders and fluxes for aluminum.

**Table 13.3 Recommended Materials for Soldering Various Metals**

<b>Metal</b>	<b>Solder</b>	<b>Flux (if used)</b>	<b>Remarks</b>
<b>Carbon and Low Alloy Steels</b>	All Tin-lead (tin from 15-50%. 40-50% preferred)  Lead-silver (95-97.5% Pb, balance silver) or Tin-antimony	Rosin	If rosin fluxes are used, surfaces to be joined should be precoated with tin or tin-lead solder alloys.  Gives greater creep strength at elevated temperatures.
<b>Stainless Steels</b>	Tin-lead with at least 50% tin	Strong (usually contains zinc chloride with up to 25% HCl)	Not readily soldered. Flux residues must be removed after soldering. Joint temperature should not exceed 700°F. Pre-tinning of joint surfaces is desired.
<b>Oxygen-Free and Tough-Pitch Copper</b>	50-50 Tin-lead 95 tin - 5 antimony  30-40 Tin-lead	Zinc chloride  Rosin flux	Preferred. High strength and/or lead free deposit. Most commonly used.
<b>Brass</b>	60 Tin - 40 Lead	Zinc-chloride or rosin	40 and 50% tin alloys are more widely used. Antimony must not exceed 0.5%; causes brittle joints.
<b>Phosphor (copper-tin) Bronzes</b>	50-50 tin-lead		30 and 40 tin alloys are also satisfactory.
<b>Aluminum and Silicon Bronzes</b>	Use solder paste	Zinc-chloride - HCl	Precleaning in acid is desirable. Post-cleaning is necessary.
<b>Nickel-Silver Alloys (cupro-nickel)</b>	Tin-lead containing 35-50% tin	Acid or Rosin	
<b>Beryllium-Copper</b>	50-50 tin-lead 95 tin - 5 antimony or 97.5 lead-1.5 silver-1.0 tin	Activated Rosin	Recommended for elevated temperature application.
<b>Nickel and Nickel Alloys</b>	50-50 or 60-40 tin-lead	Zinc chloride  Activated Rosin or organic acid	Flux residues must be removed after soldering. May be used on nickel and monel.
<b>Zinc and High Zinc Alloys</b>	50-50 tin-lead and 90 lead, 8 cadmium; 2 zinc	Not necessary but generally recommended	Low-soldering temperatures are required to avoid grain growth of zinc and minimize surface alloying.
<b>Zinc-Base Die Castings</b>	83 cadmium-17 zinc	Not required	Apply solder with iron by rubbing over surface to be joined.

### Soldering of Magnesium and Magnesium Alloys

Since soldering generally tends to result in brittle joints, it is recommended only to fill in small surface defects in castings.

### Soldering of Lead and Tin Alloys

For soldering of lead to lead and to other metals, a so-called "wiping technique" generally is used. Because of their wide melting range, 35 tin-65 lead solders are generally employed.

### Soldering of Aluminum and Aluminum Alloys

Small parts can be satisfactorily soldered with the proper alloys and fluxes. Difficulties are usually encountered with larger sections, over 20 square inches in area, because of the high thermal conductivity of aluminum, which makes it difficult to retain the required soldering temperature long enough to complete the joint. Where large sections are to be soldered, preheating to a temperature near the soldering temperature may be advisable. Distortion is also a problem with larger sections.

Since soldered aluminum joints, on exposure to moisture or aqueous solution, are corroded by galvanic action, soldering should be used only in applications where the joint can be kept dry or can be protected by suitable nonmetallic coatings or paints.

Although all permanent-mold and sand-casting alloys can be soldered, it is not generally recommended. Where soldering of die castings is desirable, the castings should first be copper-plated and then soldered with the same procedure as recommended for the soldering of copper. Where aluminum alloys are to be soldered to other metals or alloys, the aluminum should be precoated with tin or plated with copper, then soldered with 50 tin-50 lead or similar alloys.

Various proprietary fluxes, usually of a high fluoride content, are commercially available. Flux removal after soldering is essential.

## DESIGN CONSIDERATIONS

### Strength

The strength of solders is relatively low. For tin-lead soldered joints the short-time tensile strength varies from about 3500 psi to about 6500 psi for the 62 tin-38 lead eutectic alloy. The room temperature creep strength is considerably less, amounting to a maximum of about 3000 psi for the eutectic alloys.

With increasing temperature, the strength of the solder is further decreased. The short-time tensile strength generally is 40 to 50 percent lower at 200°F and 60 to 75 percent lower at 300°F than at room temperature.

The shear strengths of tin-lead solders are generally 10 to 50 percent lower than the respective tensile strengths. Impact strengths vary from about 12 foot-pounds for the low-tin solders to 15 foot-pounds for the 62 tin-38 lead eutectic solder alloy.

Because of the relatively low strength of the solder alloy, a well designed soldered joint should employ lock seaming, folding, crimping, riveting, spot welding or other similar procedures. In these types of joints the solder does not carry the structural load but serves primarily to seal and solidify the joint.

When it is not practical to place the load into the structure, the soldered seams should be placed at locations where the load is smallest. Thus corner and edge joints should be

avoided in favor of lap- and cap-type joints. However, even at best, lap joints are not as strong as lock-seamed, riveted, or bolted joints.

### Multiple Joints

Where the design calls for several soldered joints, they should, when possible, be sufficiently separated from each other in order to avoid or minimize remelting of the solder made in the initially soldered joints during the soldering of subsequent seams. Otherwise, weakened joints may result from excessive alloy diffusion.

### Joint Clearance

Ordinarily, a joint clearance of from 0.003 to 0.010 inch is satisfactory, depending upon the materials to be joined, the soldering process, and the flux and solder alloy used. This insures that the molten solder penetrates and completely fills the joint by capillary action. Insufficient clearance may prevent penetration of the solder and result in a so-called "dry" joint. Where wider clearances are to be used, the surfaces should be precoated with tin (pretinned) or solder alloy. In general, tin-lead solders with high tin content require smaller clearances. The lower tin solders, being more sluggish, require wider clearances of from 0.004 to 0.010 inch. Pretinned or solder-coated surfaces may be satisfactorily bonded with a clearance as small as 0.001 inch.

Allowance also should be made for thermal expansion. Depending upon the soldering temperature range of the particular solder alloy used, expansion to temperatures between 500 and 700 F should be considered. Where dissimilar-metal tube and socket type joints are to be made, the higher-expansion material should be on the outside. The clearance must be sufficiently wide at the soldering temperatures to allow penetration of the solder. If the higher-expansion materials would be on the inside, the clearance might be closed before the solder could enter the joint, or if a sufficiently wide clearance had to be allowed for in the design, the solder might crack on cooling because of excessive tensile stresses at the bond. In long seams, particularly where dissimilar metals are to be joined, it is a good practice to tack the surfaces at the middle, at each end, and at 2- to 3-inch intervals.

Figure 13.1 shows some typical recommended joint designs.

### REFERENCES

Laughner and Hargan, "Handbook of Fastening and Joining of Metal Parts"

Metals Handbook, 1948 Edition

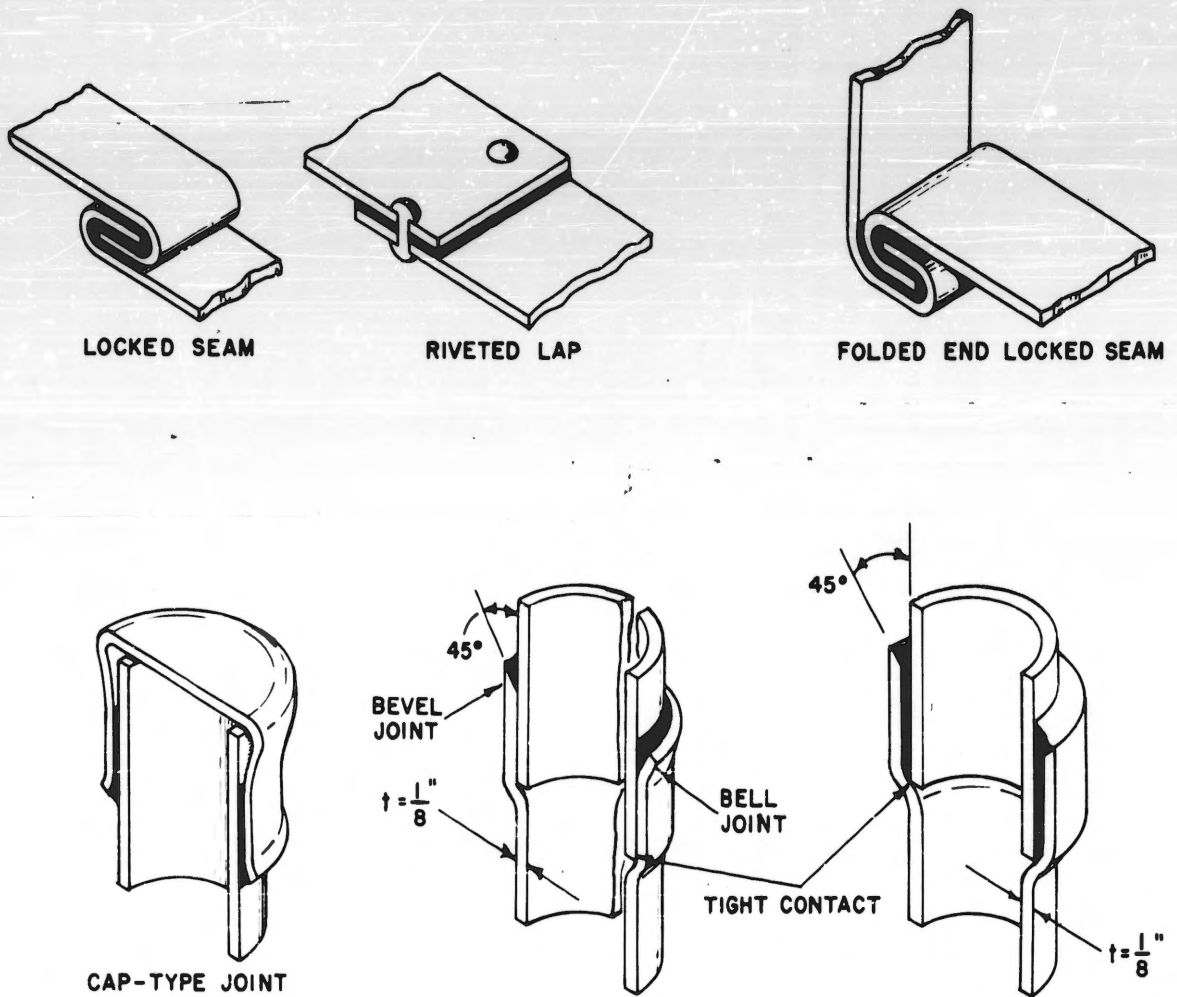


Figure 13.1 Recommended Soldering Joint Designs

## CHAPTER 14

### BRAZING

#### PROCESS

Brazing includes a group of processes wherein coalescence is produced by heating to suitable temperatures above 800°F and using a nonferrous filler metal, having a melting point below that of the base metal. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

Each subdivision of brazing indicates a different method of heating as shown in Table 14.1.

Table 14.1 Brazing Methods

Brazing Technique	Method of Heating
Torch	Gas Flame
Twin-carbon-arc	Electric arc maintained between two carbon electrodes
Furnace	Furnace
Induction	Resistance of the work to the flow of induced electric current
Resistance	Resistance to the flow of electric current in a circuit of which the work is a part
Dip	Molten chemical or metal bath. (When a metal bath is used, the bath provides the filler metal)
Block	Heated blocks applied to the parts to be joined
Flow	Molten nonferrous filler metal poured over the joint until brazing temperature is attained

#### BRAZING ALLOYS

Brazing alloys are of 3 types; copper alloys, aluminum alloys, and silver alloys.

Copper brazing generally is used only with ferrous materials and the cupronickel alloys because of the high temperature required to melt copper. Many carbon and alloy steels can be brazed with only a suitable reducing atmosphere for a flux. Steels containing considerable chromium, silicon, aluminum, or manganese require protection against oxidation.

Special alloys of aluminum are used in aluminum brazing. These are available from a number of primary producers, as well as from welding- and brazing-equipment manufacturers. Although brazing alloys are available in many forms, brazing wire and precut rings are more in demand for furnace brazing than other forms. Brazing sheet is available from primary producers.

Silver has long been used as an ingredient of brazing alloys because of the lower melting point of these alloys and for such advantages as good malleability and ductility, high strength, good corrosion resistance, and high electrical and thermal conductivity. A low melting point decreases the time, heat, and fuel required to make joints and affords a larger factor of safety against overheating the metals to be joined. The latter factor is important when brazing many nonferrous metals, especially those based on copper, particularly in the form of thin sheets and tubes. Malleability and ductility are important, not only in the joint itself, but also in permitting the brazing alloy to be rolled into thin sheets and strips or drawn into fine wire, thus contributing to convenience and economy in making joints. Silver imparts a penetrating quality to the alloy which is valuable for reaching points of minimum clearance.

Tables 14.2, 14.3, and 14.4 include the compositions, other properties and advantages of the most common copper, copper-silver, and aluminum brazing alloys respectively.

Table 14.2 Copper Brazing Alloys

Composition (%)				Freezing Range (°F)			Remarks
Copper	Zinc	Tin	Other	Solidus	Liquidus	Color	
99.9 min.				1980	1980	Yellow	For hydrogen brazing of ferrous parts. Strong. Ductile. Withstands high temperature.
94.8 min.		0.75 max.	2.75-3.5 Si	1850	1980	Yellow	Silicon-bronze alloy. For hard facing, brazing steel sheet, joining copper to steel.
Remainder		0-1.0	4.0 - 8.0 P	1300	1750	Yellow	Phosphorus-bronze alloy. For hard facing, brazing copper to steel, brazing steel sheet.
78-82	Remainder			1725	1875	Yellow	General Purpose. For brazing copper, nickel, and ferrous material.
59-72	Remainder	0 - 1.5		1625	1760	Yellowish	See above.
45-55	Remainder			1570	1620	Yellowish	See above.
50	Remainder	3.0-5.0		1575	1620	Yellow-white	
Remainder	55-59		7.0-9.0 Ni	1520	1600	White	For nickel-silver and cupronickel alloys. Inexpensive.
Remainder	57-65	5.0-9.0		1385	1440	Dark gray	

**Table 14.3 Silver-Copper Brazing Alloys**

Composition (%)				Freezing Range (°F)			Remarks
Silver	Copper	Zinc	Other	Solidus	Liquidus	Color	
10	52	38		1510	1600	Brass-yellow	Used for high-strength joints in heavy ferrous and non-ferrous parts. High temperature. Low cost.
20	45	35		1430	1500	Brass-yellow	For joining of either copper-base alloys or steel
20	45	30	5 Cd	1430	1500	Brass-yellow	General-purpose alloy. Low cost. For joining copper, brass, nickel, steel
30	38	32		1370	1410	Brass-yellow	
40	36	24		1330	1445		
45	30	25		1250	1370	Yellow-white	Widest use in silver-copper-nickel group, ferrous and non-ferrous. Free flowing.
50	34	16		1280	1425	Yellow-white	Popular for electrical and refrigeration equipment, ferrous and nonferrous.
60	25	15		1260	1325	Yellow-white	Can be used to join tungsten to copper.
65	20	15		1200	1325	Silver-white	Used by silversmiths since color matches sterling. Free flowing.
70	20	10				Silver-white	Chiefly on sterling.
72	28			1435	1435		Elastic composition.
80	16	4				Silver-white	Copper wire for drawing. Strong and ductile.
15	80	5		1200	1300	Yellow	Nonferrous materials only. Free flowing, ductile, moderate cost. Self-fluxing.
50	15.5	16.5	18 Cd	1160	1175	Yellow	For ferrous and nonferrous materials. Lowest melting point of brazing alloys. Strong. Ductile.

Table 14.4 Aluminum Brazing Alloys

Alloy *	Type	Core Material	Brazing Range (°F)	Thickness Range (inches)	Remarks
1	Sheet, coated, one side	3003			
2	Sheet, coated, two sides	3003			
11	Sheet, coated, one side	3003	1110-1140	0.006-0.102	
12	Sheet, coated, two sides	3003	1110-1140	0.006-0.102	
21	Sheet, coated, one side	6951	1110-1120	0.019-0.102	Can be heat treated.
22	Sheet, coated, two sides	6951	1110-1120	0.019-0.102	Can be heat treated.
713	Sheet, all filler metal		1130-1140	0.007-0.102	
718	Wire, all filler metal		1100-1120	0.062-0.187	Color of wire blends with that of 1100, 3003, 5052 and 6061 when anodized in chromic acid.

\* These alloy designations indicate standard commercial alloys used in brazing aluminum. Alloys 1 and 2 are clad with 4043, and alloys 11, 12, 21, and 22 are clad with 4343.

## BRAZING FLUXES

Borax or mixtures of borax and boric acid are satisfactory fluxes for silver or copper brazing alloys. Many manufacturers add to these, small proportions of phosphorous and halogen salts, or a bifluoride composition. These latter fluxes are generally required for brazing stainless steel, beryllium, copper, and silicon bronze. As is the case with solder fluxes, the products of each manufacturer vary slightly in content and activity.

For brazing aluminum, fluxes containing fluorides and chlorides are generally specified and can be obtained from many industrial producers.

## ADVANTAGES

Basic advantages of brazed joints include uniformly high strength under different load conditions, relatively low distortion and residual stress concentration, and the inherent possibility of high production rates. With properly designed parts for brazing into assemblies, simplified and lower-cost fabrication is possible. This is nearly always true when the design is such that many parts can be placed in a furnace and brazed at the same time.

In addition to these basic advantages, brazed joints have other useful characteristics. They are highly resistant to vibration and impact loading and maintain their strength at high temperature. Because of the deep penetration of the brazing alloy into the minute clearances, joints are pressure-tight. Thermal and electrical conductivity is high. Simultaneous hardening of steel, especially of air-hardening types, can be obtained when joints are brazed in a furnace or salt bath. If desirable, parts can be assembled, then brazed in an atmosphere that prevents decarburization, and emerge completely finished, hardened, and ready for tempering. Because of the protective atmosphere, surfaces are clean and bright, thus saving the usual cleaning and pickling expense.

Characteristics of the brazing material and the type of brazing method have an effect on the properties of the joint. For proper wetting, both the metals joined and the molten brazing material must be free of oxides when the brazing temperature is reached. Oxides are prevented from forming throughout heating by (1) a reducing atmosphere, (2) the addition of flux to the joint, or (3) the exclusion of oxygen during heating by immersion in a molten bath. Silver brazing, for example, uses any of these methods. Copper brazing is commonly done in furnaces containing controlled reducing atmospheres. But several recent applications use high-temperature salt baths or induction heating for brazing copper with a flux or a reducing atmosphere to prevent oxidation.

## DESIGN CONSIDERATIONS

By proper design it is always possible to make a joint as strong as the metals joined. Often the strength of the joint greatly exceeds that of the alloy employed for brazing. Strength of joints, therefore, depends upon the design, area, and thickness of the joint and the composition of metals joined and of the brazing alloy.

Joints having a conductivity equal to that of copper can be made if the recommended overlap of one and one half times the section thickness is used. Such brazed joints retain their conductivity because they are not affected by oxidation or mechanical loosening.

Of the three general types of joints, butt, scarf, and lap or shear, the last is most commonly used and recommended; these are discussed later under Figure 1. Butt joints are generally not recommended and should be avoided if possible because they are difficult to make properly. Surfaces to be joined must be cut or machined square and flat so that when pressed together they will have the close clearance required for high strength. Fillets of brazing alloy in butt joints are wasteful and do not add appreciably to the strength of the joint.

A scarf joint, with its joint area larger than that of a butt joint, has higher strength and no increased thickness at the joint. Parts can be held in place readily with clamps during brazing. Joints of this type are used on such parts as band saw blades, large fabricated pipes, and tank construction.

Lap or shear-type joints can be designed with any desired factor of safety by varying the lap area. The standard depth, (X), of lap in a flat joint is given by use of the following formula:

$$X = \frac{YTW}{L}$$

where Y = factor of safety

T = tensile strength of material of weaker member

W = unit thickness of weaker member

L = unit shear strength of brazing alloy

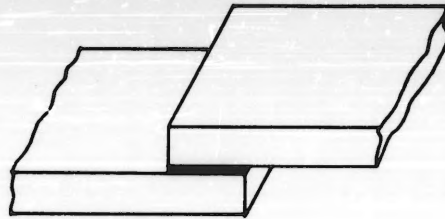
In joining tubes with a brazed lap joint the proper depth of lap is given by the formula:

$$X = \frac{W(D-W)YT}{LD}$$

where D is the diameter of cylindrical shear area and other letters are the same as above.

### Joint Design

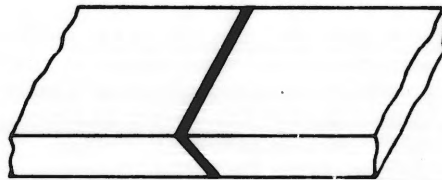
The following figures with attending notes give some of the general points which a designer must consider.



(A) LAP JOINT



(B) BUTT JOINT



(C) SCARF JOINT



(D) SCARF JOINT

Figure 14.1

- (1) There are three basic types of joint design used for brazing, the lap joint (A), the butt joint (B), and the scarf joint (C) and (D).
- (2) There are many combinations and variations of these basic joints. Scarf joints are used to increase the cross-sectional area and provide a larger surface for the brazing filler metal.
- (3) Tee joints and corner joints are regarded as butt joints.
- (4) Butt joints are limited in joint area to the cross-sectional area of one member. They should be used only when service requirements are not severe and where leak tightness and strength are relatively unimportant.

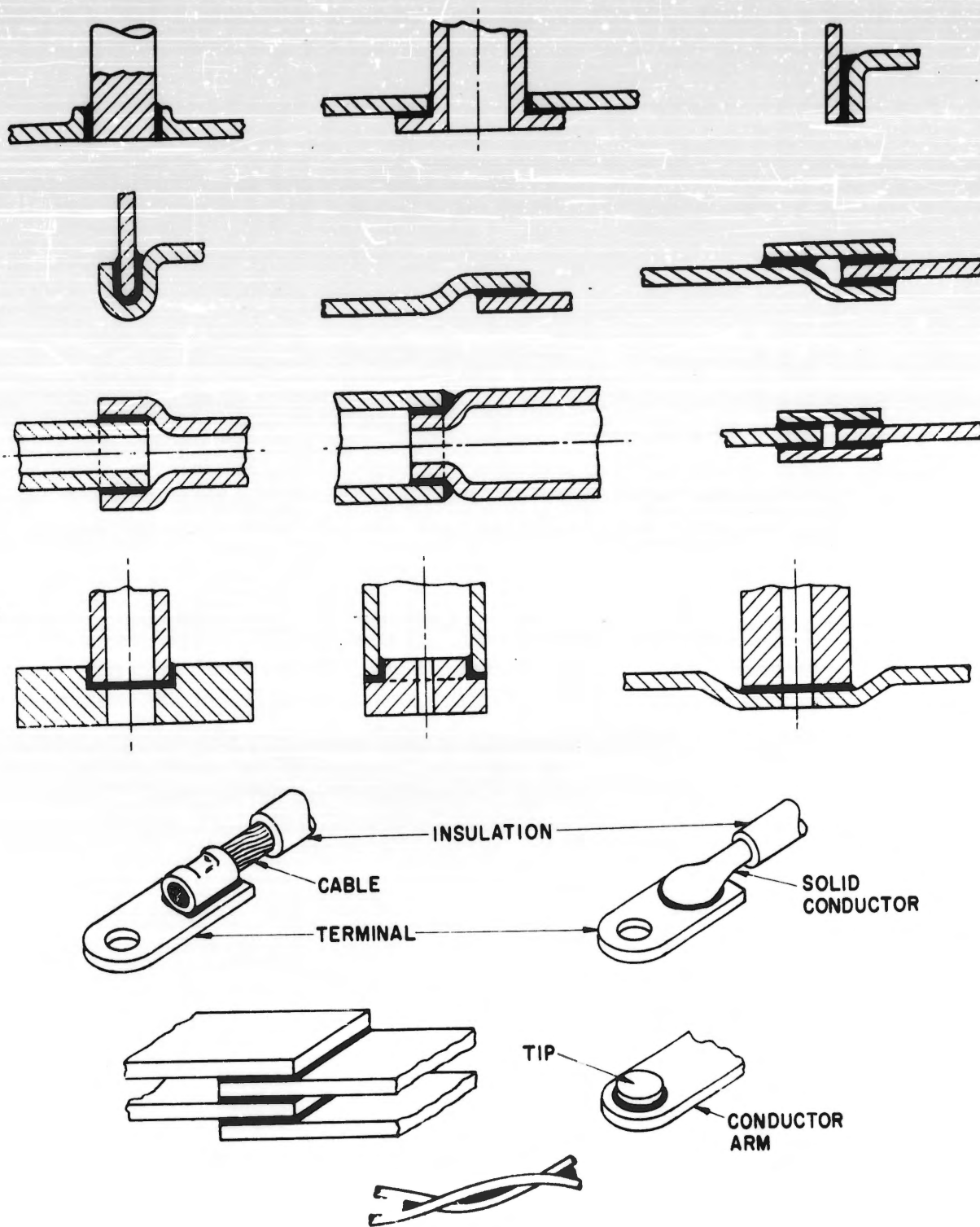


Figure 14.2

- (1) These joints represent typical examples of brazed joint designs where normal mechanical strength is required.
- (2) The necessary joint clearance should be maintained at brazing temperature. Clearances at room temperature should allow for expansion.
- (3) When brazing dissimilar metals it is advisable to check their coefficients of expansion. When one part fits within another, uneven expansion could cause a metal-to-metal contact or, conversely, an excessive clearance which could prevent capillary attraction.

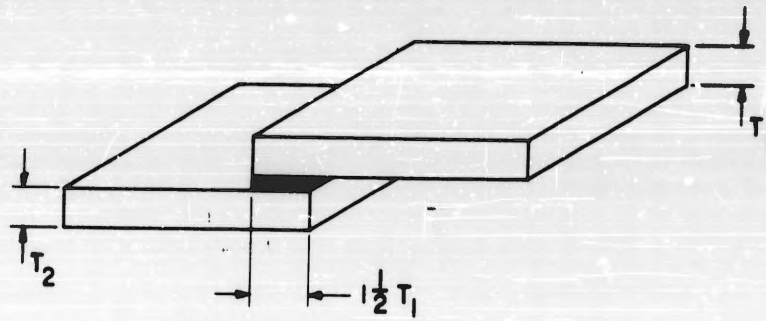


Figure 14.3

Maximum electrical conductivity will be obtained if the proper clearances are used. Voids will reduce the area through which the current can pass. Lap joints are recommended for this reason, when design considerations will permit. The optimum lap for joints to obtain maximum electrical conductivity is a lap of one and one half times the thickness of the thinner member of the joint.

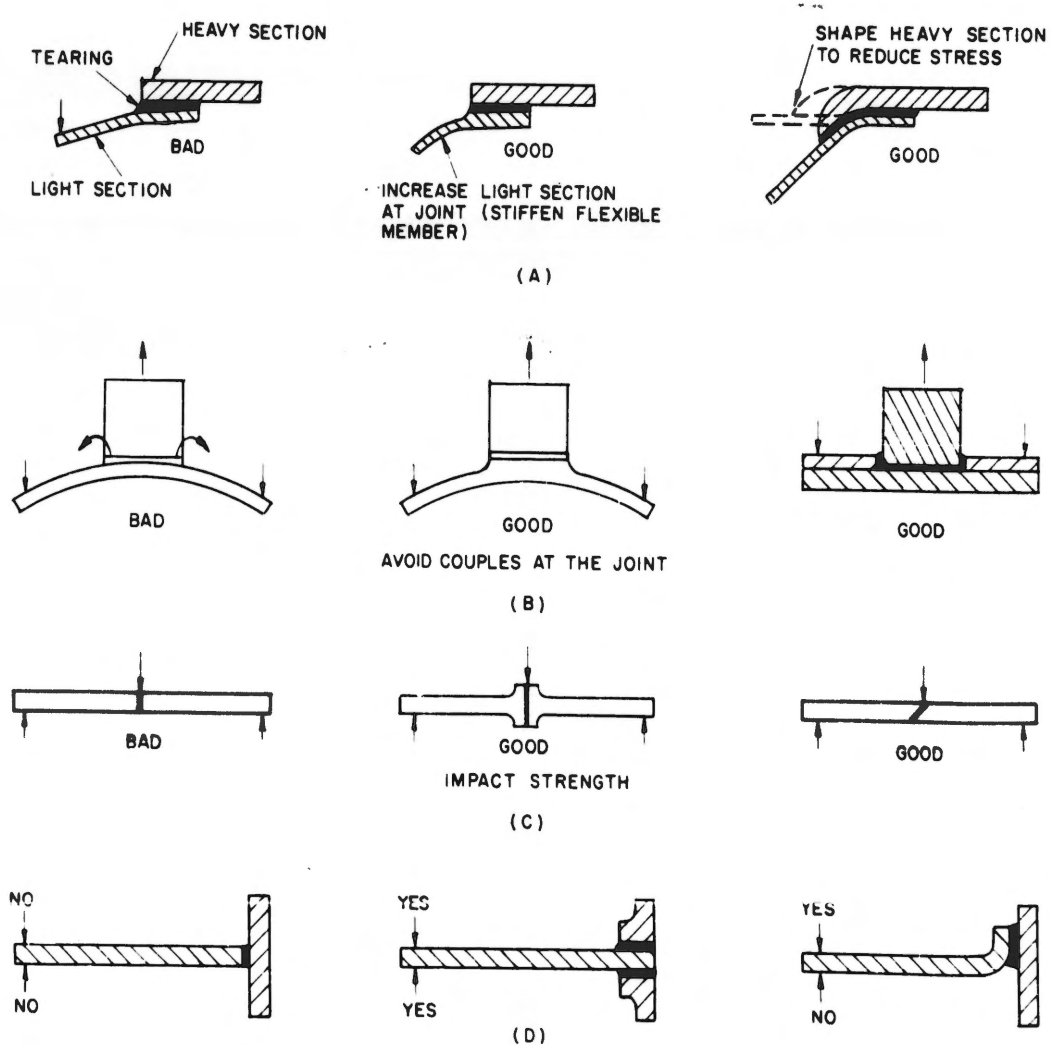


Figure 14.4

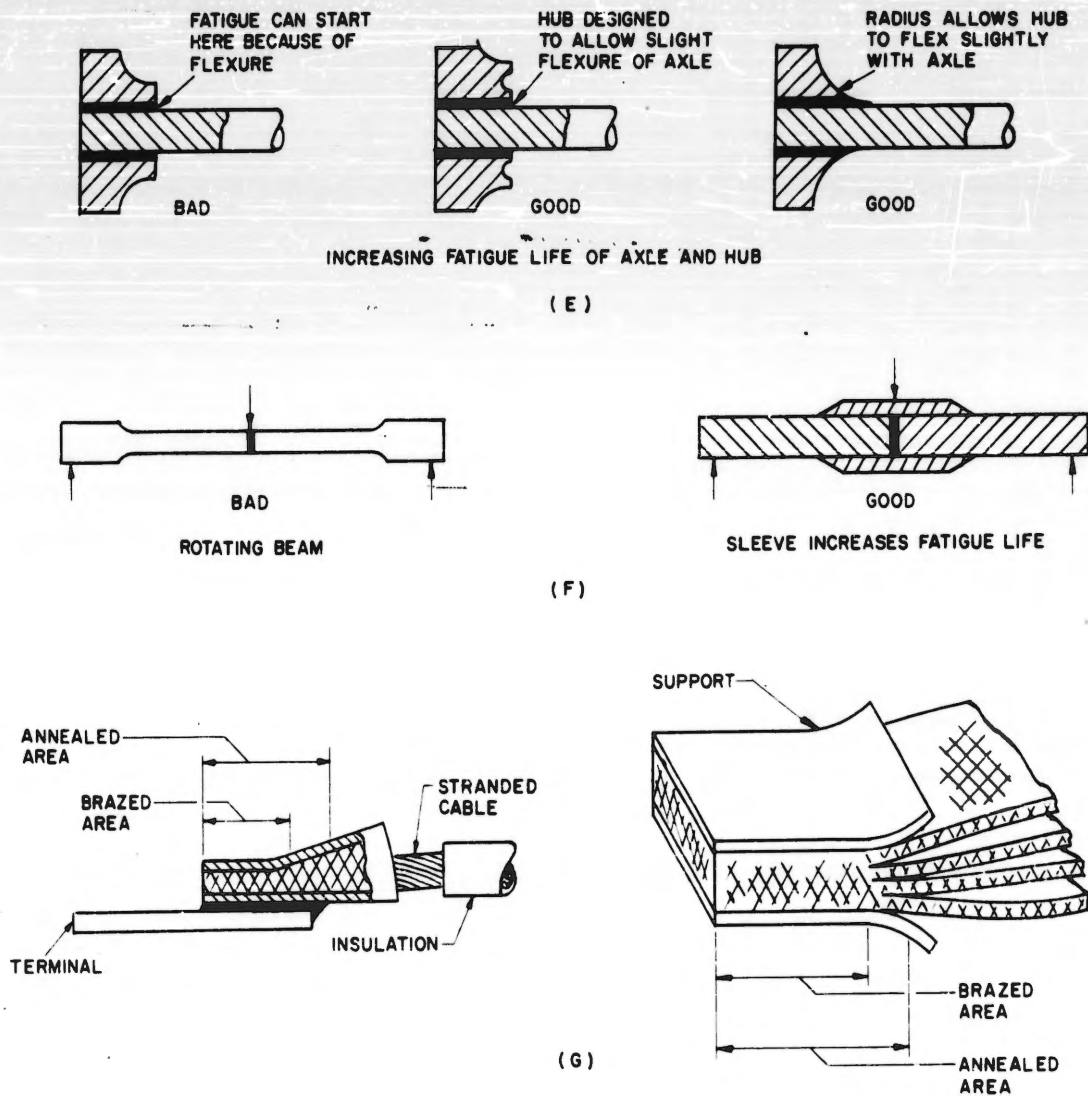


Figure 14.4 (contd)

- (1) Joint failure in (A) is likely to start at points of stress concentration. This can be avoided by designing a joint to impart flexibility (reduced rigidity to such points). A light section, brazed to a heavy section, will have a point of high stress concentration as indicated by the arrow. An increase of the cross-sectional area (of the light section) at the joint will stiffen the flexible member and minimize tendency to tear at this point. The same purpose is effected by beveling the heavy section at the point of stress. This imparts flexibility to the joint.
- (2) Flexibility in (B) is obtained by increasing the cross section of the weaker member in the area of stress concentration. Tendency to tear can be avoided also by stiffening the joint as illustrated.
- (3) The impact resistance of a butt joint in (C) can be increased by providing a larger joint area. This may be done by increasing the thickness of the joint or by using a scarf joint.
- (4) The relative weakness of the tee joint in (D) can be eliminated by either of the second designs illustrated. In both examples the joint area has been increased and adequate strength and support provided.
- (5) The fatigue life of an axle and hub in (E) can be increased considerably when

due allowance is made for flexure. This adjustment must be made in the hub either by redesigning to allow a slight flexure of the axle, or by means of the radius to permit the hub to flex slightly with the axle.

- (6) The relatively low strength of a butt weld in a rotating beam in (F) reduces the fatigue life of the part. The use of a sleeve strengthens the joint and increases the fatigue life.
- (7) Parts which are subject to vibration or fatigue in (G) should be supported mechanically beyond the brazed joint and annealed base metal. A careful evaluation of the conditions encountered during service operations will enable the designer to adapt his joint design accordingly, and thus increase the service life of the part.

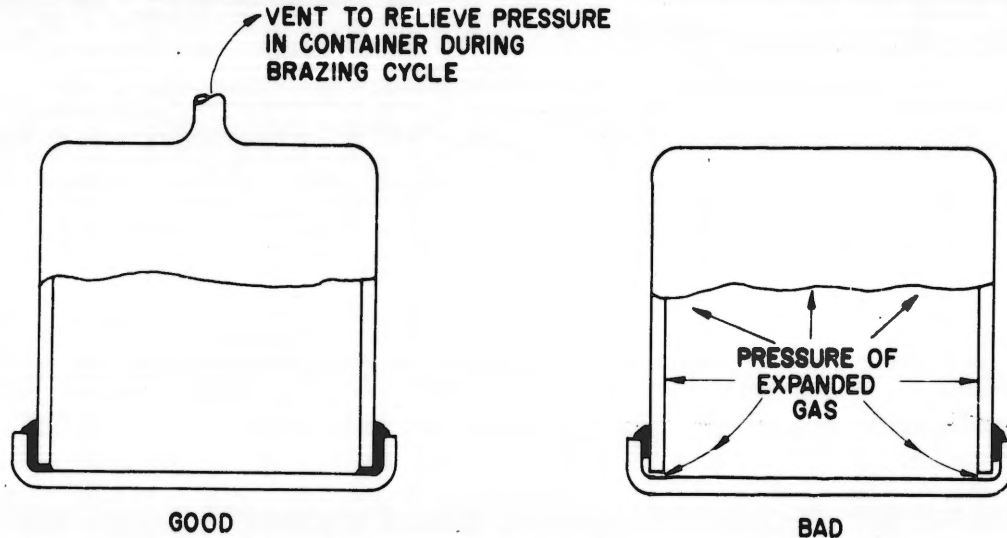


Figure 14.5

- (1) The importance of proper venting is one of the principal factors in the design of pressure-tight assemblies.
- (2) The heat of the brazing operation expands the air or gases within the container so rapidly that the assembly may be forced apart, unless adequately vented. The same internal pressure may act on the filler metal and restrict capillary attraction.

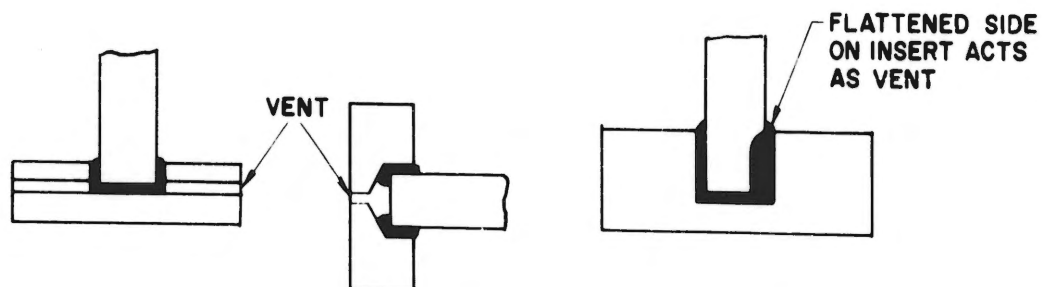


Figure 14.6

- (1) Dead-end holes may be regarded as small pressure vessels since pressure will be built up unless a vent is provided. Design considerations will determine whether longitudinal or transverse vents should be used.
- (2) When this method is impracticable, the side of the insert may be flattened and this acts as a vent to provide a means of escape for the bases.

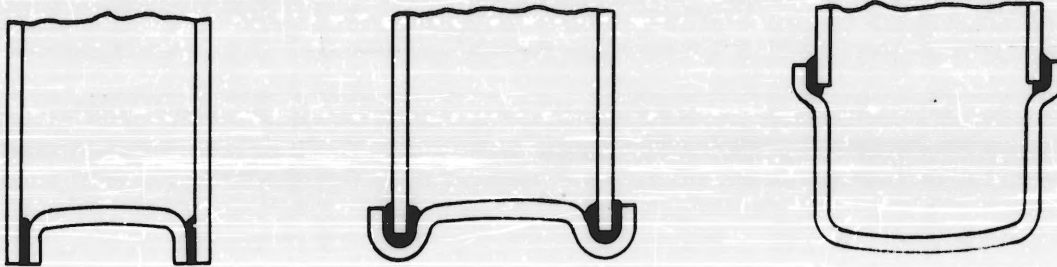


Figure 14.7

Lap joints are always recommended for pressure-tight assemblies. They provide the greatest strength and the maximum brazed area to reduce the possibility of leaks. Space considerations and service conditions may impose joint design restrictions, but it is good practice to provide a brazed area sufficiently large to allow for all service contingencies.

#### REFERENCES

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Laughner and Hargan. "Handbook of Fastening and Joining of Metal Parts"

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## CHAPTER 15

### WELDING

#### PROCESS

Welding is a metal joining process wherein coalescence is produced by heating to suitable temperatures, with or without the application of pressure, and with or without the use of filler metals.

#### References

There are three Military Standards that should always be referenced when welds are specified on drawings. These Standards are as follows:

JAN-STD-19	Joint Army-Navy Standard for Welding Symbols
MIL-STD-20	Welding Terms and Definitions
MIL-STD-22	Welded Joint Design

These standards, if used correctly, will provide the designer, draftsman, welder, and machinist with an equivalent understanding of the fundamentals necessary to identify and interpret welds as depicted on engineering drawings.

#### Welding Methods

Welding methods are grouped into the categories of arc, resistance, gas, forge, thermite, and recently developed welding methods. The following paragraphs give general definitions of each:

Arc Welding. Figure 15.1 illustrates the subdivisions of the arc welding process. The most commonly used processes are: (1) shielded metal-arc welding, (2) atomic hydrogen welding, (3) inert gas metal-arc welding, and (4) submerged arc welding, and are shown in the figure with heavy borders.

The following definitions should help the designer's understanding.

**Shielded Metal-Arc Welding** - An arc-welding process wherein coalescence is produced by heating with an electric arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the covering. Pressure is not used and filler metal is obtained from the electrode.

**Impregnated Tape Metal-Arc Welding** - An arc welding process wherein coalescence is produced by heating with an electric arc between a metal electrode and the work. Shielding is obtained from decomposition of an impregnated tape wrapped around the electrode as it is fed to the arc. Pressure is not used and filler metal is obtained from the electrode.

**Shielded Stud Welding** - An arc welding process wherein coalescence is produced by heating with an electric arc drawn between a metal-stud, or similar part, and the other work part, until the surfaces to be joined are properly heated, when they are brought together under pressure. Shielding is obtained from an inert gas such as helium or argon.

**Atomic Hydrogen Welding** - An arc welding process wherein coalescence is produced by heating with an electric arc maintained between two metal electrodes in an atmosphere of hydrogen. Shielding is obtained from the hydrogen. Pressure and filler metal may or may not be used.

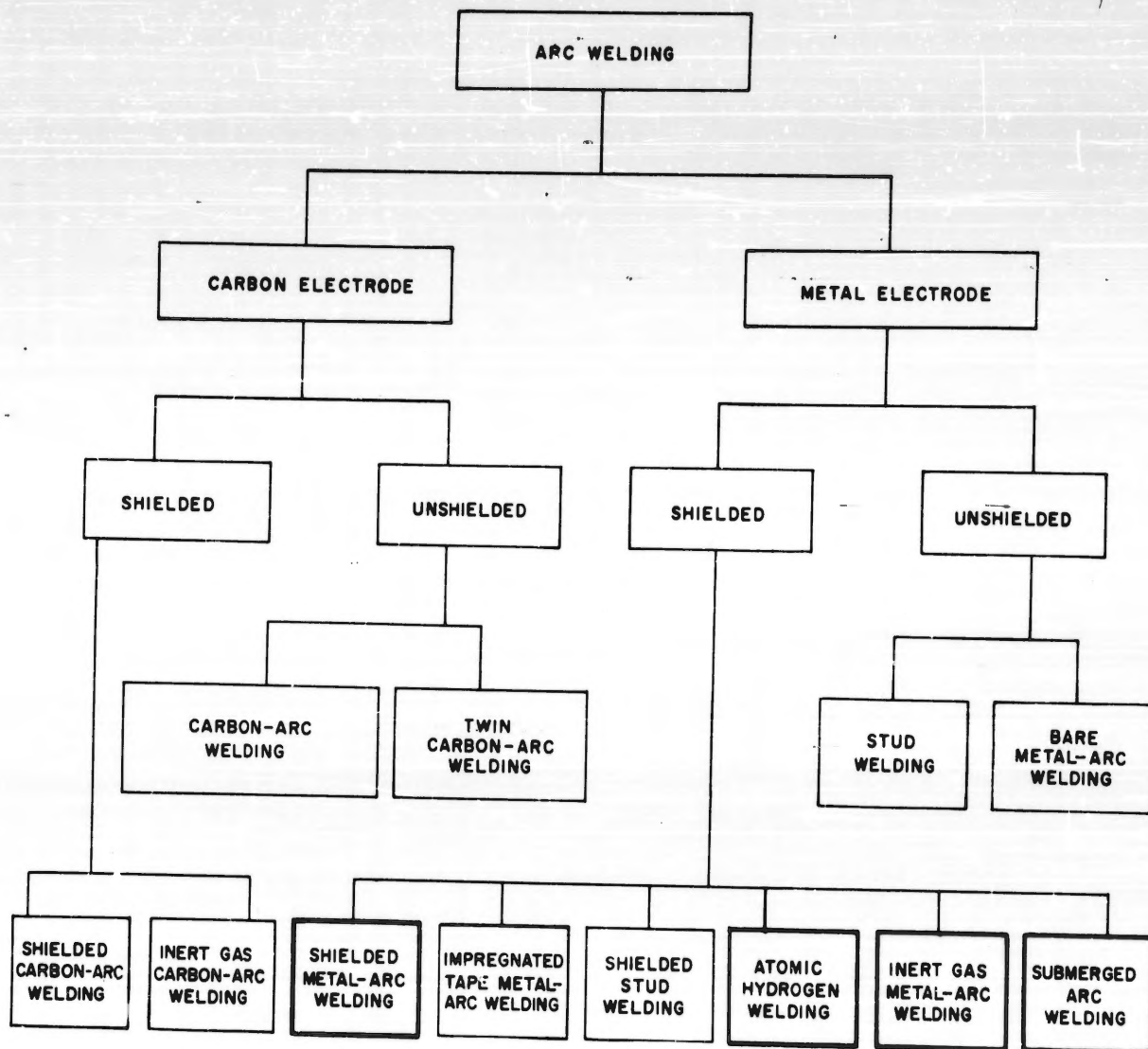


Figure 15.1 Subdivisions of the Arc Welding Process

**Inert Gas Metal-Arc Welding** - An arc welding process wherein coalescence is produced by heating with an electric arc between a metal electrode and the work. Shielding is obtained from an inert gas such as helium or argon. Pressure and filler metal may or may not be used.

**Arc Welding** - A group of welding processes wherein coalescence is produced by heating with an electric arc, with or without the application of pressure, and with or without the use of filler metal.

**Shielded Carbon-Arc Welding** - An arc-welding process wherein coalescence is produced by heating with an electric arc between a carbon electrode and the work. Shielding is obtained from the combustion of a solid material fed into the arc or from a blanket of flux on the work, or both. Pressure and filler metal may or may not be used.

**Inert Gas Carbon-Arc Welding** - An arc welding process wherein coalescence is produced by heating with an electric arc between a carbon electrode and the work. Shielding is obtained from an inert gas such as helium or argon. Pressure and filler metal may or may not be used.

**Carbon-Arc Welding** - An arc welding process wherein coalescence is produced by heating with an electric arc between a carbon electrode and the work; no shielding is used. Pressure and filler metal may or may not be used.

**Twin Carbon-Arc Welding** - An arc-welding process wherein coalescence is produced by heating with an electric arc maintained between two carbon electrodes; no shielding is used. Pressure is not used and filler metal may or may not be used.

**Submerged Arc Welding** - An arc welding process wherein coalescence is produced by heating with an electric arc between a bare metal electrode and the work. The welding is shielded by a blanket of granular, fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplementary welding rod.

**Stud Welding** - An arc welding process wherein coalescence is produced by heating with an electric arc drawn between a metal stud, or similar part, and the other work part, until the surfaces to be joined are properly heated, when they are brought together under pressure; no shielding is used.

**Bare Metal-Arc Welding** - An arc-welding process wherein coalescence is produced by heating with an electric arc between a bare or lightly coated metal electrode and the work; no shielding is used. Pressure is not used and filler metal is obtained from the electrode.

Resistance Welding. The following definitions apply the resistance welding method:

**Resistance Welding** - A group of welding processes wherein coalescence is produced by the heat obtained from resistance of the work to the flow of electric current in a circuit of which the work is a part, and by the application of pressure.

**Spot Welding** - A resistance-welding process wherein coalescence is produced by the heat obtained from resistance to the flow of electric current through the work parts, held together under pressure by electrodes. The size and shape of the individually formed welds are limited primarily by the size and contour of the electrodes.

**Seam Welding** - A resistance welding process wherein coalescence is produced by the heat obtained from resistance to the flow of electric current through the work parts, held together under pressure by circular electrodes. The resulting weld is a series of overlapping spot welds made progressively along a joint by rotating the electrodes.

**Projection Welding** - A resistance welding process wherein coalescence is produced by the heat obtained from resistance to the flow of electric current through the work parts, held together under pressure by electrodes. The resulting welds are localized at predetermined points by the design of the parts to be welded. The localization is usually accomplished by projections, embossments or intersections.

**Flash Welding** - A resistance-welding process wherein coalescence is produced simultaneously over the entire area of abutting surfaces, by the heat obtained from resistance to the flow of electric current between the two surfaces, and

by the application of pressure after heating is substantially completed. Flashing and upsetting are accompanied by expulsion of metal from the joint.

**Upset Welding** - A resistance-welding process wherein coalescence is produced, simultaneously over the entire area of abutting surfaces or progressively along a joint, by the heat obtained from resistance to the flow of electric current through the area of contact of those surfaces. Pressure is applied before heating is started and is maintained throughout the heating period.

**Percussion Welding** - A resistance-welding process wherein coalescence is produced, simultaneously over the entire area of abutting surfaces, by the heat obtained from an arc produced by a rapid discharge of stored electrical energy, with pressure percussively applied during or immediately following the electrical discharge.

Gas Welding.- The following definitions apply to the gas welding method:

**Gas Welding** - A group of welding processes wherein coalescence is produced by heating with a gas flame, with or without the application of pressure, and with or without the use of filler metal.

**Air-Acetylene Welding** - A gas-welding process wherein coalescence is produced by heating with a gas flame obtained from the combustion of acetylene with air, without the application of pressure and with or without the use of filler metal.

**Oxy-Acetylene Welding** - A gas-welding process wherein coalescence is produced by heating with a gas flame obtained from the combustion of acetylene with oxygen, with or without the application of pressure and filler metal.

**Oxy-Hydrogen Welding** - A gas welding process wherein coalescence is produced by heating with a gas flame obtained from the combustion of hydrogen with oxygen, without the application of pressure and with or without the use of filler metal.

**Pressure Gas Welding** - A gas-welding process wherein coalescence is produced, simultaneously over the entire area of abutting surfaces, by heating with a gas flame obtained from the combustion of a fuel gas with oxygen, and by the application of pressure and without the use of filler metal.

Forge Welding.

Forge Welding, in which the parts to be joined are externally heated and then welded by pressure applied through dies or rolls, or by blows from a hammer, will not be considered in detail in this chapter because of the specialized nature of the process, which is not necessarily of value to the aircraft designer. Hammer welding is used basically in blacksmith shops and in certain shops specializing in heavy equipment-railroad rolling stock and steam boilers. Roll welding is commonly limited to the cladding of steel, while die welding is widely used in the fabrication of pipe. The following definitions, however, are of interest to gain an understanding of all welding methods:

**Forge Welding** - A group of welding processes wherein coalescence is produced by heating in a forge or other furnace and by applying slow or impact pressure.

**Hammer Welding** - A forge welding process wherein coalescence is produced by heating in a forge or other furnace and by applying pressure by hammer blows.

**Die Welding** - A forge welding process wherein coalescence is produced by heating in a furnace and by applying slow pressure by dies.

**Roll Welding** - A forge welding process wherein coalescence is produced by heating in a furnace and by applying pressure by rolls.

**Thermit Welding.** The following definitions apply to the thermit welding method. This method also has limited use in the aircraft industry.

**Thermit Weld** - A group of welding processes wherein coalescence is produced by heating with superheated liquid metal and slag resulting from a chemical reaction between a metal oxide and aluminum, with or without the application of pressure. Filler metal, when used, is obtained from the liquid metal.

**Non-Pressure Thermit Welding** - A thermit welding process wherein coalescence is produced by heating with super-heated liquid metal resulting from the chemical reaction between a metal oxide and aluminum, without the application of pressure. Filler metal is obtained from the liquid metal.

**Pressure Thermit Welding** - A thermit welding process wherein coalescence is produced by heating with superheated liquid metal and slag resulting from the chemical reaction between iron oxide and aluminum, and by applying pressure. The liquid metal from the reaction is not used as filler metal.

**New Processes.** Research is being carried out constantly to produce new welding processes and refinements of old processes. Some of the more promising developments in welding research are as follows:

**Ultrasonic Welding** - Ultrasonic welding is a process for the joining of metals without the aid of solders, fluxes, or filler metals and usually without externally applied heat. The metals to be joined are clamped at low static pressure between welding tips or sonotrodes, and ultrasonic energy is introduced for a brief interval, usually 1 to 3 seconds. A strong metallurgical bond is produced without the significant external deformation which characterizes pressure welding and without the heat-affected zones implicit in resistance welding.

**Slag Welding** - Slag welding is a Russian process that resembles submerged-arc welding. This process produces a groove weld by placing a certain amount of flux into a longitudinal seam. An arc is initiated with a wire, exists for a short time until the slag becomes molten, and then goes out. The wire then feeds through the molten slag by resistance, and deposition rates are obtained that are in excess of the regular submerged-arc welding process. The initiation of the arc is to obtain only molten slag. Deposition rates in the order of 30 to 40 pounds per hour can be obtained.

The limitation of slag welding is that the parts to be joined must be of a heavy gauge. It is used for heavy welds in pressure-vessels, or fillet welds of 2 or 3 inch sections.

The main advantages of slag welding are speed, metal deposition rate and quality. Also, floor space is conserved since a seam weld can be produced vertically.

The quality of weld is improved because dendrites are at right angles to the metal, therefore, if there are any minute slag inclusions or sulphur or phosphorus-rich areas, they will not promote cracking in the same way that the submerged-arc welding process does.

**Cold Pressure Welding** - Cold welding is the joining of two metallic surfaces through the application of pressure alone. However, it involves more than pressure; it is based on a rigid analysis of the flow of metals and the development of special tools to produce the deformations required to direct this flow into a true weld.

The importance of this process, particularly as applied to aluminum, stems from the the following advantages:

- (1) Joints are efficient and often are as strong as or stronger than the metals being joined. The reason is that the weld area does not have the cast-structure characteristics of other welding processes, but is actually work hardened to some degree.
- (2) Welds respond to heat treatment if the parent metals are heat treatable.
- (3) Dissimilar materials can be joined, such as aluminum to copper, silver, lead, or nickel.
- (4) Thin sheets can be bonded readily to thick sections.
- (5) Equipment is simple and inexpensive. Hand tools similar to conventional pliers can be used for small diameter wire and thin sheets; conventional fly presses are satisfactory for thicker parts; and power presses are needed only for large and heavy pieces.
- (6) The welder needs no special skill or training.
- (7) The process can be adapted to applications that are physically impossible with other forms of welding. Thin sections like aluminum foil, for example, cannot be welded by methods employing heat because of the danger of burning the foil. For the same reason, heat may be a disadvantage when welding thick to thin sections.

## DESIGN CONSIDERATIONS

### Design Fundamentals

In planning welded fabrication, the first consideration is to design for welding. The mere substitution of welds for mechanical connections does not constitute the correct approach. The following suggestions should be followed in the design of composite structures:

- (1) Locate the joints so that they will be readily accessible to the welder.
- (2) Design joints so that a minimum of machining will be required in the joint preparation.
- (3) Use through welds in preference to fillet welds for welding stiffeners in restrained locations.
- (4) To avoid corner cracks and improve weldability, use relief holes at the right-angled junction to through plates.
- (5) Use high-alloy, high strength, or corrosion-resisting materials only where required.
- (6) Use welding symbols that adequately describe the type of joint desired. The JAN-STD-19 system is recommended.
- (7) Know the efficiencies that can be expected from welded joints and the types of joints that will provide acceptable strength most efficiently.
- (8) Design welding grooves for welding conditions as well as for the required strength.
- (9) Make provision for inspection of the weld in critical locations on heavy weldments.
- (10) Select and apply materials with the objective of reducing the machining required on the finished product. Use standard instead of special rolled sections to effect reductions in overall costs.

- (11) Specify stress-relieving or other stabilizing treatment on drawings whenever such treatment is considered necessary or where good dimensional stability is required.
- (12) Don't use specifications that are more rigid than necessary to accomplish the desired results.
- (13) Don't overweld; not only are time and material wasted, but warpage and stresses are greater and appearance is usually bad.

#### Design of Welded Joints

Correct joint design is a vital part of welding procedure. The safety and service life of the welded assembly depend upon the efficiency of the welded joint. Correct joint design can help to control distortion, reduce shrinkage cracking, facilitate good workmanship, and produce sound welds economically.

The joint designs delineated in this chapter were selected because they are the most common joints for the process indicated. Some processes have not been considered because of their limited applicability to the aircraft industry.

#### Selection of Welding Process

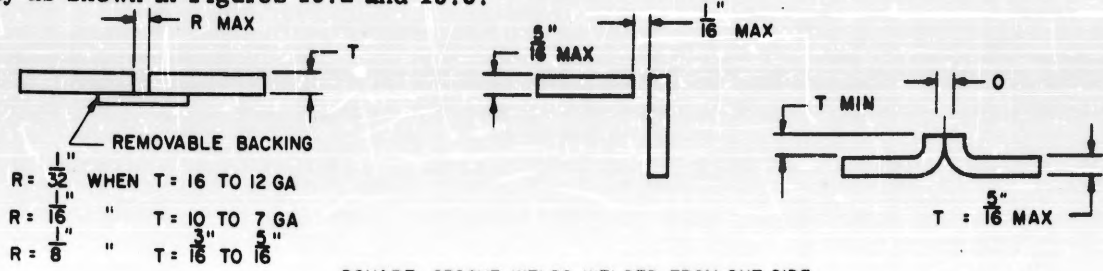
In selecting a welding process the product to be welded must fulfill the engineering design and service requirements. The factors involved in selection of the most suitable welding process will depend on the following:

- (1) engineering design and service requirements of the product.
- (2) inherent characteristics differentiating the various welding processes.
- (3) characteristics of the welds made by the various processes.
- (4) composition of metals to be welded.
- (5) welding joint design.
- (6) economics of the process.

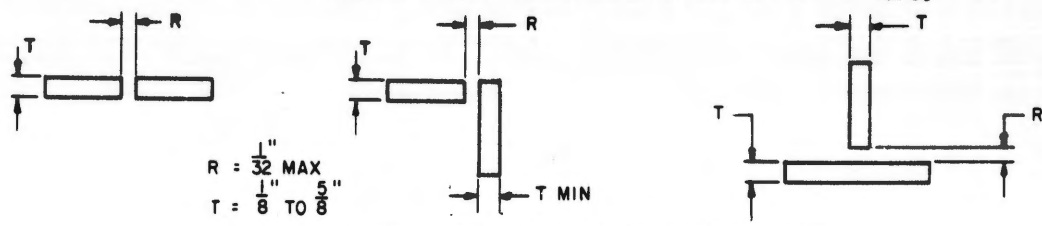
Table 15.1 indicates in general the recommended processes for welding metals and alloys. The table includes only the most commonly used welding processes.



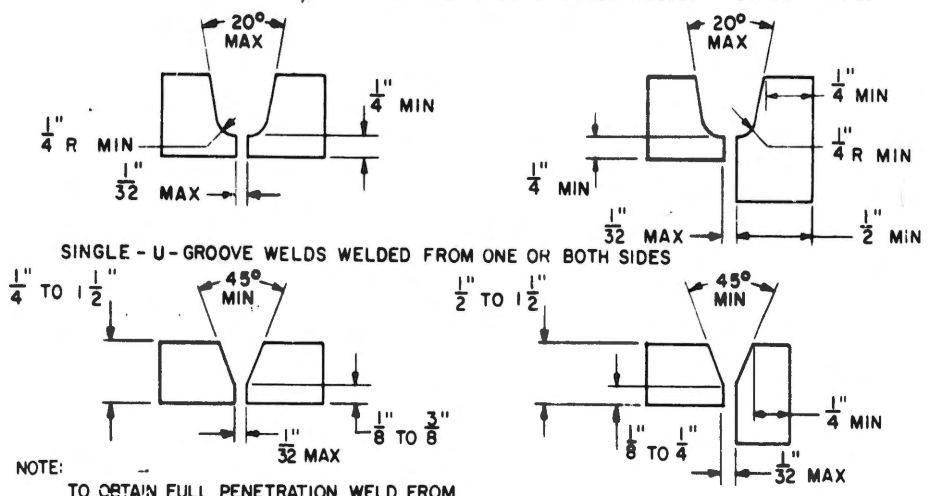
**Typical Joints for the Arc- and Gas-Welding Processes.** These processes may be applied by manual or by machine methods. Comments as to joint penetration obtainable apply to the shielded metal-arc, inert-gas metal-arc and submerged arc welding of steel only as shown in Figures 15.2 and 15.3.



SQUARE-GROOVE WELDS WELDED FROM ONE SIDE

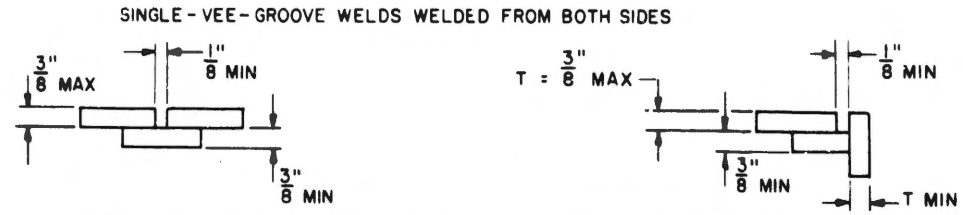


SQUARE-GROOVE WELDS WELDED FROM BOTH SIDES

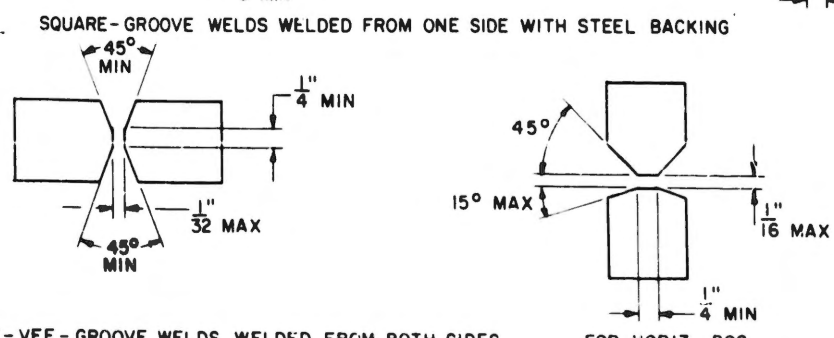


SINGLE - U - GROOVE WELDS WELDED FROM ONE OR BOTH SIDES

NOTE:  
 TO OBTAIN FULL PENETRATION WELD FROM ONE SIDE USE THE SMALL ROOT FACE DIM. AND REMOVABLE BACKING



SINGLE - VEE - GROOVE WELDS WELDED FROM BOTH SIDES



SQUARE-GROOVE WELDS WELDED FROM ONE SIDE WITH STEEL BACKING

DOUBLE - VEE - GROOVE WELDS WELDED FROM BOTH SIDES

FOR HORIZ. POS.

Figure 15.2 Typical Joints for the Submerged Arc-welding Processes

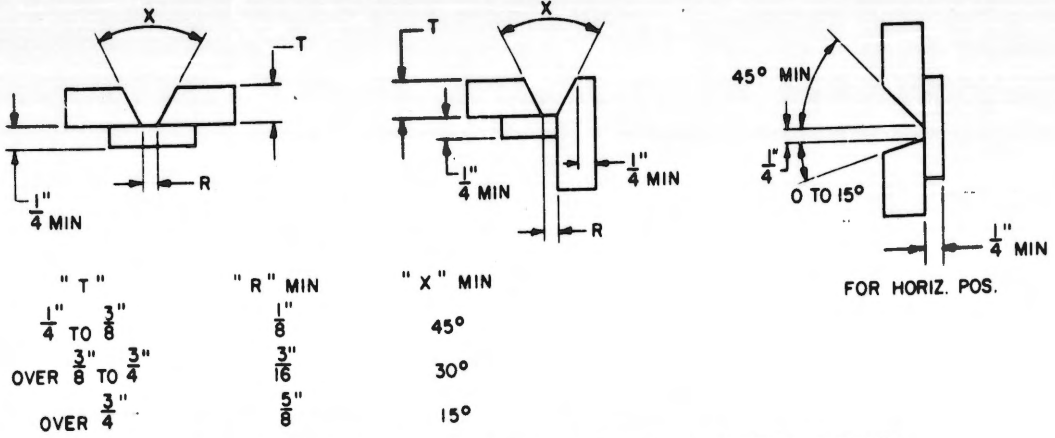
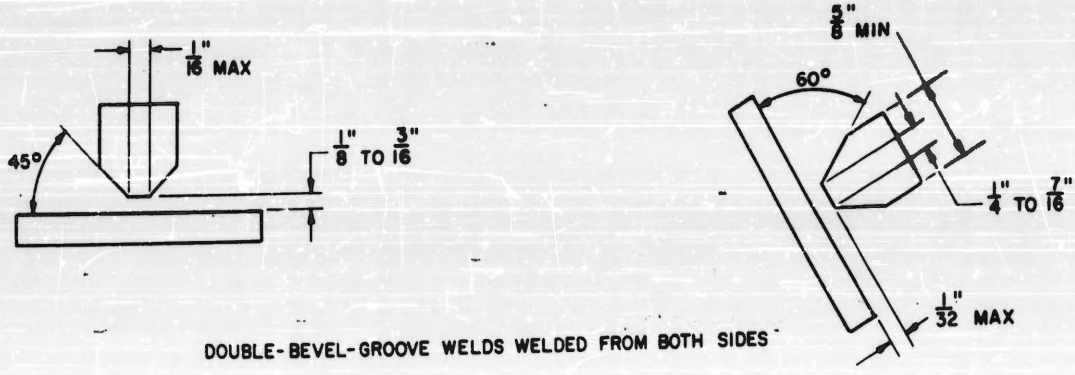
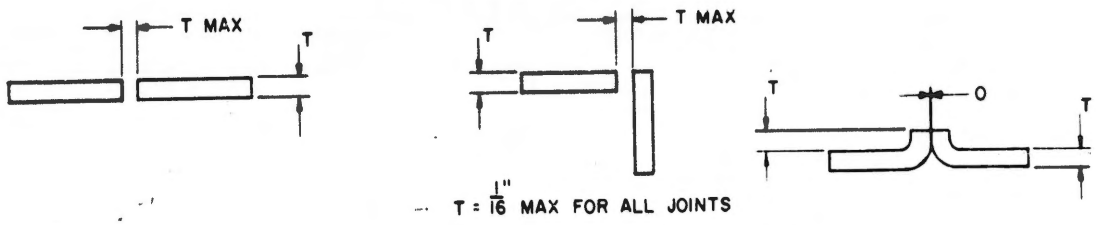
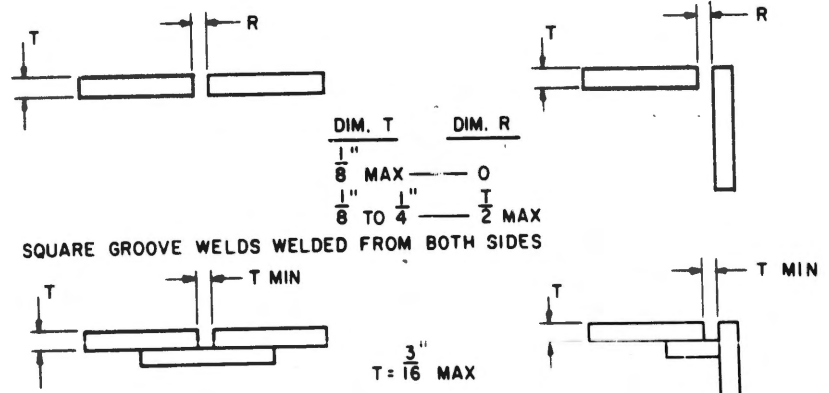


Figure 15.2 (contd)



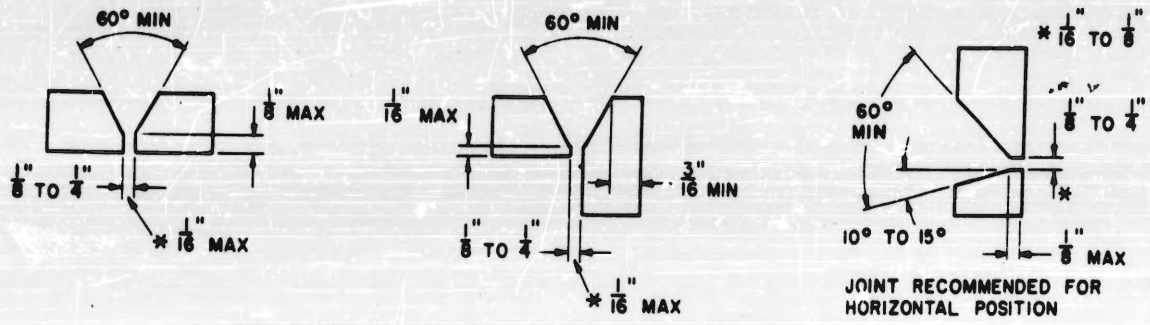
SQUARE GROOVE WELDS WELDED FROM ONE SIDE



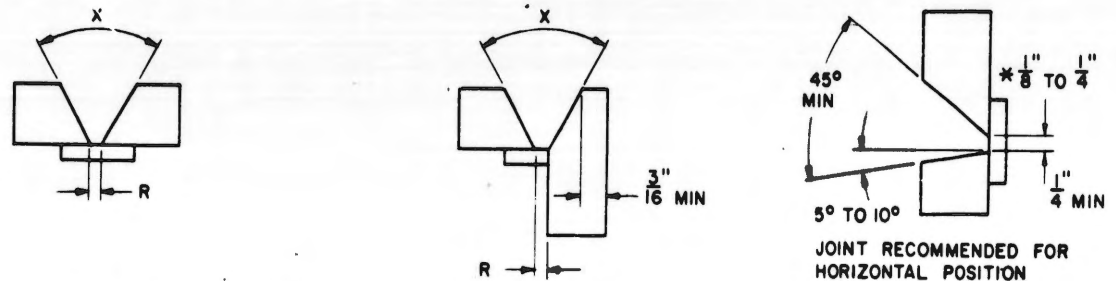
SQUARE GROOVE WELDS WELDED FROM BOTH SIDES

SQUARE GROOVE WELDS WELDED FROM ONE SIDE WITH BACKING

Figure 15.3 Typical Joints for the Shielded Arc, Inert-Gas Arc, and Gas Welding Processes

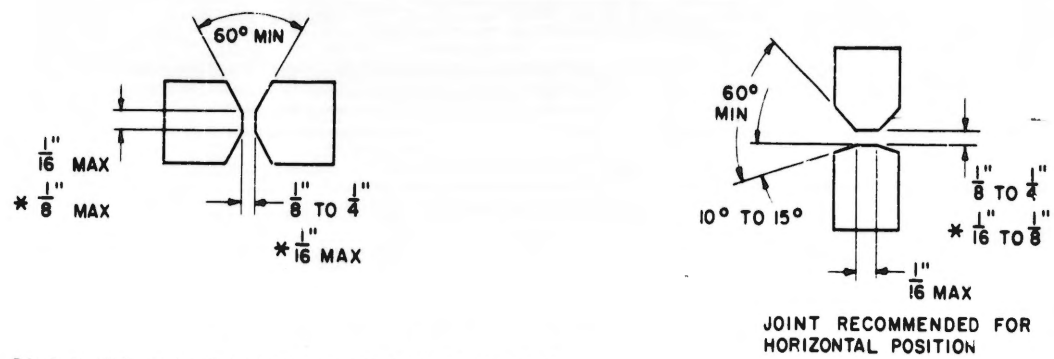


SINGLE-VEE-GROOVE WELDS WELDED FROM ONE OR BOTH SIDES

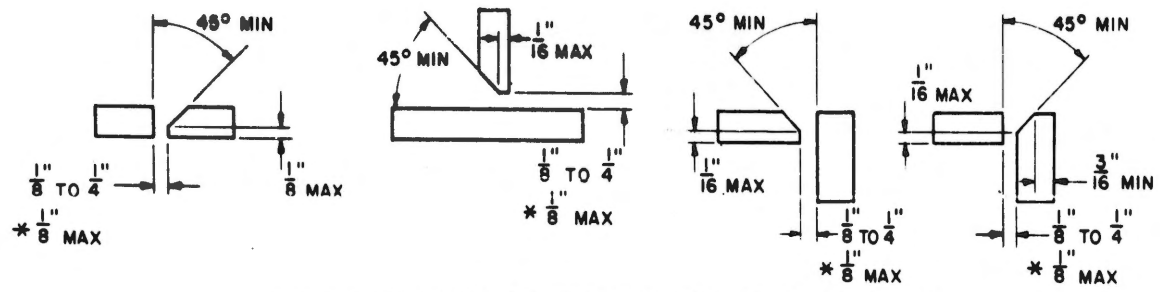


ANGLE X	DIM. R	POSITIONS * R
45° MIN	1/4 MIN	ALL * 1/8 MIN
20° MIN	1/2 MIN	F, V, O * 1/4 MIN
12° MIN	1/2 MIN	F * 1/4 MIN

SINGLE-VEE-GROOVE WELDS WELDED FROM ONE SIDE WITH STEEL BACKING

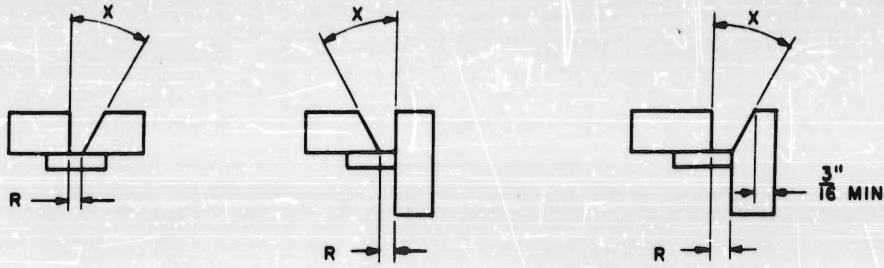


DOUBLE-VEE-GROOVE WELDS WELDED FROM BOTH SIDES



SINGLE-BEVEL-GROOVE WELDS WELDED FROM ONE OR BOTH SIDES

Figure 15.3 (contd)

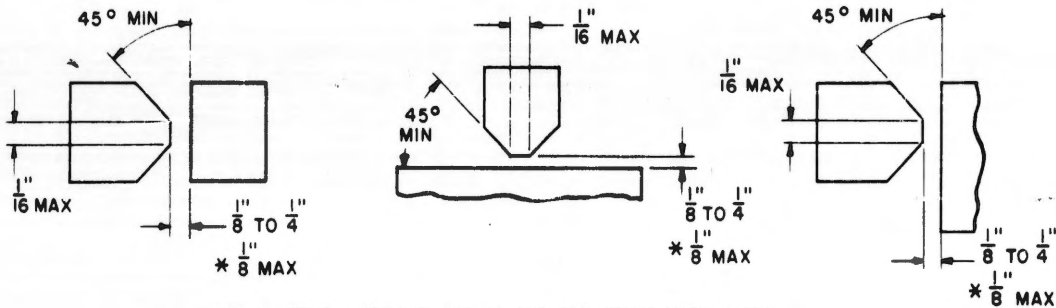


ANGLE X	DIM. R	POSITIONS * R
45° MIN	1/4" MIN	ALL * 1/8" MIN
35° MIN	3/8" MIN	ALL * 1/4" MIN
25° MIN	3/8" MIN	F, V, O * 1/4" MIN

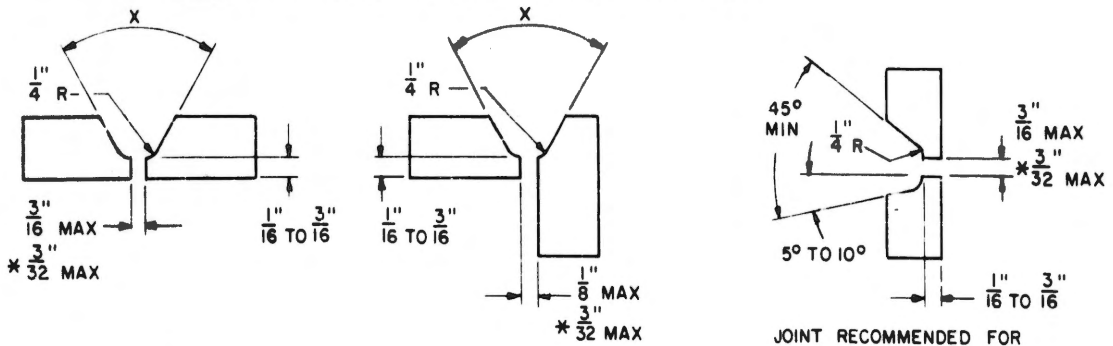


ANGLE X	DIM. R	POSITIONS * R
45° MIN	1/4" MIN	ALL * 1/8" MIN
35° MIN	3/8" MIN	ALL * 1/4" MIN

SINGLE-BEVEL-GROOVE WELDS WELDED FROM ONE SIDE WITH BACKING



DOUBLE-BEVEL-GROOVE WELDS WELDED FROM BOTH SIDES

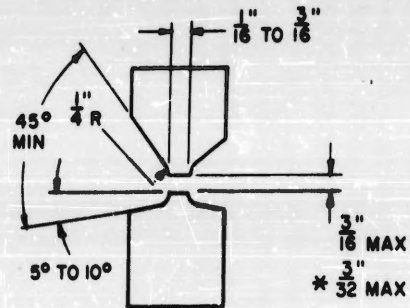
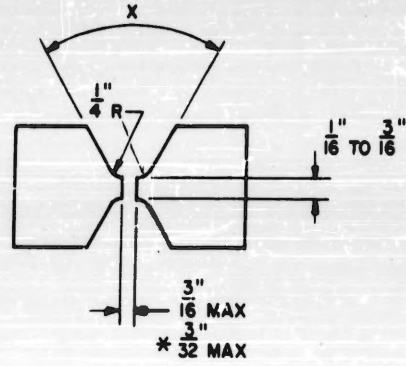


ANGLE X	POSITIONS
45° MIN	ALL
20° MIN	F, V, O
12° IN	F

JOINT RECOMMENDED FOR HORIZONTAL POSITION.

SINGLE-U-GROOVE WELDS WELDED FROM ONE OR BOTH SIDES

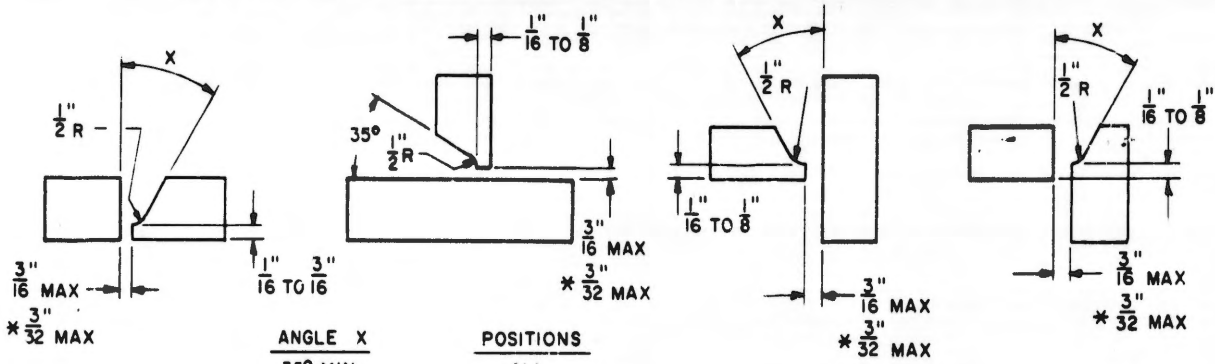
Figure 15.3 (contd)



JOINT RECOMMENDED FOR HORIZONTAL POSITION

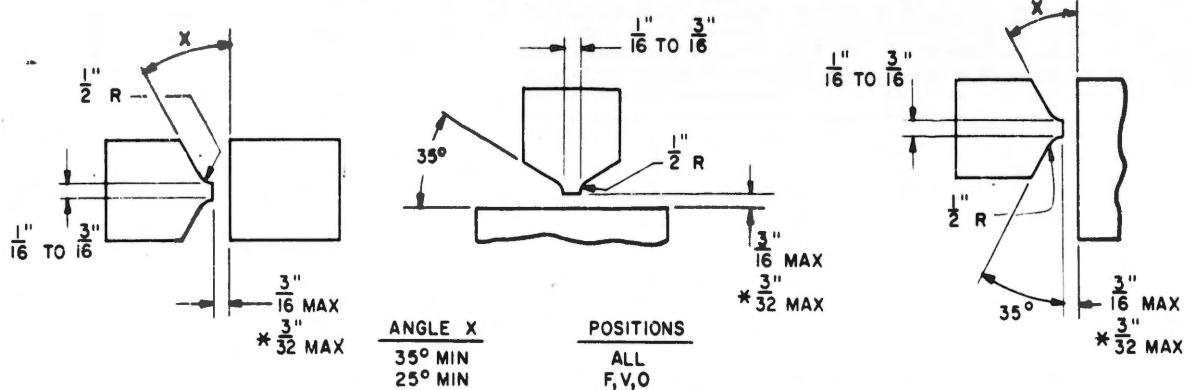
ANGLE X	POSITIONS
45° MIN	ALL
20° MIN	F, V, O

DOUBLE-U-GROOVE WELDS WELDED FROM BOTH SIDES



ANGLE X	POSITIONS
35° MIN	ALL
25° MIN	F, V, O

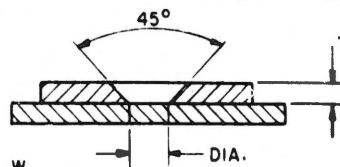
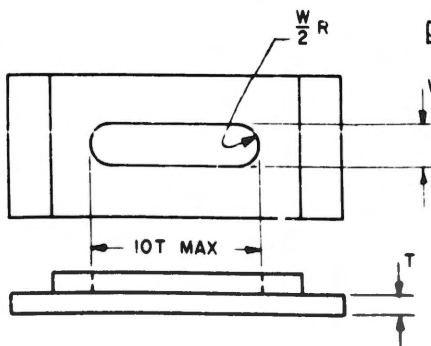
SINGLE-J-GROOVE WELDS WELDED FROM ONE OR BOTH SIDES



ANGLE X	POSITIONS
35° MIN	ALL
25° MIN	F, V, O

DOUBLE-J-GROOVE WELDS WELDED FROM BOTH SIDES

JOINT FOR PLUG WELD



DIM. T	DIA.
UNDER 1/8"	1/4" MIN
1/8" TO 1/2"	2T MIN
OVER 1/2"	T + 1/2"

DIM. T	DIM. W
UNDER 1/4"	2T MIN
1/4" AND OVER	1 1/2 T MIN

JOINT FOR SLOT WELD

The following joints in Figures 15.4 through 15.33 include those commonly used with all arc- and gas-welding processes except stud welding and pressure gas welding.

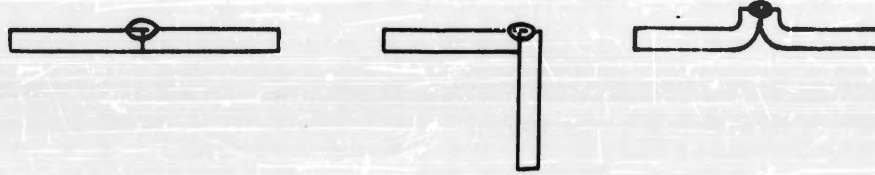


Figure 15.4

- (1) Strength depends on degree of joint penetration. Adequate procedure control and inspection are very important.
- (2) Should not be used when tension due to bending is concentrated at the root of the weld.
- (3) Should not be used when subject to fatigue, impact loading, service at low temperature or under corrosive conditions.
- (4) Economical in preparation and welding.

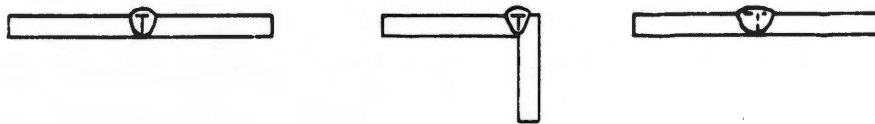


Figure 15.5

- (1) Complete joint penetration obtainable on relatively thin materials.
- (2) Fairly strong in static tension, but for reliability under more severe service conditions, joints in Figures 15.7, 15.8 and 15.11 are recommended.
- (3) Should not be used when tension due to bending is concentrated at the root of the weld.
- (4) Should not be used when subject to fatigue, impact loading, or service at low temperature.
- (5) Economical in preparation and welding.
- (6) For submerged arc welds, a removable backing means is required for all thicknesses. With this provision the design can be recommended for joints as thick as 5/16 inch.

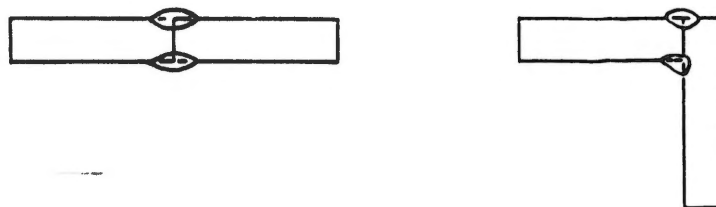


Figure 15.6

- (1) Strength depends on degree of joint penetration, plus throat of fillet weld in the case of the corner joint. Careful procedure control necessary for reliable degree of joint penetration.
- (2) For static loading only; should not be used when subject to fatigue, impact, or service at low temperature.
- (3) Economical in preparation and welding.

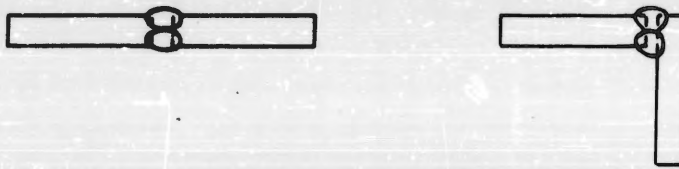


Figure 15.7

- (1) Suitable for all types of loading.
- (2) Economical in preparation and welding.
- (3) Complete joint penetration is obtainable with no root opening on materials up to 1/8 inch thick and with adequate root opening ( $T/2$ ) on materials up to 1/4 inch thick, with shielded metal-arc and inert-gas metal-arc processes. If full strength is desired on joints from 1/8 to 1/4 inch thick, the root of the first pass should be chipped out to sound metal before depositing the second weld.
- (4) Complete joint penetration is obtainable with no root openings on joints up to 5/8 inch thick with the submerged arc process. For thicker joints it may be advisable to chip out the root of the first pass so that complete penetration may be obtained without depositing too much reinforcing metal. The shape and volume of reinforcement limit the thickness of this type of joint that can be submerged arc welded.

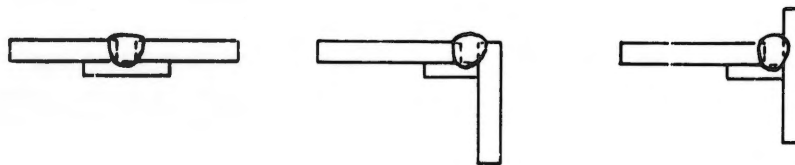


Figure 15.8

- (1) For shielded metal-arc and inert-gas metal-arc processes, suitable for materials up to 3/16 inch thick with adequate root opening ( $T$ ). For submerged arc process, suitable for materials up to 3/8 inch thick using a minimum root gap of 1/8 inch. For thicker materials, joint in Figure 15.12 is recommended.
- (2) Useful when all welding must be done from one side.
- (3) Suitable for all types of loading, except corrosive service.
- (4) Preparation relatively inexpensive.
- (5) Backing may be removed after welding if desired.

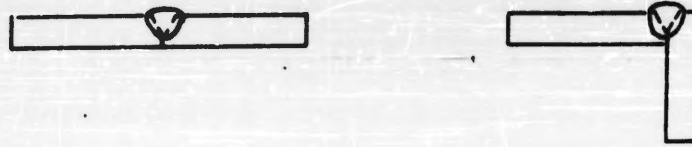


Figure 15.9

- (1) Strength depends on degree of joint penetration which is usually slightly less than the depth of chamfering. For full strength, joints in Figures 15.11, 15.12, or 15.14 are recommended.
- (2) Economical from standpoint of welding required when depth of chamfering does not exceed  $3/4$  inch.
- (3) Should not be used when tension due to bending is concentrated at the root of the weld.
- (4) Should not be used when subject to fatigue, impact loading, service at low temperature or under corrosive conditions.
- (5) Preparation and welding relatively inexpensive.

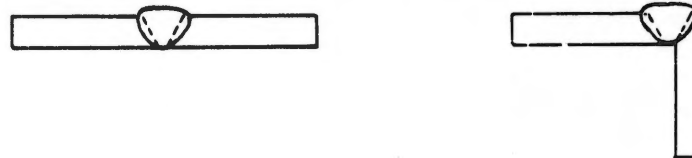


Figure 15.10

- (1) Economical for thicknesses between  $1/4$  and  $3/4$  inch from standpoint of welding required.
- (2) Fairly strong in static loading, but for reliability under more severe service conditions, joints in Figures 15.11 or 15.12 are recommended.
- (3) Should not be used when tension due to bending is concentrated at the root of the weld.
- (4) Should not be used when subject to fatigue, impact loading or service at low temperature.
- (5) Preparation and welding relatively inexpensive.
- (6) For submerged arc welds, a removable backing is required for all thicknesses. With this provision, joints as thick as  $1\ 1/2$  inches can be welded.
- (7) Submerged arc welding may be used in combination with root passes deposited by shielded metal-arc or inert-gas metal-arc process.

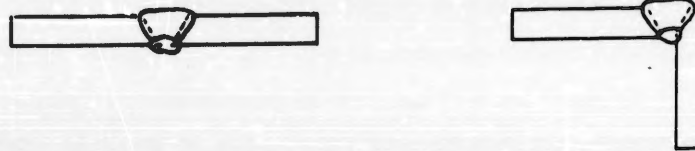


Figure 15.11

- (1) Full strength obtainable for all types of loading.
- (2) To obtain full strength, the root of the first weld should be chipped out to sound metal before depositing the second weld.
- (3) Economical for thicknesses up to 3/4 inch from standpoint of welding required.
- (4) In the case of the corner joint, a fillet weld may be added for additional strength.
- (5) For submerged arc welds, chipping of the root of the first weld to sound metal is generally not necessary or required to ensure a sound joint.

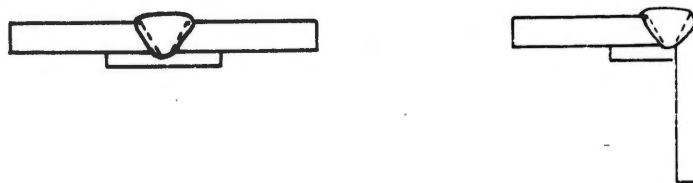


Figure 15.12

- (1) Full strength obtainable for all types of loading. Do not use in corrosive service, unless backing is removed.
- (2) Economical for thicknesses up to 3/4 inch from standpoint of welding required.
- (3) Desirable when all welding must be done from one side.
- (4) Backing may be removed after welding if desired.

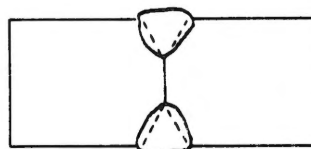


Figure 15.13

- (1) Strength depends on total penetration which is usually slightly less than the total depth of chamfering.
- (2) For static loading only; should not be used when subject to fatigue, impact or service at low temperature.
- (3) Economical when depth of chamfering on each side does not exceed 3/4 inch.
- (4) For full strength, joints in Figures 15.14 or 15.30 are recommended.



Figure 15.14

- (1) Full strength obtainable for all types of loading.

Notes (2), (3) and (4) apply to the shielded metal-arc and inert-gas metal-arc processes.

- (2) Economical for thicknesses up to 1 1/2 inch from standpoint of welding required.
- (3) To obtain full strength, the root of the first weld should be chipped out to sound metal before depositing the second weld.
- (4) For thicker materials, joint in Figure 15.30 is recommended.
- (5) This is the standard two-pass submerged arc design in which the heavy root faces are tightly butted and act as a backing for the first pass. Chipping of the root of the first pass is not necessary to obtain a sound, full-strength joint.
- (6) Two-pass submerged arc welds obtainable up to 2 1/4 inch thickness. For thicker materials, joint in Figure 15.28 is recommended.

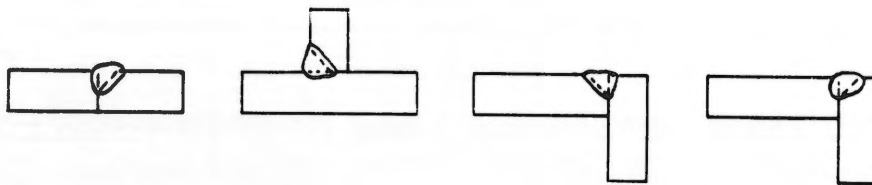


Figure 15.15

- (1) Strength depends on degree of joint penetration which is usually slightly less than the depth of chamfering.
- (2) Difficult to obtain a sound weld due to the perpendicular groove face. Vee and U grooves preferable.
- (3) Economical from standpoint of welding required when depth of chamfering does not exceed 3/4 inch.
- (4) Should not be used when tension due to bending is concentrated at the root of the weld.
- (5) Should not be used when subject to fatigue, impact loading, service at low temperature or under corrosive conditions.

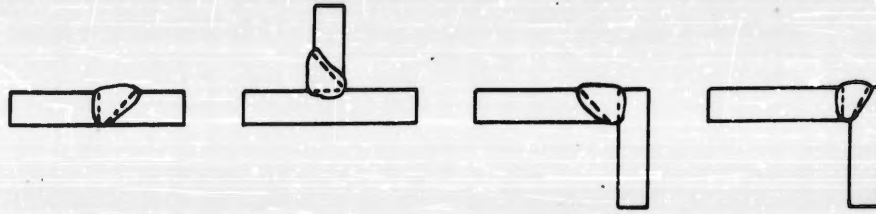


Figure 15.16

- (1) Fairly strong in static loading, but for reliability under severe service conditions, joints in Figures 15.17 or 15.18 are recommended.
- (2) Difficult to obtain a sound weld due to perpendicular groove face.
- (3) Economical for thicknesses between 1/4 and 3/4 inch from standpoint of welding required.
- (4) Should not be used when tension due to bending is concentrated at the root of the weld.
- (5) Should not be used when subject to fatigue, impact loading or service at low temperature.
- (6) For submerged arc welds, a removable backing means is required for all thicknesses.
- (7) Submerged arc welding may be used after the root passes have been deposited by the shielded metal-arc process.

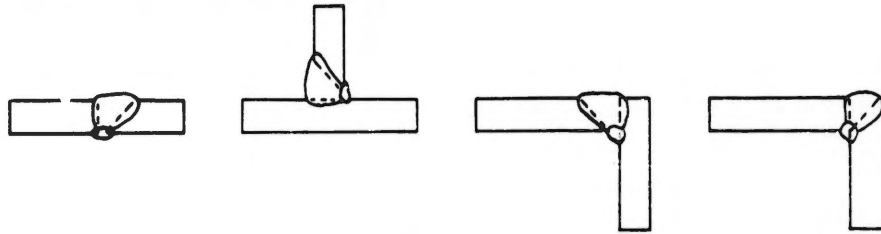


Figure 15.17

- (1) Full strength obtainable for all types of loading.
- (2) To obtain full strength, the root of the first weld should be chipped out to sound metal before depositing the second weld.
- (3) Difficult to obtain a sound weld due to perpendicular groove face.
- (4) Economical for thicknesses up to 3/4 inch from standpoint of welding required.
- (5) In the case of tee and corner joints, fillet welds may be added for additional strength.
- (6) For submerged arc welds, chipping of the root of the first weld may not be necessary to ensure a sound joint.

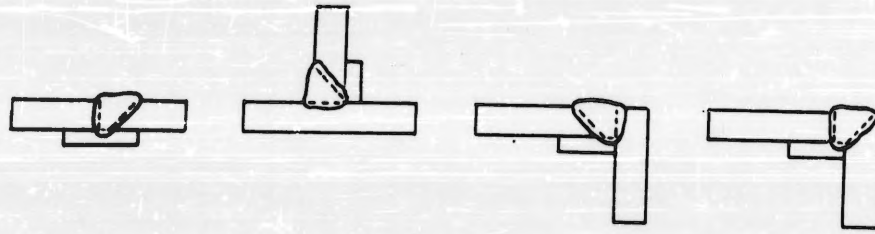


Figure 15.18

- (1) Full strength obtainable for all types of loading. Do not use in corrosive service without removal of backing.—
- (2) Difficult to obtain a sound weld due to perpendicular groove face.
- (3) Economical for thicknesses up to 3/4 inch from standpoint of welding required.
- (4) Desirable when all welding must be done from one side.
- (5) Backing may be removed after welding if desired.

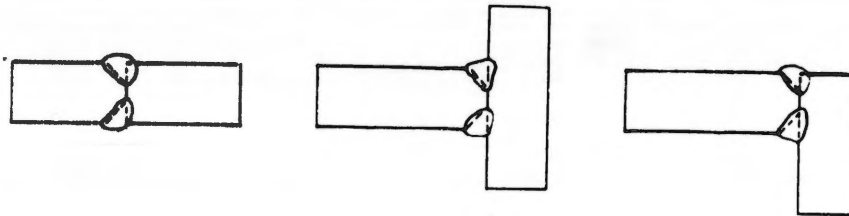


Figure 15.19

- (1) Strength depends on total joint penetration, which is usually slightly less than the depth of chamfering.
- (2) Difficult to obtain sound welds due to perpendicular groove face.
- (3) For static loading only; should not be used when subject to fatigue, impact or service at low temperature.
- (4) Economical from standpoint of welding required when depth of chamfering on each side does not exceed 3/4 inch.
- (5) For full strength, joint in Figure 15.20 is recommended.

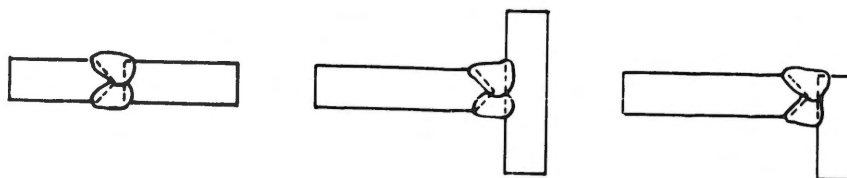


Figure 15.20

- (1) Full strength obtainable for all types of loading.
- (2) Difficult to obtain a sound weld due to perpendicular groove face; also difficult to chip the root of the weld.
- (3) To obtain full strength, the root of the first weld should be chipped to sound metal before depositing the second weld.
- (4) Economical from standpoint of welding required when thickness does not exceed 1 1/2 inches.
- (5) For thicker materials, joints in Figures 15.25 or 15.30 are recommended.

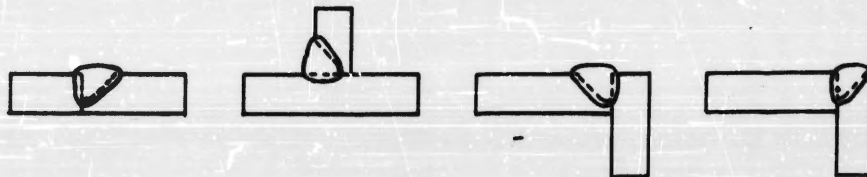


Figure 15.21

- (1) Strength depends on degree of joint penetration which is usually equal to or slightly less than the depth of chamfering.
- (2) Difficult to obtain a sound weld due to perpendicular groove face.
- (3) More economical from standpoint of welding required when depth of chamfering exceeds  $3/4$  inch.
- (4) More expensive to prepare.
- (5) Should not be used when tension is concentrated at the root of the weld.
- (6) Should not be used when subject to fatigue, impact loading or service at low temperature or under corrosive conditions.

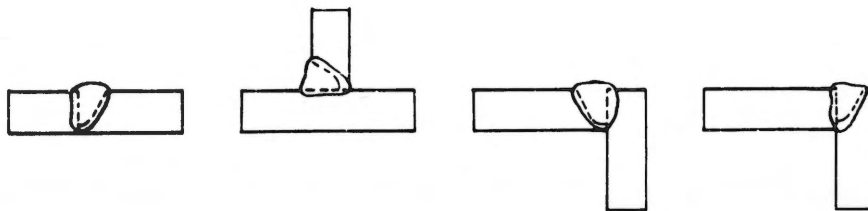


Figure 15.22

- (1) Fairly strong in static loading, but for full strength, joint in Figure 15.23 is recommended.
- (2) Difficult to obtain a sound weld due to perpendicular groove face.
- (3) More economical from standpoint of welding required when thickness exceeds  $3/4$  inch.
- (4) More expensive to prepare.
- (5) Should not be used when tension due to bending is concentrated at the root of the weld.
- (6) Should not be used when subject to fatigue, impact loading or service at low temperature.
- (7) For submerged arc welding, a removable backing means is required for all thicknesses.
- (8) Submerged arc welding may be used after the root passes have been deposited by the shielded-arc process.

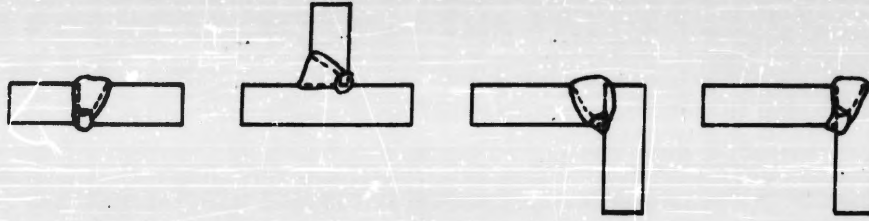


Figure 15.23

- (1) Full strength obtainable for all types of loading.
- (2) To obtain full strength, the root of the first weld should be chipped out to sound metal before depositing the second weld.
- (3) Difficult to obtain a sound weld due to the perpendicular groove face.
- (4) More expensive to prepare.
- (5) More economical from standpoint of welding required when thickness exceeds 3/4 inch.
- (6) In the case of tee and corner joints, fillet welds may be added for additional strength and to improve stress distribution.
- (7) For submerged arc welds, chipping of the root of the first weld may not be necessary to ensure a sound joint.

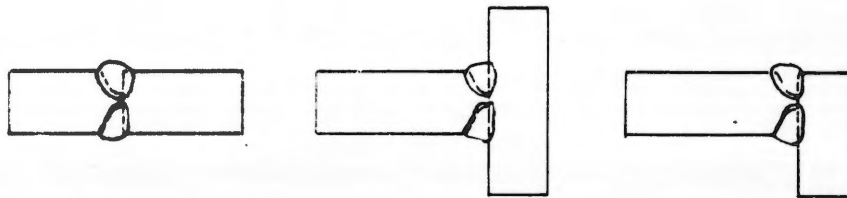


Figure 15.24

- (1) Strength depends on total joint penetration, which will usually be equal to or slightly less than the depth of chamfering.
- (2) Difficult to obtain a sound weld due to the perpendicular groove face.
- (3) More economical when the depth of chamfering on each side exceeds 3/4 inch.
- (4) More expensive to prepare.
- (5) For static loading only; should not be used when subject to fatigue, impact, or service at low temperatures.
- (6) For full strength, joints in Figures 15.25 or 15.30 are recommended.

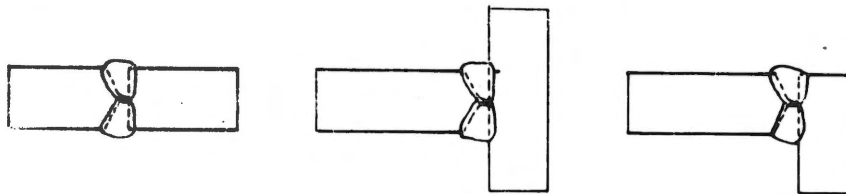


Figure 15.25

- (1) Full strength obtainable for all types of loading.
- (2) Difficult to obtain a sound weld due to perpendicular groove face.
- (3) To obtain full strength, the root of the first weld should be chipped out to sound metal before depositing second weld.
- (4) More expensive to prepare.

- (5) Economical from standpoint of welding required when depth of chamfering on each side exceeds  $3/4$  inch.
- (6) In the case of tee and corner joints, fillet welds may be added for additional strength and to improve stress distribution.
- (7) For submerged-arc welds, chipping of the root of the first weld may not be necessary to ensure a sound joint.



Figure 15.26

- (1) Strength depends on degree of joint penetration, which is usually equal to the depth of chamfering. For full strength, joints in Figures 15.28 or 15.30 are recommended.
- (2) Economical from the standpoint of welding required when the depth of chamfering exceeds  $3/4$  inch.
- (3) Most easily welded groove but expensive to prepare.
- (4) Should not be used when tension is concentrated at the root of the weld.
- (5) Should not be used when subject to fatigue, impact loading, service at low temperature, or under corrosive conditions.



Figure 15.27

- (1) Fairly strong in static loading, but for full strength, joint in Figure 15.28 is recommended.
- (2) Economical from standpoint of welding required when thickness exceeds  $3/4$  inch.
- (3) Most easily welded groove, but expensive to prepare.
- (4) Should not be used when tension due to bending is concentrated at the root of the weld.
- (5) Should not be used when subject to fatigue, impact loading or service at low temperature.
- (6) If used for submerged arc welding, a removable weld backing means must be provided.
- (7) Submerged arc welding may be used after the root passes have been deposited by the shielded metal-arc or inert-gas metal-arc process.

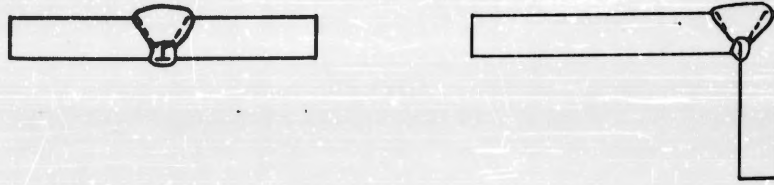


Figure 15.28

- (1) Full strength obtainable for all types of loading.
- (2) To obtain full strength, the root of the first weld should be chipped out to sound metal before depositing second weld.
- (3) Economical from standpoint of welding required when thickness exceeds  $3/4$  inch.
- (4) Most easily welded groove, but expensive to prepare.
- (5) In the case of the corner joint, a fillet weld may be added for additional strength.
- (6) For submerged arc welds, chipping of the root of the first weld may not be necessary to obtain a sound joint.

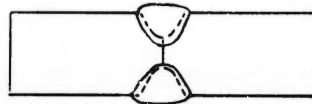


Figure 15.29

- (1) Strength depends on total joint penetration, which is usually equal to the depth of chamfering.
- (2) Most easily welded groove, but expensive to prepare.
- (3) For static loading only; should not be used if subject to fatigue, impact, or service at low temperature.
- (4) Economical from standpoint of welding required when the depth of chamfering on each side exceeds  $3/4$  inch.
- (5) For full strength, joint in Figure 15.30 is recommended.

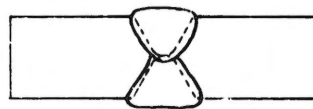


Figure 15.30

- (1) Full strength obtainable for all types of loading.
- (2) To obtain full strength, the root of the first weld should be chipped out to sound metal before depositing the second weld.
- (3) Most easily welded groove, but expensive to prepare.
- (4) Economical from standpoint of welding required when thickness exceeds  $1\ 1/2$  inches.

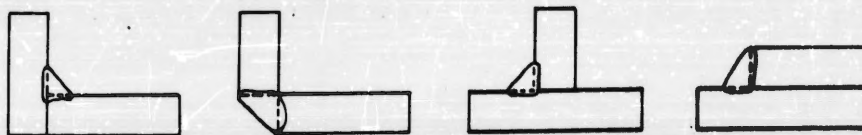


Figure 15.31

- (1) Strength depends on size of fillet.
- (2) No preparation required.
- (3) Should not be used when tension due to bending is concentrated at the root of the weld.
- (4) Should not be used when subject to fatigue or impact loading.



Figure 15.32

- (1) Full strength in static loading obtainable with adequate size of fillet welds.
- (2) No preparation required.
- (3) Economical from standpoint of welding required on moderate thicknesses.
- (4) In the case of the lap joint, maximum strength in tension is obtained when the lap equals five times the thickness of the thinner member.

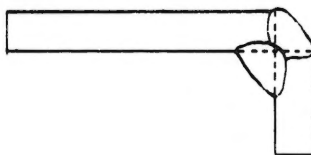


Figure 15.33

- (1) Full strength obtainable for all types of loading.
- (2) To obtain full strength, the root of the first weld should be chipped out to sound metal before depositing the second weld.
- (3) Economical from the standpoint of welding required on moderate thicknesses.
- (4) For submerged arc welds, chipping of the root of the first weld may not be necessary to obtain a sound joint.

**Typical Joints for the Resistance Welding Process.** Design for resistance welding requires a complete knowledge of each of the processes available, the possibilities of applied usage, the limitations imposed by available equipment, and the economic considerations involved. The design of the joint is influenced by the design of the product, the process selected and the type of equipment to be used. The joints shown in Figure 15.34 through 15.38 are typical for resistance welding.

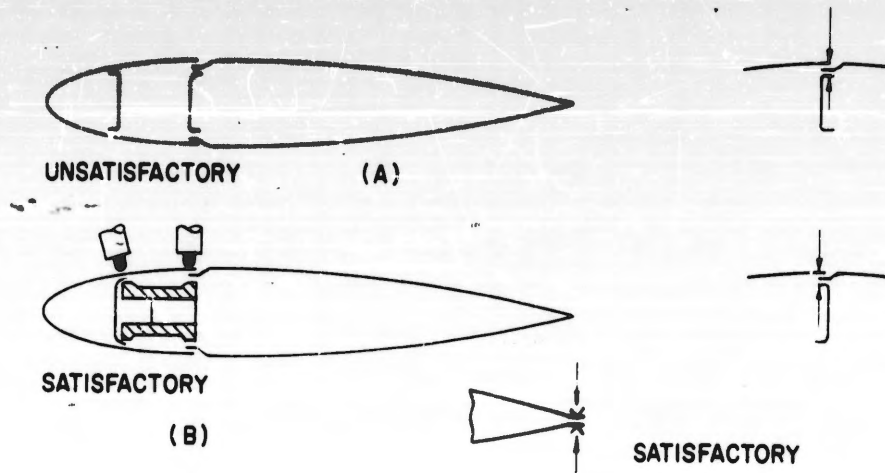


Figure 15.34

- (1) Strength requirements in A are satisfactory but intersecting parts eliminate the possibility of spot welding.
- (2) The flanges have been reversed in B to permit the placing of a mandrel on the inner surfaces. Spot welding can be accomplished by the exterior application of electrode tips.

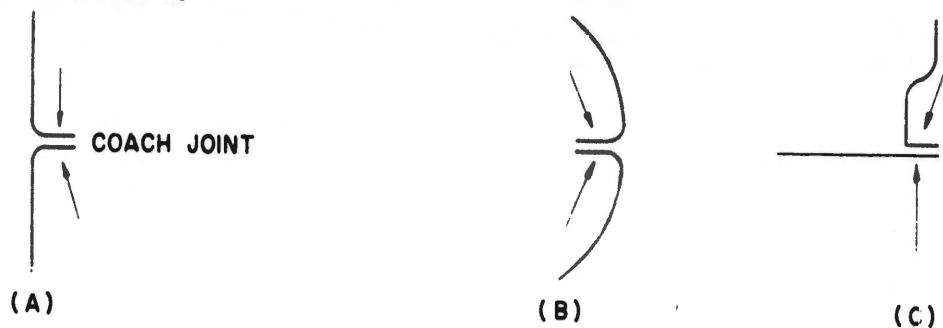


Figure 15.35

- (1) Conventional flanged lap joint, A.
- (2) Flanges terminating from curved surfaces, B.
- (3) Combination of flange at a 90-degree angle and a flat surface edge, C.

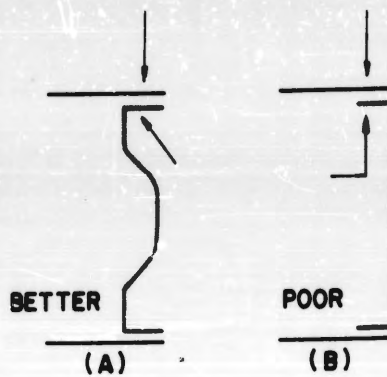


Figure 15.36

Accessibility for welding tips is one of the chief requisites of good joint design. The flanges in (A) and (B) are equal size yet (A) provides instant accessibility and (B) presents a problem of insertion and location of inner welding tip.

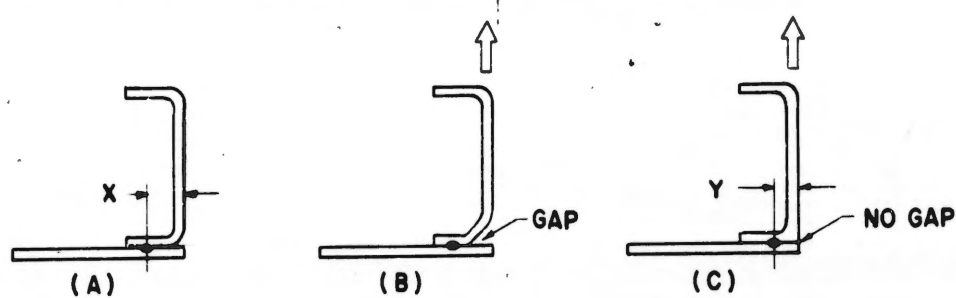


Figure 15.37

- (1) Spot welds in A must be located in relation to the various stresses encountered. A spot weld placed at point X will not prevent the part from deforming under stress.
- (2) Deformation under stress in B has caused a gap to the edge of the spot weld.
- (3) When the spot weld in C is located at the root of the flange, the mechanical strength is increased and the same tension can be resisted without deformation.

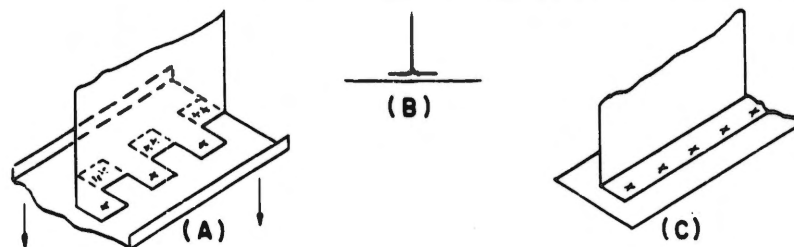


Figure 15.38

- (1) Balance in A is obtained by dividing the stress equally on both sides of the line of stress by means of scalloped flanges.
- (2) Method B gives perfect balance by dividing the stress.
- (3) The stress in C is unbalanced because spot welds are made on one side only with no flange to compensate on the other side.

Typical Joints for the Projection Welding Process. Figures 15.39 through 15.41 show typical joints for projection welding.

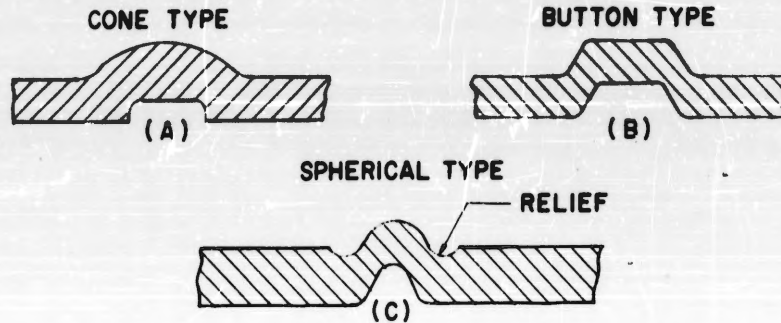


Figure 15.39

- (1) The cone-type projection is more rigid than the button and is used for heavier sheets, from 12 to 5 gage metal.
- (2) The button-type projection is used for jointing flat sheets with thicknesses varying from 24 to 13 gage maximum. Projections should be uniform, the correct type for the application, and of the correct proportion. The punching operation should be carefully controlled to prevent the button being sheared, which would result in loss of strength in the weld area.
- (3) The spherical-type projection is used for projecting welding heavy sections, forgings and the like. This projection is prepared with a cavity, or relief, surrounding the projection and into which the displaced metal can flow as it reaches its plastic state. This prevents sheet separation or expulsion when the projection upsets.

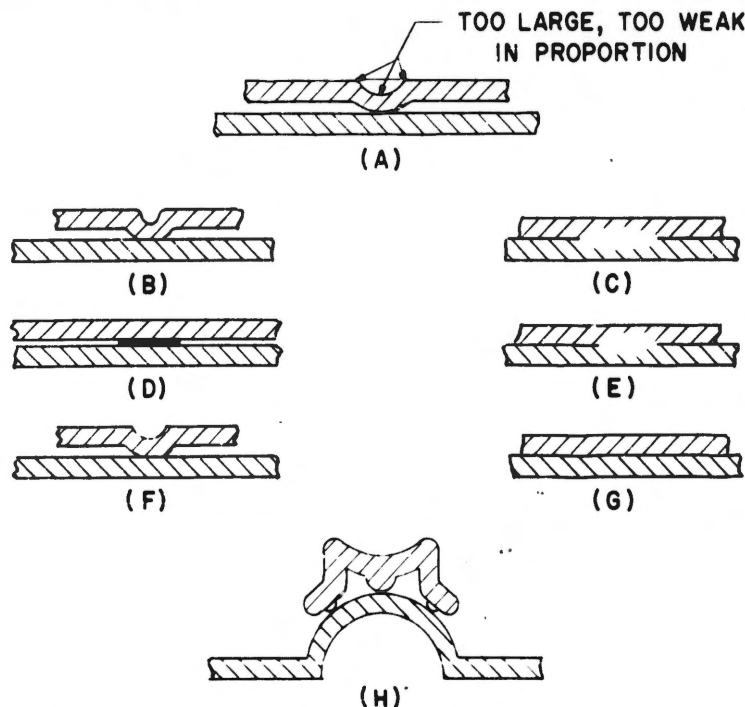


Figure 15.40

- (1) Projection is too weak in A in proportion to the thickness of the part being welded because the diameter of the projection is too great. The rigidity of the projection must be sufficient to withstand all pressures encountered before the welding current is applied.

- (2) The projection in B is designed to allow sufficient mass to raise the opposing surface to welding temperature. Too small a projection will collapse before this temperature has been reached and an inefficient bond will result.
- (3) C illustrates an efficient projection weld. The mass of the projection was sufficient to heat the contacting surface and equal penetration has been obtained in both parts.
- (4) D is an unsatisfactory weld because the surfaces are separated.
- (5) E is satisfactory because the weld achieves the desired objective; surfaces are in intimate contact, there is no expulsion of metal or sheet separation at the weld.
- (6) F is unsatisfactory: the projection has been partially sheared during the forming operation.
- (7) The weld in G, with a deformed or sheared projection, will lack strength and tear out easily.
- (8) Unsatisfactory design in H; too critical for practical purposes. Dies would have to be in perfect alignment and projections prepared with complete accuracy or deformation would result. Projections should be designed to prevent deformation or distortion of parts during formation or during the welding operation.

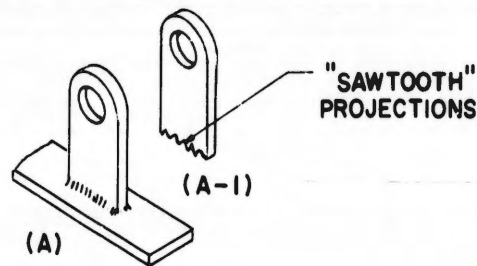


Figure 15.41

This type of projection is commonly used on stampings. It is inexpensive to prepare and produces a high-strength weld. It is often specified for clad or plated surfaces to ensure breaking through the coating.

Typical Joints for the Seam Welding Process. Figures 15.42, 15.43, and 15.44 show typical seam welding joints.

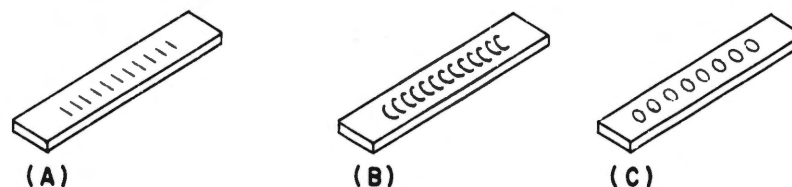


Figure 15.42

- (1) A continuous seam is formed when the welding current is uninterrupted.
- (2) A series of continuous overlapping spot welds is formed by the rotating wheel when the current is regularly interrupted. Both (A) and (B) type welds exhibit similar properties on metals of equal thickness. Both seams are gas and watertight.
- (3) The spot welds in (C) are spaced at predetermined distances by interrupting the weld current at constant intervals. Seams are neither gas- nor watertight but they can be produced at high speed.

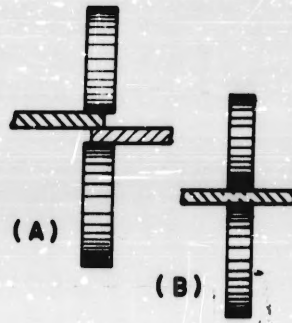


Figure 15.43

- (1) The overlapping edges of two sheets are positioned between the rotating wheels. The application of the welding current and pressure causes the metal to become plastic and "mash" or forge together. The resulting seam is only slightly thicker than the diameter of a single section.
- (2) A constant thickness can be obtained on mash-welded joints by shaving or rolling after welding.

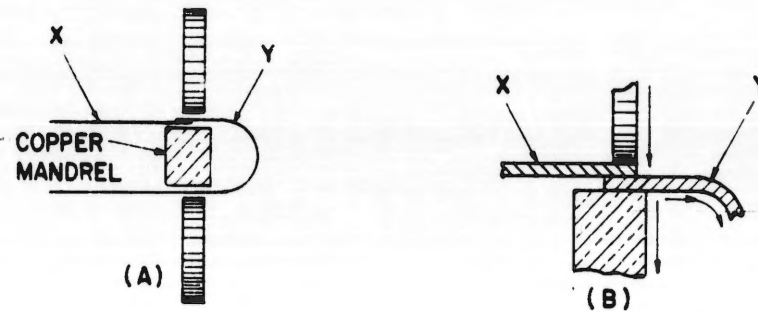


Figure 15.44

- (1) Unsatisfactory in A, the welding current will always follow the line of least resistance. It will shunt (short circuit) into Part X to the lower wheel, without passing through the copper mandrel.
- (2) Satisfactory in B, a simple change in design forces the current to flow from the wheel through Part X into Part Y. Thus, an efficient weld is produced whether or not the current passes through the copper mandrel or shunts around Y to the lower wheel.

Typical Joints for the Flash and Upset Butt Welding Process. Figures 15.45, 15.46 and 15.47 show typical joints for flash and upset butt welding.

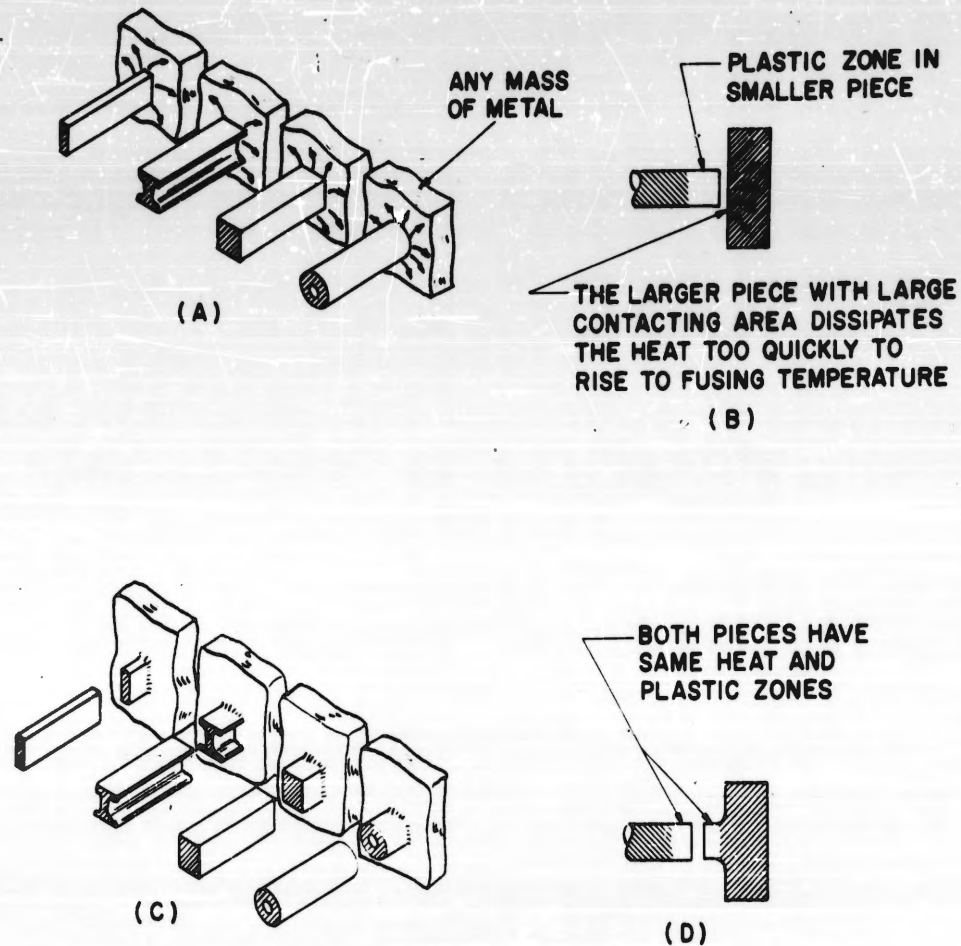


Figure 15.45

- (1) If these examples of rectangular bar, I-section, square bar and tubular sections in A are to be flash welded successfully to the larger masses of metal, the joint design must be changed. The heat from the flash would rapidly raise the temperature of the smaller section to welding heat, but the larger mass would dissipate the heat and not reach fusing temperature.
- (2) An unsatisfactory bond in B would be obtained due to the larger contacting area conducting the heat away too rapidly.
- (3) Satisfactory joint designs in C are obtained by matching sections.
- (4) The correct heat balance in D is maintained by providing equal cross-sectional areas. The plastic zones surrounding the contacting surfaces are equal in both parts. The welding temperature of both parts is reached simultaneously and a satisfactory weld results. The cross-sectional area of one part must be within 15% of the other in order to obtain satisfactory flash butt welds.

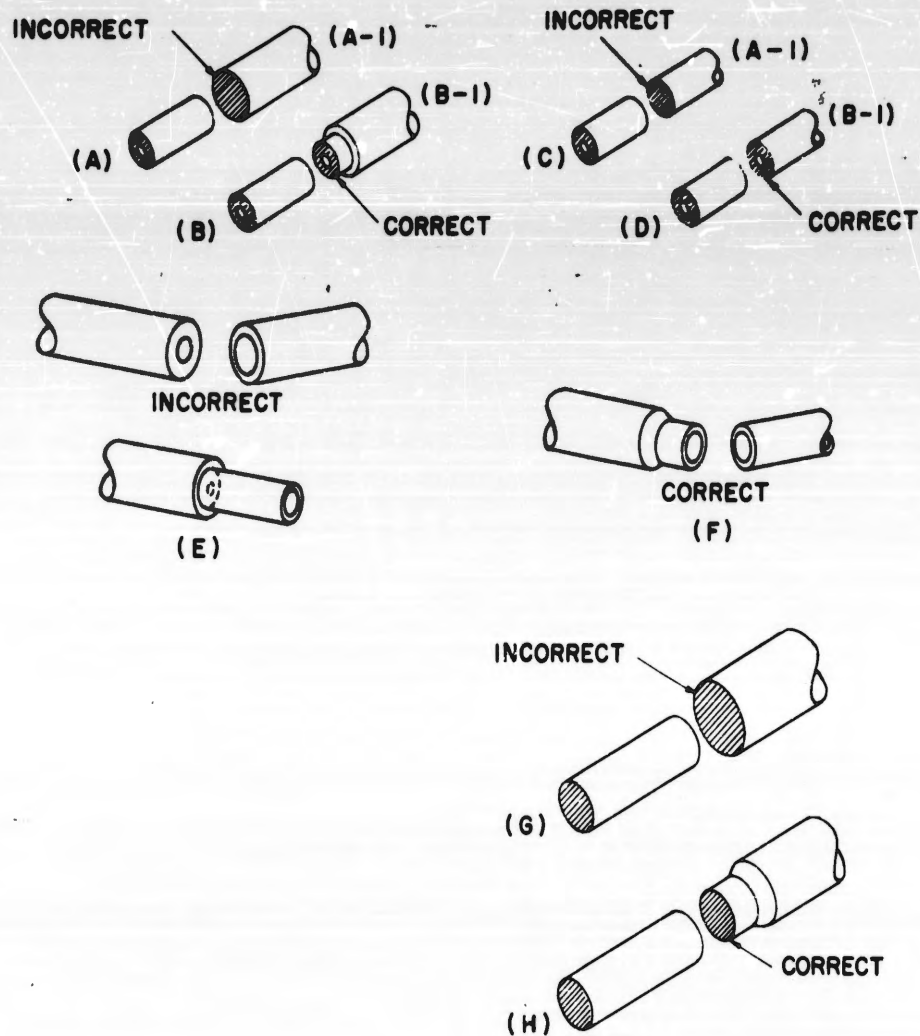


Figure 15.46

- (1) Unsatisfactory in A because the cross-sectional areas are unequal.
- (2) Joint design corrected in B by machining the shaft to equal the cross section of the tube. A hole has been drilled in the shaft to correspond with that in the tube.
- (3) An unsatisfactory joint in C will result when flash welding parts of equal external dimensions when one part is tubing and the other is a solid shaft.
- (4) Satisfactory joint design in D is accomplished by drilling a hole in the solid shaft to make the cross-sectional areas of both parts equal.
- (5) Unsatisfactory in E because one tubular section is more than 15% greater than the other.
- (6) The internal and external diameters of the heavier walled section in F are machined so that the inside and outside diameters of both parts are equal.
- (7) Unsatisfactory welds in G are obtained between solid shafts of unequal diameters.
- (8) Joint design in H is correct when the outside diameter of the larger shaft is machined down to equal the cross-sectional area of the smaller shaft.

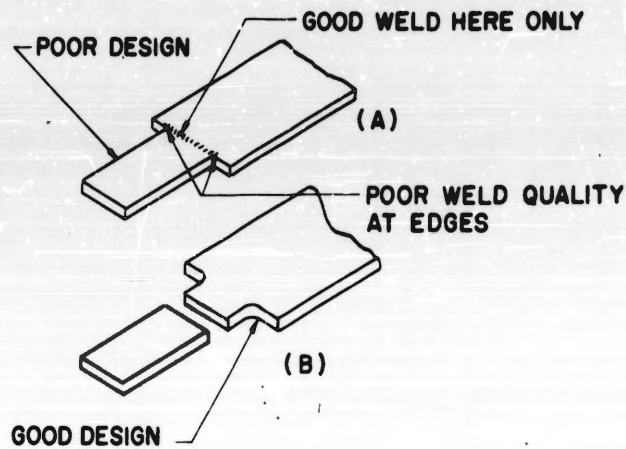


Figure 15.47

- (1) Unsatisfactory in A, weld lacks strength. The center portion alone will be welded. The extremities will not be welded to the larger section because of the dissipation of heat from the greater area of metal.
- (2) Good joint design in B. The cross-sectional area of both sections is identical and excellent welds will result.

#### REFERENCES

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Kent's Mechanical Engineers Handbook, Design and Production Volume, 12th Edition

Laughner and Hargan, "Handbook of Fastening and Joining of Metal Parts"

Metals Handbook, 1948 Edition

Bolz, Production Processes

**CHAPTER 16**  
**SURFACE FINISH**

**PROCESS**

Without needing to know just how to operate a particular machine to attain a desired degree of surface roughness, there are certain other aspects of all the methods which should be understood by the design engineer. Knowledge of such facts as degree of roughness obtained by any operation and the economics of attaining smoother surfaces with each operation; will aid him in deciding just which surface roughness to specify.

In general, and as shown in Figure 16.1, surface roughness is defined as the average deviation expressed in micro-inches from the mean surface (NAS-30, National Aircraft Standards). Some activities may use the root-mean-square average deviation and others the arithmetic average deviation; although the two averages described are not mathematically equivalent, agreement exists that the difference between them is negligible and the term "average" is universal. The mean surface is located in such a way that the volume of peaks of the surface cross-section above it exactly equals the volume of valleys below it.

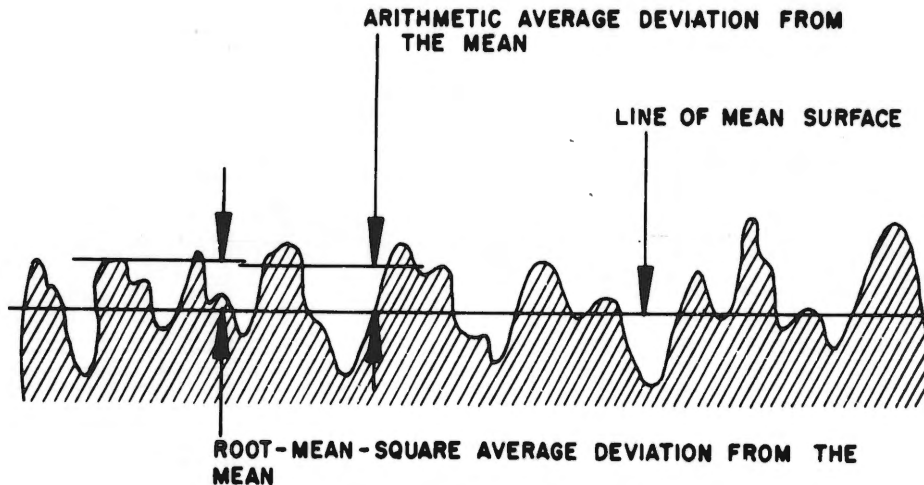


Figure 16.1 Surface Roughness


**ADVANTAGES AND LIMITATIONS**

As an aid towards understanding the applications of various surface finishes the following list describes some typical ones and the methods used:


↙ This surface results from processes which produce mirrorlike surfaces free from tool grinding or visible marks of any kind. The finish is used for rolls for roller bearings subject to heavy loads, for packings and rings that slide across the direction of the finish grain, and for precision tool components. Because of high cost, this finish is used only when essential. Typical processes which result in this finish are:

- (1) precision boring
- (2) diamond grinding
- (3) machine lapping and hyprolapping


- (4) superfinishing
- (5) bright polishing
- (6) very fine buffing

**8**  This surface results from processes which will produce a very close tolerance, scratch free surface. The finish is used for the interior surfaces of hydraulic struts, for hydraulic cylinders, pistons and piston rods for "O" ring packings, for journals operating in plain bearings, for cam faces, for raceways, and for rolls of antifriction bearings when loads are nominal. This finish is normally used only when coarser finishes are known to be inadequate. Typical processes which result in this finish are:

- (1) machine lapping and hyprolapping
- (2) superfinishing
- (3) microhoning
- (4) buffing and polishing
- (5) roller burnishing
- (6) very fine cylindrical grinding

**16**  This surface results from processes which will produce a finish that is used where surface finish is of prime importance for proper functioning. The finish is used for rapidly rotating shaft bearings, for heavily loaded bearings, for rolls in bearings of ordinary commercial grades, for hydraulic applications for static sealing rings, for the bottom of sealing-ring grooves, for journals operating in plain bearings, and for extreme tension members. Typical processes which result in this finish are:

- (1) fine surface grinding
- (2) smooth reaming
- (3) fine cylindrical grinding
- (4) smooth emery buffing
- (5) coarse honing and coarse lapping
- (6) gear burnishing and gear shaving
- (7) finish milling
- (8) gear shaving and scraping
- (9) cold drawing (rod, wire, etc.)

**32**  This surface results from processes which produce a fine machine finish. The finish is normally found on parts subject to stress concentrations and vibrations, for brake drums, broached holes, gear teeth, and other precision machined parts. It may also be used for bearings where accuracy is essential, motion is continuous, and loads are light, particularly if the lay is in the direction of motion. This surface usually requires removing tool marks by subsequent hand work such as with emery cloth. Typical processes which result in this finish are:

- (1) commercial carbide or diamond boring
- (2) medium surface grinding
- (3) coarse to medium cylindrical grinding
- (4) reaming
- (5) cold rolling
- (6) extruding
- (7) coining
- (8) cold upsetting

63 ✓  
This surface results from processes which produce a high quality smooth machine finish; as smooth a finish as can be economically produced by turning and milling without subsequent operations, and can be produced on a surface grinding machine. This finish is suitable for ordinary bearings, for ordinary machine parts where fairly close dimensional tolerances must be held, and for highly stressed parts that are not subject to severe stress reversals. Typical processes which result in this finish are:

- (1) drilling
- (2) gear cutting
- (3) hollow milling
- (4) slotting
- (5) spinning
- (6) die casting
- (7) precision casting

125 ✓  
This surface results from high grade machine work where high speeds, fine feeds, light cuts, and sharp cutters are used to produce a smooth machine finish. This surface may also be produced by all methods of direct machining under proper conditions. This finish should not be used on sliding surfaces, but is not objectionable for rough bearing surfaces where loads are light and infrequent or for moderately stressed machine parts which require moderately close fits. Typical processes which result in this finish are:

- (1) permanent mold casting
- (2) rough milling
- (3) sintered (powdered metallurgy) products
- (4) disc grinding
- (5) planing and shaping
- (6) spot facing
- (7) coarse surface and cylindrical grinding
- (8) ordinary hand filing.

250 ✓  
This surface results from average machine operations using medium feeds. The appearance of this finish is not objectionable and can be used on non-critical surfaces of components, and for mounting surfaces for brackets, etc. Typical processes which result in this finish are:

- (1) counterbore and countersink
- (2) very rough surface grind
- (3) punch and saw
- (4) medium machining such as turning, boring, rough planing, very rough milling
- (5) forging and swaging

500 ✓  
Very rough surface resulting from heavy machine feeds. It is suitable for clearance cuts and edges of machined parts which do not contact other parts. It is not suitable on components subject to high stresses or where vibration could cause fatigue failure. Typical processes which result in this finish are:

- (1) very rough turning or planing
- (2) sand casting
- (3) hand grind
- (4) machine forging

In addition, Table 16.1 shows the ranges of surface finishes attained by various methods and gives a rough means of estimating the extent of increased cost in attaining finer finishes over the commercially practicable values with each method.

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Table 16.1 Typical Surface Finishes

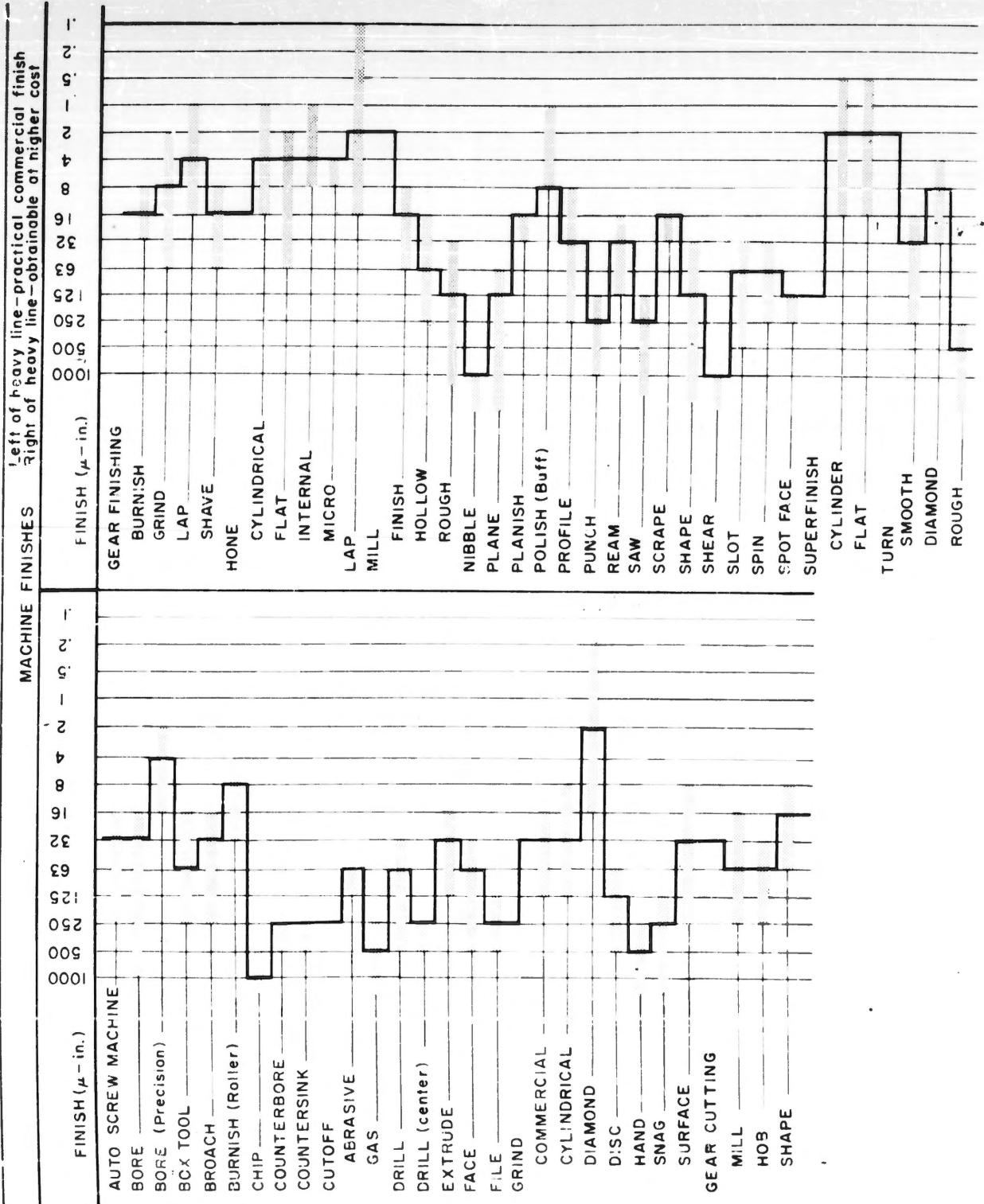
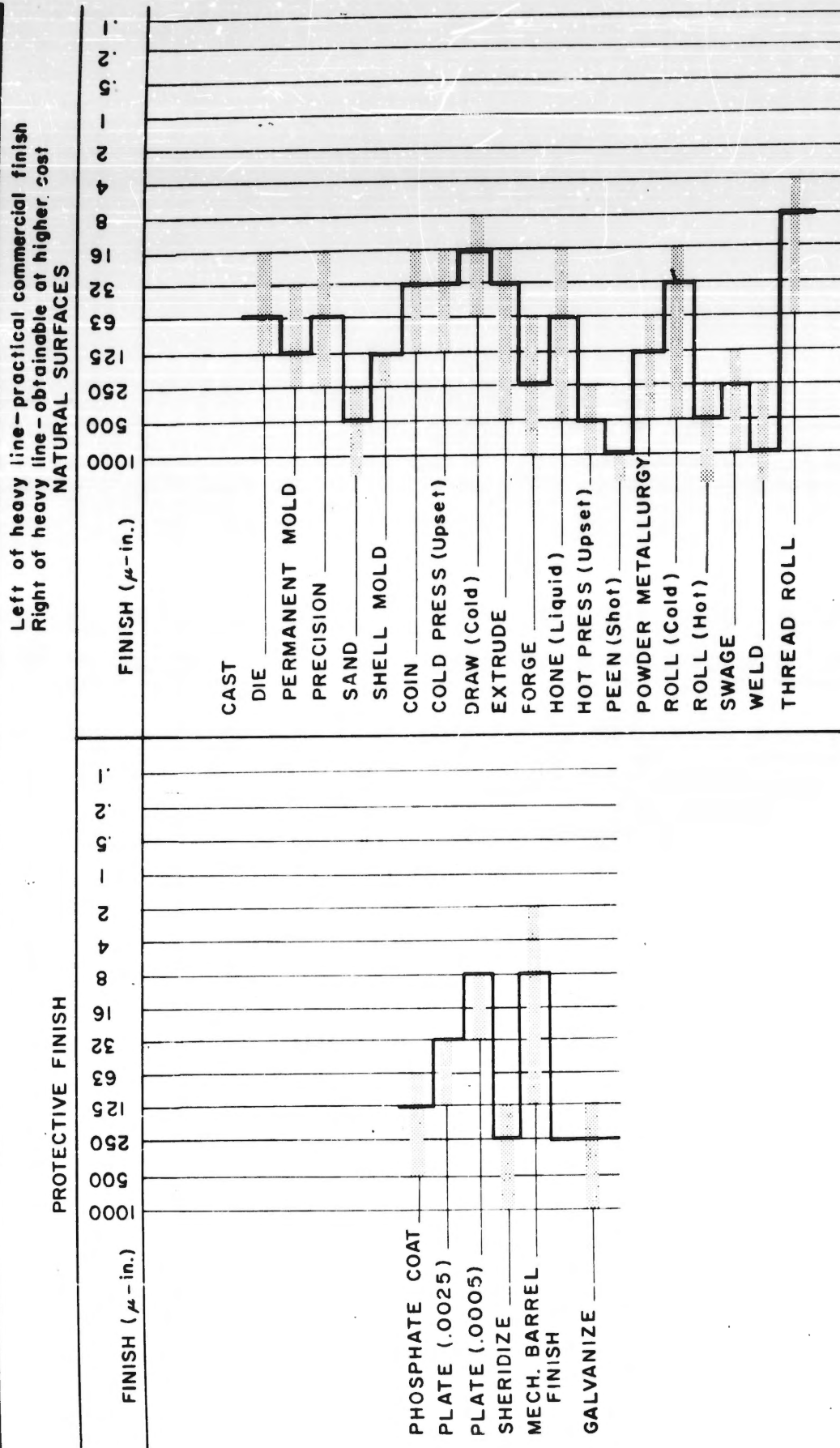


Table 16.1 Typical Surface Finishes (cont'd)



## CHAPTER 17

### SURFACE CLEANING

#### PROCESS

The cleaning of metals is usually done for reasons of appearance, or as preparatory operation to painting, plating, rust-proofing, or further processing. The multitude of cleaning methods may be generally classified as follows:

- Mechanical Methods
  - abrasive blasting
  - wire brushing
  - tumbling
- Flame cleaning
- Solvent cleaning and vapor degreasing
  - immersion
  - vapor degreasing
  - combination
- Acid pickling, electrolytic polishing, alkaline derusting
- Phosphatizing
- Molten sodium hydroxide cleaning
- Alkaline-detergent cleaning
  - still-tank or vat electrocleaning
  - steam gun
  - washing-machine
- Emulsion cleaning
  - soak
  - spray
  - washing-machine

#### Description of Methods

There is no hard and fast rule which states how a metal can be cleaned. The soil to be removed, the purpose for its removal, the equipment available to do the job, the cost of cleaning, and safety to personnel are the deciding factors. The various classes of cleaning are described as follows:

Mechanical Methods. Abrasive blasting methods involve hurling various types of abrasive materials at high velocities, either pneumatically or centrifugally, onto a part in order to remove scale, molding sand, or to produce a bright and clean surface. Parts cleaned in this way include forgings, castings, stampings and heat-treated parts made from iron, steel, aluminum, brass, and magnesium. Depending on the part and its material, abrasives used include grit, sand, shot, clover seed, tenite balls, and ground walnut shells, peach and apricot pits.

Wire brushing methods (including also non-metallic fiber brushes), hand or machine operated, find good adaptation for cleaning of metals prior to repair work, welding, painting, and for general surface improvement such as deburring, buffing, polishing, surface and joint blending, and many others. No specific rules can be established for which brush to use for any particular job; most jobs have their own characteristics which through study and trial will determine proper brush use and technique.

Tumbling methods of cleaning a volume of parts in a revolving barrel, sometimes including an abrasive blasting feature, are very rapid means of cleaning, deburring, and surface finishing. Often an aggregate of steel balls, stars, slugs, jacks, stones, or even

very small parts are used to create the abrasive action in a slowly revolving barrel, or sometimes water and soap with abrasives are used for faster action. This particular method is very economical.

**Flame Cleaning.** This method of cleaning, primarily as preparation for painting, uses a multiple-orifice oxyacetylene torch. Due to rapid localized thermal expansion, and by using a reducing type flame, any present iron oxide will be converted to iron. A particular convenience in this method is that oil and grease are burned away with a resulting warm and dry surface.

**Solvent Cleaning.** Using solvents to remove oil, grease, and slushing compounds involves basically dipping, wiping, or spraying parts with a solvent such as gasoline, kerosene, naphtha, carbon tetrachloride, or Stoddard solvent. Sometimes a hosing action of the solvent may be used to aid in removing heavier pieces of dirt and foreign material.

**Vapor Degreasing.** Using the solvents, stabilized trichlorethylene or perchlorethylene, vapor cleaning involves lowering the part into a chamber containing the vaporized solvent. The solvent condenses on the part, dissolving oil and grease, and falls back into a vat. Practically all metals may be cleaned in this way; however, materials such as water, fatty acids, alcohol, and fine aluminum shavings must be kept out of the solvent since they cause the liberation of hydrochloric acid. This method does not always produce clean surfaces since mineral salts, soil, and some soaps are not removed; however, the method is extremely rapid and, thus, popular.

**Acid Pickling.** Dipping parts into acid pickling tanks is a widely used cleaning method for removing scale, oxide coating, and stains and for producing various surface finishes such as bright, polished, etched, or matte. In addition to straight immersion methods, electrolytic and spray pickling are used popularly. Additional equipment is necessary for good pickling and includes preliminary alkaline cleaner, rinsing equipment and final neutralizing alkaline baths after pickling.

There are many pickling solutions available, depending on the material being cleaned, material to be removed, and finish effect desired. Briefly they are described by material to be cleaned as follows:

**Iron and steel - Sulfuric acid and muriatic acid solutions to remove scale and oxides.**

Ferric sulfate solution for etching.

The patented Bullard-Dunn process which uses a sulfuric acid bath containing tin or lead salts and incorporates electroplating. As the scale is removed, plated tin or lead stops further attack; the plating is later removed anodically.

Hydrofluoric acid solutions to dissolve sand from castings.

**Stainless steel - Sulfuric plus muriatic acid or nitric plus hydrofluoric acid solutions for loosening scale.**

Nitric plus muriatic acid solutions for bright dipping.

Diluted nitric acid for passivating.

**Copper and its alloys -**

Diluted sulfuric acid for removing scale and light stains.

Sulfuric plus nitric acid solutions for rapid removal of scale.

Ferric sulfate plus sulfuric acid solutions to remove red and black scale and status.

Ferric sulfate plus citric acid, cream of tartar, acetic acid solutions for bright dipping.

**Aluminum and its alloys -**

Alkaline solutions for etching sheet products.

Nitric acid solutions to bright-dip sheet products.

Nitric plus hydrofluoric acid solutions to bright-dip and etch castings.

Sulfuric plus chromic acid solutions to deoxidize and bright-dip wrought products.

Nickel-chloride plus muriatic acid solutions to etch pure aluminum.

**Zinc and its alloys -**

Alkaline or acid solutions similar to aluminum pickling methods for etching.

Chromic acid plus sodium sulfate solutions for bright-dip.

**Titanium -**

Hot nitric plus hydrofluoric acid solutions for removing scale.

**Electrolytic Polishing.** This method involves anodic treatment of a metal piece in an acid bath. In this way, different surface finishes may be obtained which vary in smoothness and polish. The method is readily adaptable to carbon and stainless steels, aluminum, nickel, magnesium, copper, zinc and their alloys.

**Alkaline Derusting.** This is a relatively new process involving dipping a part in an alkaline bath, causing current to flow to the part so that hydrogen forming on the part aids in removing rust while the caustic action serves to further clean the part.

**Phosphatizing.** This process involves the forming of a phosphate coating on a part in order to inhibit corrosion, act as a lubricant, reduce wear, and to act as a base surface for painting. In general, a part must first be cleaned before phosphatizing.

Materials commonly applicable to this process are iron, steel, zinc, cadmium, and aluminum. The part is dipped, sprayed, or hand wiped with a phosphatizing solution, rinsed, sometimes sealed, and then dried.

**Molten Sodium Hydroxide Cleaning.** A very successful way of descaling stainless steel and iron castings is by immersion of the part into molten sodium hydroxide with or without the use of electric current. Then the part is quenched in water to explode off remaining scale and finally acid cleaned and rinsed.

**Alkaline-detergent Cleaning.** Using alkaline solutions is an effective method for cleaning both ferrous and non-ferrous materials. Basically, this method may be done by simple dipping of a part into a vat and then rinsing (still-tank immersion), dipping combined with an electric current (electro-cleaning), spraying with hot vaporized solution (steam-gun cleaning), or cleaning with a special rotary machine or conveyor (washing-machine cleaning).

Choice of method and solution is very wide and is determined by the material to be cleaned and the amount and type of foreign material to be removed.

**Emulsion Cleaning.** In the cleaning method, a solution of grease solvent, emulsion agent, and coupling agent is applied to a part by direct immersion, spraying, or washing machine methods to remove paint, oil, grease, or carbon deposits. Since the solution is partially soluble in both oil and water, the part, after solvent emulsifying action, is then usually rinsed in water.

**Cleaning Capabilities**

Cleaning methods applicable to the common metals include the following:

Aluminum and Aluminum Alloys<sup>(1)</sup> Aluminum can be blast-cleaned using organic grits, barrel burnished, cleaned with inhibited alkalies, etched with strong alkalies, solvent-cleaned with both the emulsion-spray-type and soak-type emulsion cleaners, electrocleaned (usually cathodically), vapor-degreased, cleaned with combination phosphoric acid grease solvent cleaners, deoxidized with fluosilicic acid compounds at room temperature or sodium bisulfate compounds at around 180°F, anodized in sulfuric or chromic acid solutions, and electroplated if given a predeposit or zinc.

Brass, Bronze, Copper. Copper is seldom blast-cleaned but can be cleaned with organic grits. Brass and bronze are frequently blast-cleaned. Copper shot is not available for this use. Barrel burnishing is widely practiced on all three metals. All three can be cleaned with alkalies, though at times certain inhibited alkalies must be used. Electrocleaning is widely practiced, as are solvent cleaning, vapor degreasing, and emulsion and solvent degreasing. These metals are often plated with copper, nickel, and chrome.

Cast Iron, Steel, Tool Steel, Stainless Steel. All four metals are grit-blasted, barrel-burnished, soak-cleaned with alkalies, electrocleaned using both direct and reverse current, solvent- and emulsion-cleaned, and vapor-degreased. Flame cleaning is practiced on cast iron and steel. Polished stainless steel is seldom blast-cleaned, because pitting does away with stainless properties. If used to remove scale, sand blasting should be carried out with extreme care.

Lead. Lead is a soft metal and is seldom blast-cleaned. Lead die castings may be cleaned in a burnishing barrel. Specially inhibited alkaline cleaners and electrocleaners must be used. Lead is solvent- and emulsion-degreased and vapor-degreased.

Magnesium and Magnesium Alloys. Magnesium and magnesium-base die castings are becoming more important. Magnesium, though high on the electromotive series, behaves more like steel than like aluminum or zinc. Magnesium is not amphoteric and reacts with alkalies, forming an insoluble magnesium hydroxide coating which stops the chemical reaction at the metal surface. Dow Chemical Company has developed processes for plating on magnesium which will add to its commercial importance. Magnesium castings are blast-cleaned and magnesium generally is cleaned in alkaline soak cleaners, alkaline electrocleaners, solvent cleaners, emulsion cleaners, and vapor degreasers. Following the alkaline cleaning, a specific pickle is required to remove the insoluble surface coating

Tin and Babbitt. Tin and babbitt must be handled carefully. They can be barrel-cleaned under some conditions and alkali-cleaned with mild alkaline compounds. Solvent cleaning, vapor degreasing, and emulsion cleaning are widely practiced.

Zinc and Zinc-base Die Castings. Zinc-base die castings are widely used for automobile-hardware and plumbing fixtures and are handled much like copper and brass. Barrel cleaning and burnishing are rapidly becoming commercial processes for combined burring, polishing, and cleaning. Alkaline or emulsion-soak cleaning, both cathodic and anodic electro-cleaning, spray-washing-machine cleaning, solvent cleaning, and vapor degreasing are widely practiced in the industrial field on zinc-base die castings. Zinc base die castings are usually plated with copper, nickel, and chrome.

Zinc metal is cleaned by grit blasting, burnishing, inhibited alkaline cleaning, electro-cleaning, solvent and emulsion degreasing, and vapor degreasing.

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## CHAPTER 18

### SURFACE TREATMENT

Surface treatment in this section is distinguished from surface hardening, described in the heat treatment section, in that the surface is treated for reasons of changing or adding residual stresses as in shot peening, covering for corrosion resistance as in painting, plating and anodizing, or covering for wear resistance as in some electroplating.

#### SHOT PEENING

In the shot peening process, relatively hard particles, usually round chilled cast iron or steel shot, are thrown at high velocity against the surface of a part. As the shot strikes, the metal plastically deforms under this compressive force into an indentation. All of the indentations tend to expand and return the surface to its original shape; however, adjacent indentations and undeformed metal below the surface restrict its return thereby leaving the surface of the part with a residual compressive surface stress. These compressive stresses reduce surface tensile stresses imposed on the part during its operation or use and thus increase the mechanical properties of stress-corrosion cracking resistance, impact strength, and fatigue strength.

Although there are many other methods of prestressing which provide better end results, shot peening does have certain advantages in that it is economical, and is adaptable to many shapes and just about any material. A common and very effective way of greatly increasing metal strengths is by the combination of case hardening followed by shot peening.

#### ANODIZING

Anodizing is a process of forming a protective layer of aluminum oxide on aluminum parts. There are actually three categories that are classified as anodizing. There is ordinary anodizing, hard coat anodizing, and electrobrightening. The basic process for all three of these is the same. The coating of aluminum oxide is formed by reaction of the aluminum with electrolyte when the aluminum is made the anode. The reaction causes oxygen to be liberated at the aluminum surface and an oxide coating forms. The first formed oxide layer becomes the outer surface of the part. This first formed layer is thicker and more porous than the succeeding layers. The porosity and thickness of oxide layers decreases from the outer to the inner layer. Thus the barrier layer is very thin and non-porous. This is the layer that is significant in resisting corrosion and in displaying good dielectric properties.

Ordinary anodizing leaves a layer of 0.0001 inch to 0.0006 inch thickness. It follows the above described process. Hard coat anodizing follows the same procedure except the oxide layer is 0.001 inch to 0.005 inch thick or about 10 times thicker. Hard coat anodizing gives superior abrasion, erosion, and corrosion resistance but lowers the fatigue strength. Electrobrightening occurs when aluminum is made the anode in an electrolyte which dissolves the oxide film at about the same rate as it is formed. This process leaves a smooth, bright, mirror-like surface. Fluoboric acid is a very good electrolyte for this process.

The sequence of anodizing operations is shown in Figure 18.1. Electrobrightening is often used to remove surface contaminations prior to anodizing. This results in a very highly reflective anodized finish. After the oxide coating coating is formed, the part must be sealed by either hot water, wet steam, or dichromate sealer.

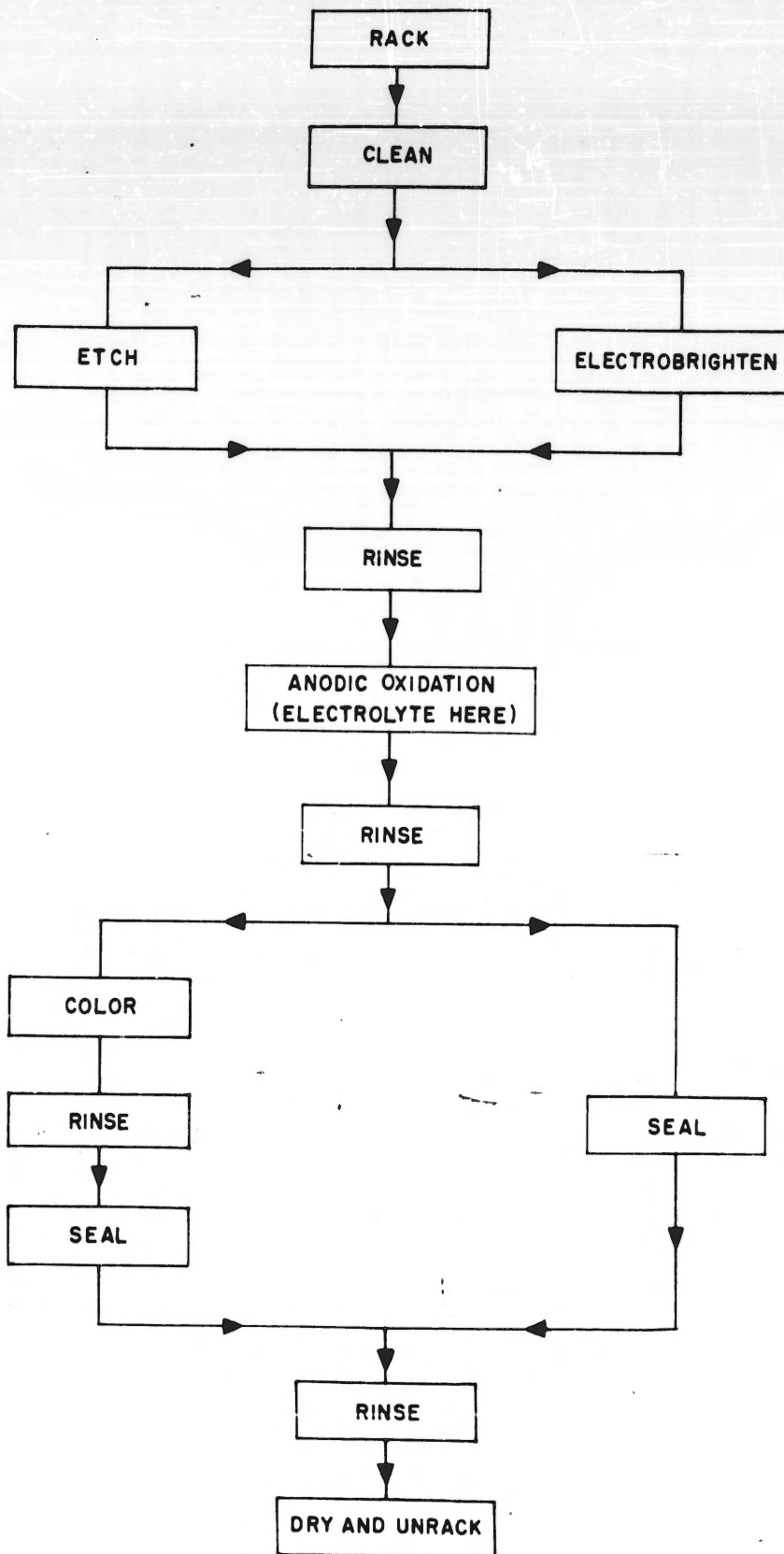


Figure 18.1 The Sequence of Anodizing

There are three common electrolytes used in the anodizing process. The names of these electrolytes are usually applied to the process itself as follows:

**Sulfuric Acid Process** - The film in this process is colorless and transparent. This is the best process for dyeing. This is the cheapest and oldest anodizing process. It requires higher voltages but leaves a hard finish.

**Chromic Acid Process** - The film in this process is opaque and ranges in color from light gray on pure aluminum to dark purple on high silica alloys. The coating from this process is thin and has fewer pores with larger diameters. The color shades attained from this process are duller than those from the sulfuric process. The chromic acid gives high corrosion and salt water resistance and low abrasion resistance. This process is not good for aluminum with over 7% total alloying elements. It is the process that is used most frequently for aircraft parts.

**Oxalic Acid Process** - The film in this process is semi-transparent and ranges in color from silver gray to bronze. The oxalic acid process is an expensive one, much more so than either of the others. Blue colors cannot be produced by this process. The oxalic acid process gives a very smooth finish with high abrasion resistance.

The hard coat anodizing process is the process that is of particular interest to the aircraft industry since parts which formerly were produced by heavier metals with inherent hardness can now be produced with a light metal and still have a hard, wear-resistant surface. Some of the parts which are now being successfully produced using hard coat anodizing are gears, pinions, bearing races, gun blast tubes, slides, pistons, cams, cylinders, and helicopter blade edges.

The electrobrightening process is of importance also since it is often used to remove burrs and sharp edges. Oftentimes it is more economical to remove burrs by this method rather than by mechanical means.

The properties of anodized aluminum depend largely on the thickness and porosity of the oxide coating. Porosity is the most important factor. Hardness and abrasion resistance both vary directly with porosity; that is, the smaller the holes, the higher the hardness and the greater the resistance. Lowering the temperature of the electrolyte decreases the porosity. Also operating at a higher current density decreases the porosity.

## PLATING

The subject of plating or metal coating can actually be subdivided into impregnating, dipping, and electroplating. Certain materials are adaptable to one or more of these processes. Each will be discussed along with the applicable design materials.

### Plating Processes

**Impregnation.** The materials which can be impregnated successfully for use in aircraft design are aluminum, chromium, and silicon. Aluminum impregnation is known as "calorizing." This consists of alloying the surface of a carbon or alloy steel, by diffusion, to a depth of 0.005 inch to 0.040 inch. After calorizing the surface usually contains about 25% aluminum. This ensures good heat and corrosion resistance. Calorizing is an especially good process for high-temperature bolts and other small parts. These parts will remain serviceable for extended periods of time at temperatures up to 1400°F.

Chromium impregnation is known as "chromizing." Chromizing consists of packing the metal to be treated in powdered alumina and chromium and heating in a protective atmosphere. This process is usually used on low carbon steel. Depending on the time and temperature of heating, the surface will usually contain 10% to 20% chromium. This is

effective in protecting turbine blades against corrosion and erosion. It is also good for any steel parts which must resist atmospheric corrosion.

Silicon impregnation is known as "siliconizing." Siliconizing is accomplished by subjecting the metal to silicon carbide and chlorine at temperatures from 1700°F to 1850°F. The process is usually used on cast or wrought, low-carbon steel. White and malleable iron can also be treated this way, but because of the higher sulfur content, the results are less satisfactory. Because siliconizing gives good wear, heat, and corrosion resistance, it is often used for rocker arms, cylinder liners, and valve parts.

Dipping. Hot dipping an aluminum coating on a part is known as "aluminizing." This is usually applied to mild steel, copper steel, and low alloy, high-strength steel. Usually the coating is about 0.001 inch per side. Aluminizing is good for extended time temperatures to 900°F and can stand short time temperatures up to 1750°F. It exhibits good heat and corrosion resistance. It is used in the aircraft industry for firewalls and other accessories.

Electroplating. The fundamental principle of electroplating or electrodeposition is the passage of an electric current from an anode (usually made of the plating material) to the workpiece, through an electrolyte containing salts of the plating metal in solution. The rate of deposition of the plate varies directly with the current density.

Chrome plating is the most common form of electroplating. Chrome plate can be applied to a part for several reasons -

- (1) it improves appearance.
- (2) it protects against corrosion.
- (3) it reduces friction.
- (4) it provides a wear resistant surface.
- (5) it increases dimensions.

However, chrome plating also has some serious disadvantages. The most important disadvantage of chrome plating is the fact that it lowers the endurance limit of the steel being plated. Although the exact reason for this is not known, it is believed to be a combination of the following:

- (1) fine cracks in the plated coating.
- (2) internal residual stresses in the plating.
- (3) hydrogen embrittlement of the steel.

Also chrome plating is extremely inefficient. Only 15% of the current is useful in depositing chromium. The other 85% of the current deposits hydrogen at the cathode. This contributes greatly to the hydrogen embrittlement.

There are two ways of counteracting the effects of lowering the endurance limit. Baking at high temperatures (over 600°F) raises the endurance limit of chrome plated steel. The same effect can be accomplished by undercoating the chrome plate with copper at high current density.

Nickel plate has the advantage of leaving a heavy deposit and plating quickly. The nickel plate lowers the endurance limit from 25% to 45%. Thus it is usually never used by itself except when the endurance limit is of no consequence in the part. Tin undercoating reduces the decrease in endurance limit and is often used under nickel plate.

Cadmium plating offers a surface that is free from porosity and internal residual stress. Heavier coats must be applied before the specimen exhibits good corrosion resistance. Cadmium plate offers no real protective coating on iron since cadmium falls below iron in the electromotive series. It also causes embrittlement of steel and specimens must be baked for

four hours before they are acceptable. Cadmium plating is expensive but it offers the desirable characteristics of soft coating, alkali resistance, good conductivity, and ease of soldering.

Zinc plating offers a soft surface that is free from porosity and has no internal residual stress. It causes embrittlement when being applied but this can be relieved by baking for three hours at temperatures over 400°F. Zinc plate is simply to apply, has economical initial cost and application, is decorative, and has good corrosion resistance.

### Plating Design Considerations

Finish. Four types of finish are available in plating; namely, lustrous, partially lustrous, nonlustrous, and colored.

Base Material. The surface of the metal to be plated must be smooth. Some care must be given to the base material. Steel stampings should be cold-rolled steel rather than hot-rolled if they are to be plated since cold-rolled offers much better surface characteristics. Zinc-base die castings are easily plated but other types of castings like sand castings require conditioning before plating.

Flexing. Hard and brittle plating materials will chip or crack in service. Chromium is brittle, nickel has some flexibility, cadmium, zinc, tin, and copper are ductile. Cadmium plating has the least tendency toward brittleness. All hardened steel parts should be baked to relieve embrittlement.

Sharp Edges and Recesses. The plating metal follows the distribution of the current. Points, edges, and protrusions are concentration points for the current and thus receive excessive metal coatings. To counteract this, large radii and fillets should be incorporated into the design.

Holes and Cavities. Holes and cavities do not receive an equal metal deposit since the current is less. Also they tend to gather cleaning and finishing compounds which are difficult to remove before plating.

Flat and Concave Surfaces. Large flat and concave surfaces should be avoided since they are difficult to plate to the required thickness.

Welding, Soldering and Brazing. Whenever possible, surfaces that are going to be welded, soldered, or brazed should not be plated. However, cadmium and zinc plate will solder with cadmium being the easier. Zinc plate can also be welded. Although cadmium plate takes a weld, it emits a deadly poisonous gas while being welded and therefore should never be welded.

Allowance for Plating. Plating builds up the material thickness and must be taken into account on close fitting assemblies and threaded parts.

Polishing. Parts requiring a high finish must be polished and buffed. Since the polishing and buffing equipment is usually automatic, it is difficult to do on complex and odd-shaped parts. Thus, shape should be considered in the design of the part.

### PAINTING

A paint is generally described as a mechanical mixture of finely divided solid pigment in a suitable liquid vehicle. There are paints that will fit almost any specification required and painting is usually the cheapest surface finishing process available. Several of the modern paints and their application are discussed below.

## Primers

It is true that if a good water-resistant stove enamel is used it will adhere well to properly degreased metal and the protection obtained will be satisfactory. However, few stove enamels are impervious to moisture and this is the gap that anti-corrosive primers fill.

The solubility in water of certain pigments such as zinc chromate provides cathodic protection, and although research on corrosion-inhibiting pigments is always being carried out, zinc chromate is the most widely used in conventional primers, with the exception of red lead.

Etching primers, which afford a high degree of corrosion inhibition, are finding an increased use in industry. They are based on special types of vinyl resin pigmented with zinc-tetroxy chromate and usually need to be mixed with an acidic component. Although this is referred to generally as a catalyst, it is not strictly correct in view of the definition of a catalyst as a substance that promotes chemical change without being chemically concerned itself in the change. There is a speedy reaction between the acid component and the base primer, and because of this the mixture should be used within a certain period otherwise gelation takes place. The main characteristics of etching primers are -

- (1) they will adhere to a large number of surfaces, including galvanized iron, brass, cadmium and other plated surfaces, as well as peculiar surfaces like plastics.
- (2) rapid speed of drying which will allow overcoating in 30 minutes at ordinary temperatures or much less at elevated temperatures.
- (3) good corrosion resistance.
- (4) their virtual replacement of metal pretreatment as an independent operation.

The primer is available in a ready-for-use state which is essentially the same as the two-solution type, but on particularly difficult surfaces the two-solution version is preferable. Also, if low-temperature air drying is used, the water sensitivity of the applied film is less. Etch primers have a much higher sensitivity to moisture than usual and metal should not be left in the primer for an undue length of time. If there is a risk of outside condensation, as in shipyards and certain aircraft factories then careful consideration should be given to their use.

Another comparatively new type of primer is the zinc-rich primer which provides an anodic coating giving cathodic protection to steel. These primers are almost half-way between galvanizing and painting, having a metallic zinc content well over 90%.

## Fillers

The same remarks do not apply to fillers, as they are in contact with the organic coating on top and separated from the inorganic metallic surface by primer. This type of paint should not be judged solely upon the thickness of deposit obtained, but on the laminated film. A very thick film can be due to the filler being heavily loaded with pigments, and this film will be very absorbent; succeeding coats of undercoat and finish will sink in and the final product will look as if it needs an extra coat of paint. If insufficient pigment is present the filler will not sand properly nor have the requisite film properties, and succeeding coats will not, or should not, sink in.

The aim of the paint manufacturer is to strike a "happy medium" and some success has been achieved recently. High-sheen primer fillers are available based on specially selected synthetic resins and inert, inorganic pigment dispersed in such a manner as to reduce to a minimum the porosity of the film.

## Finishes

In the field of finishes the position is very different due to advances with both synthetic resins and solvents. The most outstanding development under the heading "synthetic" is the epoxy, "Epikote," or epichlorhydrin diphenylpropane condensation derivative.

Epoxy resins are expensive, approaching double the price of conventional finishes, but the degree of environmental resistance shown is much higher than was possible with orthodox phenol melamine urea, and thus epoxy finishes are of interest to manufacturers of articles which come into contact with chemicals. A number of different types of epoxy paints is available, such as, air-drying when catalyzed, low-bake and medium-high bake types. If maximum resistance is required, the most expensive type epoxy resin must be used, the curing temperature being 350°F to 360°F for 45 minutes. If a lower resistance is satisfactory, cheaper epoxy resins may be used; these are stoved for 30 minutes at 250°F to 260°F. If stoving cannot be carried out, the cold-catalyzed type will give a very tough and resistant finish. The catalyst is not acidic and again the term is wrongly used because the resinous catalyst does combine with the other resins to form complex polymers. An air-drying non-catalyzed type epoxy finish is also available. As a result of accelerated weathering tests it is thought that a high degree of durability should be obtained with these resins.

An exceptional property of epoxide resins is their ability to adhere to metal and to give a high degree of protection without the necessity of using a primer. The electrical resistance of an epoxy film is also high and this probably has a bearing on its adhesion characteristics, especially as adhesion forces at interfaces can be considered to be electrical in character.

Silicones are used in engineering for special-type lubricants and mould release agents, and these properties can be attributed to the surface tension effect displayed by silicones. Mere traces of silicone fluid have profound effects on adjacent surfaces, a typical example being their use as anti-foaming agents. In processes where oils are reacted at elevated temperatures frothing is inevitable, and in the past this has seriously hampered production. By the use of as little as one part per million (less than 5 cc. of silicone per 1,000 gallons) frothing is prevented. The potency of silicones needs careful control if trouble is to be avoided in the paint shop. For example, if traces of silicone are present on a surface to be painted, a pocked finish is obtained. It is virtually impossible to remove this effect without stripping and removing the surface contamination.

Styrenated alkyds also offer excellent drying characteristics, and although they do not have quite the same high order to durability as alkyd enamels, they are widely used. The incorporation of styrene into the alkyd means a combination of drying methods, the oxidation and polymerization of the alkyd being supplemented by the evaporation drying of the styrene. For this reason the dried film is more readily attacked by solvents than a straight alkyd enamel and care needs to be exercised in the choice of succeeding coats.

## Special Paints

Metallic stopper is a paste-like product used directly on metal to fill up any depressions in the surface. The stopper has a synthetic resin base and is extremely rapid drying. When set, the stopper may be smoothed off flush with the metal surface. It is difficult to detect any difference in hardness between the stopper and the base metal and, in general, the patching may be regarded as permanent. This type of stopper is used extensively in the repair of automobile bodies.

In contrast, strippable coatings are removed easily from a surface; they are used for the protection of metal surfaces either during storage, or from damage during processing, for example, during pressing.

There is a process for the production of printed circuits which consists of reproducing the diagram of the circuit on an orthodox silk screen. This is carried out either by cut stencils or by the photo-stencil technique and a special screening resist is used for printing on to plastic-copper foil laminate. When dry the unwanted copper foil is etched away by an acid-bath immersion and the printed circuit is left in copper laminated to a plastic base.

### Paint Application

Brushing. The object of all methods of application is to spread a thin, even film of liquid over a solid surface. Brush application is usually only used industrially in cases where no alternative method may be used. This is not because brushing produced unsatisfactory results but because it is costly and slow. In some fields it is still used although spray equipment could be used. For example, coach painting and ship painting, the reason being that brush application is very efficient in working paints into a surface.

Attempts have been made to utilize this characteristic in mechanical brushing where the shape of articles to be painted is suitable. Attempts to speed up the brushing process have been made by the invention of a special paint which is fed through the stock of the brush to the bristles, thus eliminating the time wasted in dipping the bristles into the paint.

Flow Coating. Flow-coating consists essentially of conducting paint through a system of pipes in order to deliver it at strategic points where it will flow by gravity and coat the entire article. Flow coating is a useful method of painting very large articles which require painting on all surfaces and which cannot, by their size, be painted by dipping. Paints for flow coatings must have the property of wetting metal surfaces readily, coupled with a high degree of stability or freedom from change of viscosity.

Dipping. The requirements of paints for application by dipping, possibly the cheapest method of all for paint application, are similar. The process is so well known as to call for very little comment, but there are three distinct types of dipping: (1) control dipping at slow rate of extraction, (2) conveyORIZED dipping, mainly used on large industrial plants for coating large or heavy components; and (3) plunge dipping where the articles to be painted are thrust manually into the paint and hung on a conveyor or drip rack. The rheological requirements of the types of paint for ideal performance differ considerably, but it is frequently possible to use the same paint for methods 2 and 3.

Spray Painting. Spray painting is the most widely used industrial method. A recent development, the hot-spray process, utilizes the fact that paints decrease in viscosity at elevated temperature and heat is used as an alternative to thinness to facilitate the spraying of relatively viscous paints. More paint may be applied per pass of the gun than is possible by conventional cold spray methods, and where a number of coats is normally applied, considerable saving of time and consequently labor costs may be effected by its use.

The most recent development in spray painting is the airless spray method in which the paint to be applied is heated, as with the orthodox hot-spray process, and is then forced at a pressure of some 600 psi at the elevated temperature to the gun where the operator upon pressure of the trigger control releases the paint through a small fixed nozzle. The speedy release of the high pressure at the point of efflux causes a complete breakdown of the liquid state, literally exploding into the atmosphere and thus achieving the same degree of atomization as has hitherto been achieved only by the use of large quantities of air. This results in more control over the passage of the atomized paint to the job with very little spray dust and over-spray. The saving in paint is considerable, but specially formulated paints are necessary for use with this equipment.

It is not claimed that airless spray will displace the conventional air spray, and indeed for many users the initial cost of the plant will preclude its consideration, but it may well be that this method of applying paint will prove to be a major advance in paint application.

The same remarks may apply to steam spraying, in which steam replaces air as the atomizing medium and by which, it is claimed, that due to steam contracting upon cooling, spray dust is virtually eliminated and the spray particles are directed to the object to be sprayed and form on the surface rather than bouncing off it.

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## CHAPTER 19

### NON-DESTRUCTIVE TESTING

This chapter is intended to describe briefly the various methods of non-destructive testing, areas in which each is applicable, and the capabilities of each in order that the designer may better understand what types of testing and inspection are available and used in industry today.

The following paragraphs will briefly describe the various inspection and testing methods by type, and a table at the end of this section (Table 19.4), will give a compact outline of testing methods according to the characteristic or property being inspected along with general information about applications, limitations, and advantages.

#### RADIOGRAPHIC INSPECTION

Radiography makes use of X and gamma radiation projected through an object under inspection onto a film in order to form an image of the internal structure of the object. The X-ray method is basically shown in Figure 19.1.

Because of the omnidirectional characteristics of gamma radiation, many types of peripheral inspection may be employed as shown in the typical setups in Figures 19.2 and 19.3.

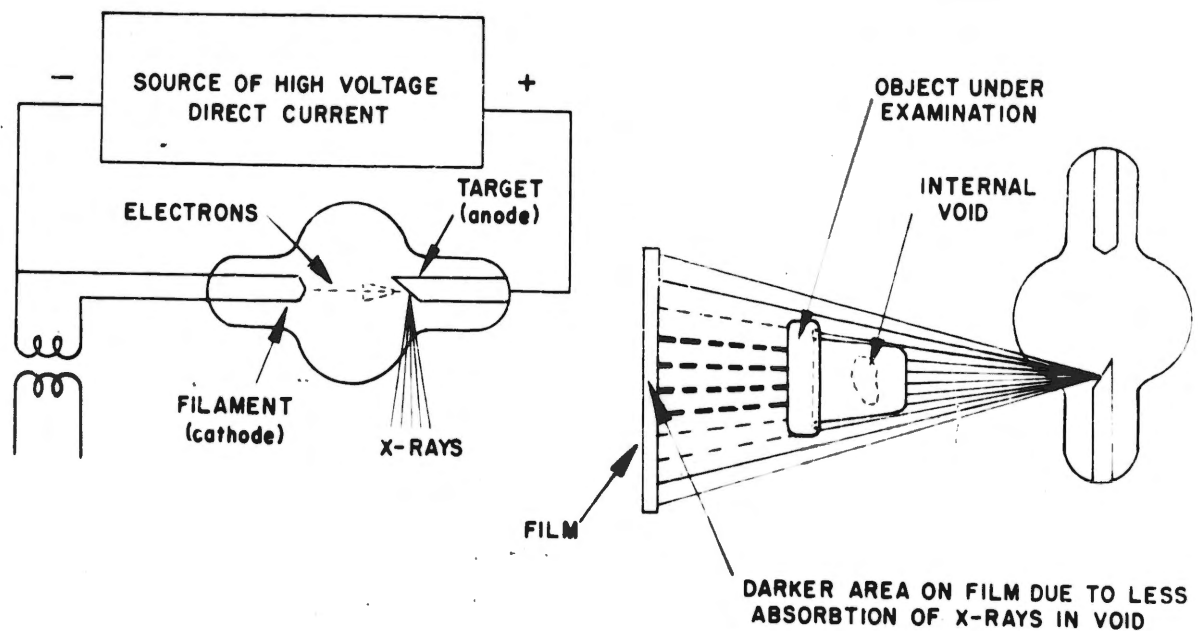


Figure 19.1 Typical X-Ray Inspection Operation

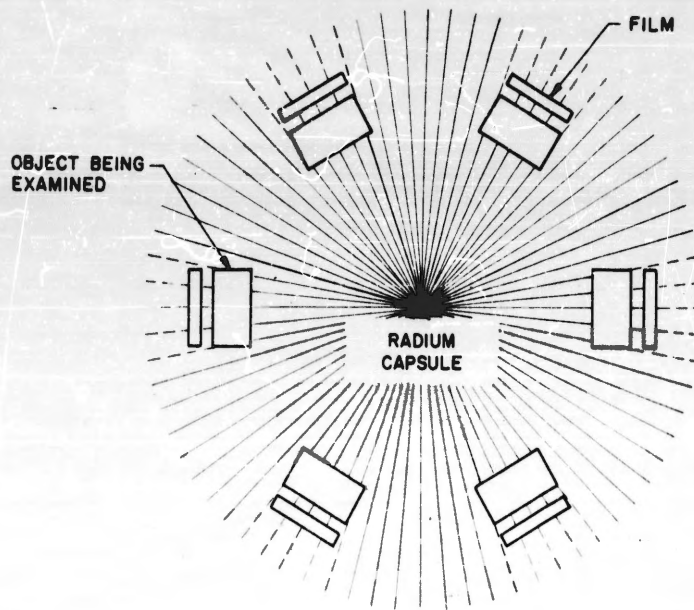


Figure 19.2 Typical Gamma Radiation Inspection Operation

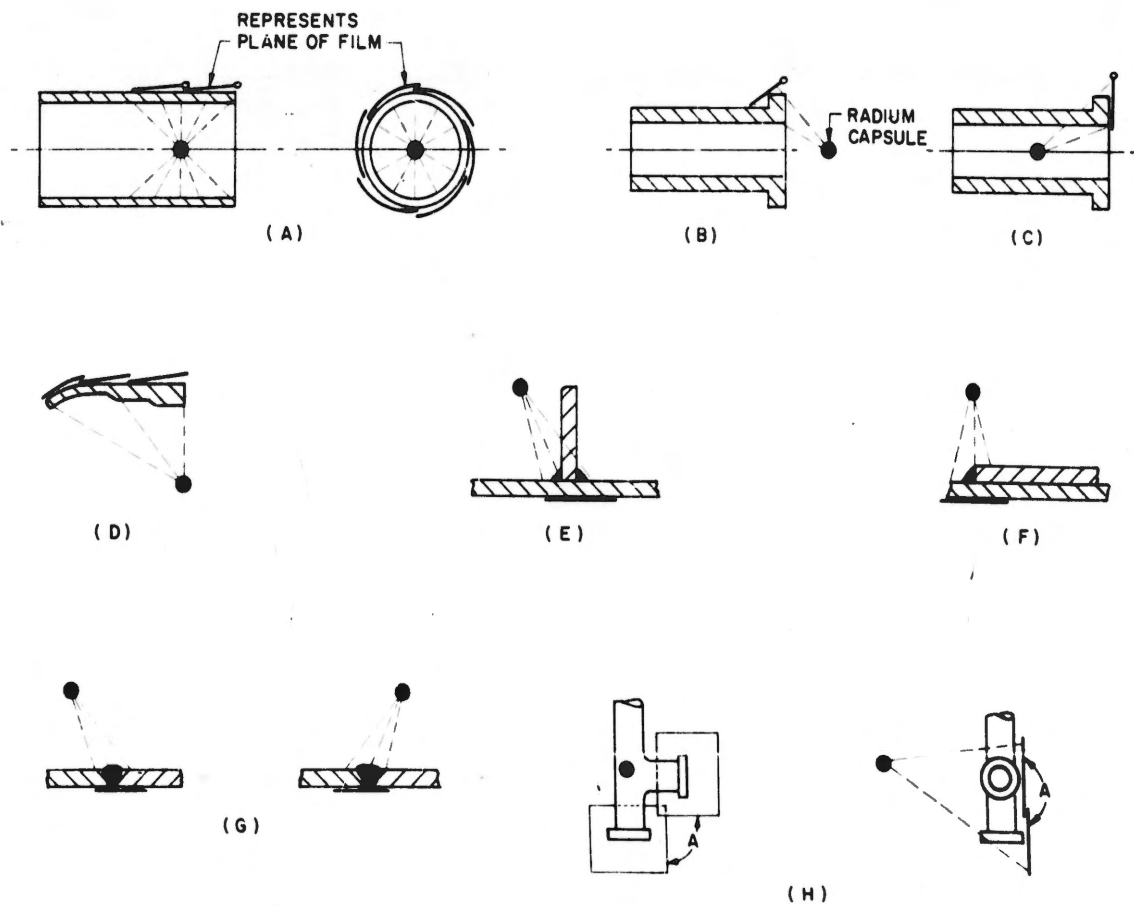


Figure 19.3 Miscellaneous Gamma Radiation Inspection Operations

Particular advantages of radiography include the following:

- (1) high inspection sensitivity.
- (2) geometric accuracy of projected image.
- (3) production of permanent record.
- (4) reliability of image interpretation.

Efficient use of X-radiation is limited to about a 12-inch penetration of steel, while gamma radiation has been used for inspecting 16 inches of steel. Radiographic inspection of foundry products will detect such flaws as shrink, hot tears, porosity, lack of fusion around chaplets, cold shuts, inclusions of sand and slag, coarse dendritic structure, and cracks. Flaws detected in welded products are gas porosity, trapped slag and flux, lack of fusion or incomplete penetration, undercutting, and cracks. An excellent additional application of radiography is for the inspection of internal and hidden parts of a complex product which might be damaged by disassembly for inspection.

An approximate standard minimum detection sensitivity available is 2%. That is, if a one inch thick plate of steel is radiographed, a change in the cross section of 0.02 inch can be detected on film. Limitations on the fineness of detail (resolution) are hard to list since they are functions of film grain size, ray source size, secondary radiation, ray wavelength, etc.

### FLUOROSCOPY

Fluoroscopy is basically similar to X-ray radiography except that it is lower powered and projects its nonpermanent image on a fluorescent screen. It does have certain advantages of a directly visible image, ability to inspect an object in motion, rapidity of inspection, and low cost. Its chief limitations include restriction of use to low absorption materials, lower sensitivity than radiography, non-permanent record, extra protection requirements from radiation, and inspection of considerably thinner sections than radiography. Practical thickness limits are as follows:

Magnesium	2.50 inches
Aluminum	2.00 inches
Steel	0.15 inch
Copper	0.12 inch
Zinc	0.11 inch

Sensitivity is limited to approximately 5% or 6%. In addition, an individual's eyesight characteristics will effect proper interpretation of the projected image.

The most common applications of fluoroscopy are for examining light alloy castings for porosity, shrink, misrun, inclusions, and location of hidden core wires; and for examining intricate assemblies such as electron tubes, small electric motors, and ammunition fuses housed in metal cases.

### MAGNETIC-PARTICLE INSPECTION

This method of inspection is commonly called "Magnaflux." It is used for inspection of flaws on or near the surface of ferromagnetic objects. This type of inspection method is used to locate fatigue cracks on parts already in service and small discontinuities that will create fatigue failures when put into service.

The process is a two step operation involving first, magnetization of the part and second, application of magnetic particles, either dry or suspended in solution. If a defect is present, there is a break in the lines of force, and the powder causes a visible indication of the size and location of the defect.

Both the kind of current and the type of powder used can be varied. Experience has shown that for surface defects, any type of current can be used and either type powder, although the wet powder has some advantages for smaller cracks. However, for subsurface defects, dry powder is much better and half wave direct current is much more sensitive.

This method can be used for detecting such surface flaws as seams, bursts, cracks, tears, and laps and such subsurface defects as nonmetallic inclusions and stringers, shrinks, and gas or slag inclusions.

Usually the parts must be demagnetized after inspection. This can be done by means of commercial demagnetizers or by subjecting the part to an alternating current field.

#### FLUORESCENT MAGNETIC-PARTICLE INSPECTION

This process is often called "Magnaglo." It uses the same equipment as the "Magnaflux" process except, instead of regular magnetic powder, this process uses fluorescent magnetic powder. This part is then viewed under an ultraviolet light and any defect becomes visible.

Some of the advantages of this process are as follows:

- (1) defect indications easily seen on rough surfaces.
- (2) absence of high lights on work surfaces.
- (3) increased sensitivity, especially to subsurface defects.
- (4) ease in detecting defects on obscure surfaces such as screw threads or spring coils.

#### FLUORESCENT PENETRANT-OIL INSPECTION

This method is commonly called "Zyglo." In this process the part is either dipped or sprayed to attain a coating of penetrant oil. The oil is then washed off by a spray of water. Since the water has a high surface tension, it does not remove the oil from the defects. After the part is dried, a developing powder is applied to the surface. This powder draws the oil out of the defect and it shows up clearly under ultraviolet light. The advantages of this method are high sensitivity and a clear indication of the defect.

#### THICKNESS GAGING

Thickness gaging is subdivided into two main categories--tube thickness gaging and film thickness gaging.

##### Tube Thickness Gaging

In tube thickness gaging, instruments which operate on both radiographic and electronic principles are available for measuring wall thickness of pipe, tubing, cylinders, pressure vessels, and flat plate.

The radiographic equipment utilizes gamma rays, some of which may pass completely through the metal and others which are scattered and emerge on the same side through which they entered. These gamma rays are picked up, amplified, and transmitted to a measuring circuit. By proper calibration against standard specimens of known thickness, the indicated readings are converted to actual wall thickness of the piece being measured.

Electronic tube inspection is used for detecting and recording such internal defects as pitting from erosion or corrosion, pinholes, cracks, and differences in compositions of nonmetallic materials. Defects appear on the record as peaks or jags which depart from the standard pattern. Thicknesses up to one foot can be measured by this process.

### Film Thickness Gaging

Gages operating on electrical principles are available for measuring the thickness of magnetic and nonmagnetic base materials without removing or damaging the coating.

One magnetic type measures the following:

- (1) nickel coating to 0.001 inch thick on a nonmagnetic base.
- (2) nickel coating to 0.002 inch thick on a ferrous base.
- (3) nonmagnetic coating to 0.080 inch thick on a ferrous base.

Another type is primarily for measuring thickness of nonmagnetic coatings on ferrous metals and it offers ranges of the following:

- (1) 0.00005 to 0.01 inch for measuring plating on small areas or in restricted spaces.
- (2) 0.001 to 0.10 inch for measuring thickness on porcelain, enamel, paints, and heavy plating.

### SONIC INSPECTION

This method involves dealing with sound waves up to frequencies of 16,000 cps. The operator uses a stethoscope and taps the specimen or part with a hammer at various intervals. The blow by the hammer sets up both a natural and a forced vibration. The sounds will be similar in good sections of the metal but a high pitched, reedy sound will occur if a defect is present. The disadvantages to this method of testing are that the defect is not located and that the findings depend largely on the operator's skill.

### ULTRASONIC INSPECTION

Ultrasonic testing involves sound wave frequencies from 17,000 cps to 11,000,000 cps. The three commonly used ultrasonic testing techniques are pulse echo, resonance, and transmission (see Table 19.1).

Table 19.1 Ultrasonic Testing

Method	Commercial Machines	Application	Testing Distance	Type Of Waves
Reflection	Ultrasonic Reflectoscope	Cracks, inclusions, segregations, bursts, porosity, shrinks, flaking, laminations.	Normal max 30 feet (in steel & aluminum) thickness 1/4 inch to 30 feet.	Longitudinal waves at normal incidence
Angle Beam		Transverse discontinuities in sheet, cracks in pipe tubing, and welds.	Normal max 15 feet (in steel & aluminum)	Transverse or longitudinal waves with incidence at angle.
Surface Beam		Inspection of smooth surfaces and sub-surfaces for discontinuities	Depth to 1 to 2 times length of wavelength	Rayleigh waves
Resonance	Sonigage Sonizon Metrogage Reflectrogage	Laminar discontinuities in sheet and plate	Depth to 1/2 wavelength	

The pulse echo technique involves a pulsed ultrasonic beam sent into the specimen. This beam reflects from the opposite side of the specimen as well as from any defect or discontinuity. Defects are located by different times of arrival of the returning echo.

The resonance test employs a mechanically driven tuning condenser to sweep the frequency of an electric oscillator through its tuning range. The oscillator in turn drives the transducer. There are momentary increases in the energy drawn by the transducer when the frequency of the oscillator coincides with a thickness resonant frequency of the specimen. A cathode ray tube or a meter can be used in measuring the energy increase. If the thickness is relatively constant, a change in the resonant frequency indicates a defect.

In the transmission method, there is a separate sending and receiving transducer. If a defect lies in the path of the beam, energy will be removed by scattering of the beam, and the signal received at the receiving transducer will be of decreased magnitude.

Aside from the ultrasonic waves already mentioned (shear and longitudinal), there are also surface or Rayleigh waves and Lamb waves. Surface waves will travel along the length of the part and detect surface and subsurface defects. Lamb waves are vibrational waves that can be classed as symmetrical or asymmetrical. The important feature about Lamb waves, which differentiates them from other types of waves, is the fact that their velocity is dependent upon their frequency and also upon the thickness and the material of the specimen. Thus by placing the transducer in the proper place, it can be ascertained if the part is vibrating properly and thus if a defect is present.

#### FORCED-VIBRATION INSPECTION

In addition to sonic equipment, there is a class of forced vibration equipment which measures and records the frequency and amplitude of mechanical vibrations. The parts that are being inspected are compared to a standard part. For each standard part there is a standard curve on the oscilloscope. When a part has a defect in it, the curve it produces will differ from the standard curve. Table 19.2 shows a comparison of some of the commercial equipment available for this type of test.

#### STRAIN ANALYSIS

When a part is designed for strength, the shape does not always lend itself readily to calculations. In a case like this, the problem can be approached by determining the state of stress experimentally. This is usually done by measuring the strain and then converting to stress by means of existing stress-strain relationships. The strain analysis can be performed in several different ways.

##### Electrical Strain Gages

Electrical strain gages almost always relate a change in resistance to the strain. There are three types of electrical resistance strain gages. Each of these will be discussed separately.

The variable potentiometer resistance gage is used where there is a large relative motion between two points. This gage uses a slide wire potentiometer for measurement of displacement. This is a very good device for measuring dynamic displacements or deflections.

INSTRUMENT	FUNCTION	RANGE	USUAL TYPE	OPERATING CHARACTERISTICS
SONIC ANALYZERS AND RECORDERS	DETECT AND RECORD DIFFERENCES IN DENSITY THROUGHOUT A SECTION OF MATERIAL, AS TO LOCATION AND AMPLITUDE.	50-12,000 KC/SEC.	STATIONARY MACHINE COMPRISING GENERATOR, SIGNAL SENDING AND RECEIVING PROVISION, AMPLIFIERS, INDICATORS, AND RECORDERS.	SIGNALS BY NONUNIFORMITIES IN MATERIAL BY CONVERTING OUTGOING ELECTRICAL SIGNALS INTO MECHANICAL SONIC ENERGY AND MECHANICAL SONIC ENERGY BACK INTO ELECTRICAL SIGNALS.
INDICATING VIBRATION METERS	INDICATE FREQUENCY OF EACH SEPARATE VIBRATION IN A COMPLEX VIBRATION.	500-20,000 CPM.	PORTABLE HAND INSTRUMENT.	FUNCTIONS MECHANICALLY. REQUIRES NO EXTERNAL CONNECTIONS OR AUXILIARY EQUIPMENT.
DIAL GAGE VIBRATION METERS	MEASURES VIBRATION AMPLITUDES.	UP TO 7200 CPM.	PORTABLE HAND INSTRUMENT.	FUNCTIONS MECHANICALLY. REQUIRES NO EXTERNAL POWER SOURCE OR AUXILIARY EQUIPMENT.
VIBRATION RECORDERS	PROVIDE PERMANENT GRAPHIC RECORD OF VIBRATION WAVE FORM, INDEXED FOR FREQUENCY AND AMPLITUDE.	600-15,000 CPM.	PORTABLE HAND INSTRUMENT.	FUNCTIONS MECHANICALLY. REQUIRES NO EXTERNAL CONNECTIONS.
DYNAMIC BALANCING UNITS	MEASURE AMPLITUDE AND PHASE ANGLE OF UNBALANCE FORCES IN HEAVY ROTATING MACHINERY.	600-10,000 RPM.	PORTABLE INSTRUMENT CONSISTING OF THREE UNITS, GENERATOR, PICKUP, AND WATTMETER.	FUNCTIONS ELECTRICALLY. REQUIRES NO EXTERNAL POWER SOURCE OR AUXILIARY INSTRUMENTS.

Table 19.2 Forced Vibration Inspection Equipment

Nonmetallic resistance gages are subdivided into two classes, unbonded and bonded. Unbonded nonmetallic gages are mechanically actuated and contain a resistance element arranged so that when one part of the gage is displaced with respect to the other, a change in pressure is developed on the measuring instrument. Bonded nonmetallic gages have the resistance element bonded directly to the material. The strain in the material changes pressure on the element bonded to it and thus couples the displacement to the change in resistance. Nonmetallic resistance gages are rapidly being replaced by metallic ones.

Metallic resistance gages are also subdivided into bonded and unbonded. Similar to the nonmetallic resistance gages, the unbonded gage has a measuring element, a metallic wire whose resistance is controlled by the motion of the mechanical parts of the gage. The bonded gage has the element bonded directly to the material in which the strain is to be measured. The metallic resistance gage can be used extensively in measuring dynamic strain in aircraft parts.

### Mechanical Strain Gages

There are several types of mechanical strain gages. All involve either a scratching of the material or a lever and dial combination. The application of mechanical strain gages is in measuring strain on large structures with static or low rate dynamic loads. Mechanical strain gages are very sensitive to shock and vibration and are incapable of really good dynamic measurements.

### Acoustical Strain Gages

This type of gage operates on the principle that a change in tension in a wire changes its vibration frequency. Thus the part to be tested is fitted with a wire and both this wire and a standard wire are plucked. The tone difference between the standard wire and the measuring wire gives a measure of the strain. The main advantages of this type of gage are extremely high sensitivity and its ability to be remotely controlled. This is a rugged gage and lends itself well to use in the field. The disadvantages of this gage are that it is only good for static measurements, it is difficult to attach, and its measuring plane is a considerable distance above the strained surface.

### Optical Gages and Photogrids

Optical strain gages are used when extremely high sensitivity is required. These gages are very sensitive to shock and vibration and thus are limited for field applications. There are two general types of optical gages, one employing a mechanical lever and the other using an interferometer principle. Both have extremely lightweight parts and thus have a fairly high natural frequency with low iner .

Another method of determining distortion of a part under stress involves the use of photogrids. A photosensitive film is applied to the surface of a part and a grid is developed on the surface. As the part is stressed under load and the surface deformed, the grids visually show the deformation, which then can be determined with various optical and mechanical instruments.

### Photoelasticity

Photoelasticity is an experimental method of stress analysis which involves passing a field of polarized light through a transparent plastic model. The purpose and thus main advantage of photoelasticity is its ability to study internal stress concentrations. Photoelasticity points the way toward design changes for stress relief. It has been used successfully in the aircraft industry for stress analysis in parts like wing ribs and others.

### Brittle Coatings

A specially prepared coating can be applied to a part which, when the part is strained, will become distorted and eventually fracture. By observing the stress pattern in the coating, one can determine the areas of highest stress and the directions of these stresses. This is often called "stress-coating".

### HARDNESS TESTING

Hardness is defined as the resistance of one substance to penetration by another substance. There are many commercial methods of determining hardness and each of them finds its use adaptable to certain industries and certain materials. Table 19.3 lists the hardness tests and gives some of their characteristics.

### COMPOSITION TESTING

Inspection testing is used as a rapid means of identifying a metal without resorting to chemical analysis. Rather than determining the chemical composition of the metal, inspection testing compares a selected property of the unknown metal with the same property of a known metal. There are four basic types of inspection tests discussed below.

A magnetic test compares the magnetic property of a known metal with that of an unknown metal. A permanent magnet is used to differentiate between magnetic and nonmagnetic metals. If both metals are magnetic, special equipment must be used.

Spark testing involves holding a piece of metal against a fine grinding wheel and observing the nature of the sparks produced. Various grades of steel give characteristic spark patterns which serve as a means of identification.

Thermoelectric testing involves a check on the electromotive force set up when two dissimilar metals in contact with one another are heated. If the two metals in contact are identical, the electromotive force is zero. The greater the dissimilarity of the metals, the larger is the electromotive force.

Chemical spot tests can be used to indicate the presence or absence of an element in a metal. These tests generally consist of applying a few drops of chemical reagent to the metal and watching for some characteristic result.

### SURFACE TESTING

#### Comparison Blocks

There are a standard set of blocks having surface roughness values of 2, 4, 8, 16, 32, 63, 125, 250, and 500 inches, rms. These roughness blocks are compared with the surface under question using the fingernail as the indicating means. The fingernail is scraped across the surface in question, then across the standard blocks until a block is found that will approximate the surface finish of the part in question. Naturally, this is only an approximation and its value is largely dependent upon the skill of the inspector.

#### Brush Surface Analyzer

This device is a combination instrument that will produce both a profile record and a meter reading in microinches, rms. The tracing device is motor driven with a diamond tip stylus. The recording is useful on irregularities up to about 0.004 inch roughness width while the meter reading is useful to about 0.012 inch roughness width.

### Proflometer

The proflometer is an electronic averaging type of instrument which gives a meter reading of the average deviation from the mean surface in terms of microinches, rms. The tracer has a diamond stylus and can be operated either manually or mechanically.

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TEST	EQUIPMENT	PENETRATOR	DEPTH OF INDENTATION	HARDNESS NUMBER CALCULATED BY	USES
BRINELL	HYDRAULIC OR DEAD WEIGHT LEVER-LOADING	HARDENED STEEL BALL OR TUNGSTEN CARBIDE BALL		LOAD DIVIDED BY SPHERICAL AREA OF INDENTATION.	LARGE PARTS OF LOW TO MEDIUM HARDNESS.
ROCKWELL	ROCKWELL TESTER	STEEL BALL OR SPHEROCOMICAL DIAMOND	.0005"	DIFFERENCE IN DEPTH OF PENETRATION OF PENETRATOR SUBJECTED TO INITIAL AND FINAL LOAD.	SMALL PARTS OF HIGH HARDNESS.
VICKERS	VICKERS TESTER (DEAD WEIGHT LEVER LOADING)	SQUARE-BASE PYRAMID DIAMOND	.002" MIN.	CONSTANT TIMES LOAD DIVIDED BY DIAGONAL OF INDENTATION SQUARED.	SMALL PARTS OF HIGH HARDNESS
KNOOP	TUKON TESTER (WEIGHT AND BALANCE BEAM)	DIAMOND PYRAMID WITH RECTANGULAR BASE AND UNEQUAL INCLUDED ANGLES.		LOAD DIVIDED BY CONSTANT TIMES THE SQUARE OF THE LONG DIAGONAL OF INDENTATION.	SMALL PARTS, THIN SECTIONS AND THIN CASES. HARDNESS SURVEYS.
SHORE SCLEROSCOPE	PORTABLE TESTER	DIAMOND TIPPED HAMMER		HARDNESS MEASURED BY HEIGHT OF REBOUND OF INDENTOR.	USE ON CASE-HARDENED SURFACES. PORTABLE SO IT CAN BE USED ON LARGE PARTS.
MONOTRON	MONOTRON HARDNESS TESTER	HEMISPHERICAL DIAMOND PENETRATOR	.0018"	READING OFF A PRESSURE GAGE AFTER LOAD IS APPLIED.	
MOH		MATERIAL HIGHER ON MOH SCALE		ARBITRARILY ASSIGNING 10 HARDNESS NUMBERS TO 10 MATERIALS AND INTERPOLATING MOH'S SCALE IS A SCRATCH HARDNESS SCALE IN WHICH EACH MINERAL CAN BE SCRATCHED BY ONE NEXT ABOVE IT.	CAN DETERMINE RELATIVE HARDNESS OF DIFFERENT MATERIALS, USUALLY NON-METALS.
HERBERT PENDULUM	INVERTED PENDULUM	STEEL BALL OR SPHERICAL FACED DIAMOND		TIME REQUIRED FOR THE PENDULUM TO COMPLETE 5 OSCILLATIONS.	
EBERBACH				MEASURING THE INDENTATION WITH AID OF MICROSCOPE.	MICROHARDNESS TEST
MICRO-CHARACTER				MEASURING THE INDENTATION WITH AID OF MICROSCOPE.	MICROHARDNESS TEST

Table 19.3 Hardness Testing Methods

**Table 19.4 Non-Destructive Testing Methods**

<b>Property Or Characteristic</b>	<b>Method of Detection</b>	<b>General Limitations</b>
Surface crack or discontinuity	Fluoroscopy Radiography Magnaflux Magnaglo Zyglo Ultrasonics	Only low absorption matls.  Only magnetic matls. Only magnetic matls.  Surface beam only
Subsurface crack or discontinuity	Radiography Sonic Ultrasonic Reflection Angle beam Forced vibration	12 inch depth  30 feet depth 15 feet depth
Tube thickness	Radiographic Electronic tube	Up to 1 foot thickness
Film thickness	Electronic-magnetic Electronic-nonmagnetic	
Strain analysis	Electrical strain gages Mechanical strain gages Acoustical strain gages Optical strain gages Photoelasticity Brittle coatings	Must be done on a model
Hardness	Brinell Rockwell Vickers Knoop Shore Scleroscope Monotron Herbert pendulum Eberach Microcharacter Moh	Microhardness test Microhardness test Strictly a comparative scale
Inspection testing	Magnetic test Spark test Thermoelectric test Chemical spot test	
Surface roughness	Surface roughness blocks Brush surface analyzer Profilometer	

## CHAPTER 20

### CHEMICAL MILLING

#### PROCESS

Chemical milling or contour etching is a technique for controlled removal of metal by chemicals rather than by conventional machining methods. The "Chem-Mill" process is a patented North American Aviation process of chemical milling. This process is used to remove metal to extremely close tolerances on parts that are shaped in such a manner that conventional machining methods would be extremely difficult or impossible.

Basically, chemical milling is a process wherein the component is immersed in an etchant (usually a strong alkaline solution), which chemically combines with component metal in an exothermic reaction that releases hydrogen and a metallic salt or oxide. Areas that should not be subjected to metal removal are protected by materials (masks) which do not react with the etchant.

#### Materials

Aluminum. Both wrought and forged aluminum alloys can be chemically milled. The porosity problem in milling cast parts has been overcome by adoption of new etchants. Heat treated alloys produce better surfaces after milling. Some of the more common aluminum alloys that are machined or formed by the chemical milling process are 2014, 5052, 6061, 7075, and 7178.

Magnesium. These alloys chemical mill with excellent results. Light cuts produce an excellent surface finish. Deep cuts tend to bring out the inherent casting porosity. Some of the magnesium alloys that have been chemical milled successfully are AZ31B, AZ91(A, B, and C), EZ33A, HK31A, HM21, ZK51A, and ZK60A.

Titanium. Titanium alloys, when chemical milled, give extremely smooth surfaces. Often the surface conditions are improved considerably, particularly in the case of extrusions where the die marks are completely removed. Some of the titanium alloys that have successfully been treated by chemical milling are A-70, A-110AT, and C-110M.

Steel. Almost any type of steel alloy can be chemical milled, regardless of the composition or the type of heat treatment that has been applied. One of the chief concerns is that of hydrogen embrittlement and often hydrogen removal techniques must be employed. Some of the applicable steel alloys are 301, 316, 321, 347, 4130, and 4340.

Others. Inconel and other nickel base alloys, chiefly the so-called superalloys, have been successfully treated by chemical milling. Some work has also been done with molybdenum, tungsten, and cobalt alloys.

#### Steps in the process

The principal steps involved in this process are cleaning, masking, scribing, and etching.

The cleaning process involves the following operations:

- (1) solvent pre-clean
- (2) rinse
- (3) alkaline clean or scale condition
- (4) rinse

- (5) deoxidize or descale
- (6) rinse
- (7) oven dry

Masking consists of coating the metal with a protective film in areas not to be chemical milled. It can be applied by:

- (1) dipping
- (2) flow-coating
- (3) spraying
- (4) roller-coating
- (5) brushing

Maskants are usually baked on at low temperatures and are carefully checked for absolute cohesion since this is essential to produce well defined edges.

After the maskant is thoroughly cured, the part is ready for scribing. Scribe templates are built to close tolerances since the amount of undercut of the etchant must be accounted for. The template defines the lines where the mask should be cut, and after this cutting takes place, the mask is removed from this area, leaving the surface to be chemically milled exposed.

Etching consists of immersing the part in a solution which removes metal from the exposed areas. The part is etched at a predetermined rate, then rinsed, demasked, and a final rinse is given.

#### ADVANTAGES AND LIMITATIONS

Some advantages of chemical milling include the following:

- (1) close tolerances can be maintained.
- (2) overall weight reduction can be accomplished.
- (3) part can be etched after it is formed.
- (4) many different thicknesses can be produced on a single part by progressively removing masking.
- (5) residual stresses are eliminated since both sides of the sheet can be processed simultaneously.
- (6) high strength-weight ratio parts can be made.
- (7) parts can be tapered successfully.
- (8) eliminates most secondary finishing operations.
- (9) many parts can be produced simultaneously.
- (10) fewer parts are rejected because of process uniformity.

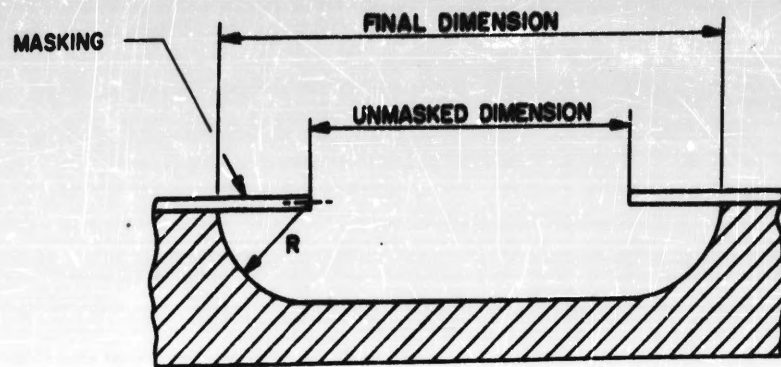
Some of the limitations of chemical milling include the following:

- (1) the process is rather slow and it takes considerable time to remove a large amount of metal.
- (2) not recommended for etching holes because of the undercutting characteristics of the etchant.
- (3) not good for processing porous aluminum castings.
- (4) surface irregularities are reproduced.
- (5) not recommended for areas where exposed area is less than twice as wide as the depth of metal removed.

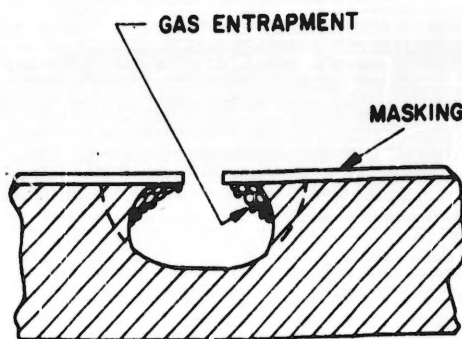
#### DESIGN CONSIDERATIONS

There are several considerations that should be kept in mind when designing for chemical

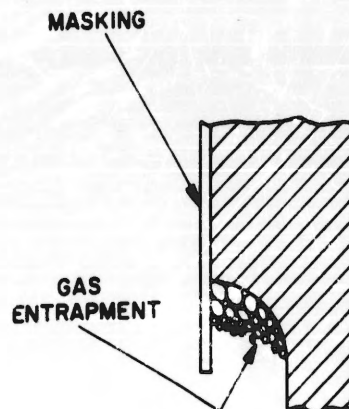
milling. Some of the practices, both good and bad, are illustrated in Figure 20.1 and chemical milling nomenclature is illustrated in Figure 20.2.



DESIRABLE ETCHING CONDITION



SMALL OPENING RESULTS IN ROUGH ETCHING AND GAS ENTRAPMENT.



VERTICAL POSITION OF ETCHING CAUSES GAS ENTRAPMENT AND INHIBITS ETCHING.

UNDESIRABLE ETCHING CONDITIONS

Figure 20.1 Chemical Milling Etching Conditions


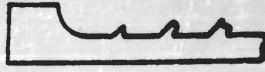

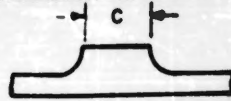
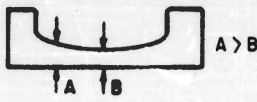

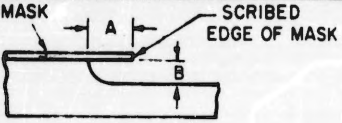
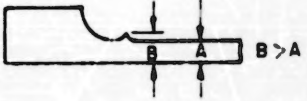
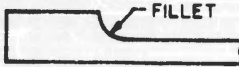

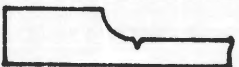
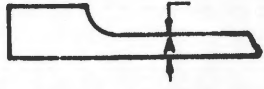
CHANNELING	 <p>THE FORMATION OF A GROOVE OR CHANNEL AT THE FILLET.</p>	ISLANDS	 <p>HIGH SPOTS WITHIN AN ETCHED AREA WHICH RESULT FROM A NON-UNIFORM ETCH RATE, THIS BEING DUE TO THE UNWANTED MASKING ACTION OF DIRT OR PARTICLES OF MASK WHICH REMAIN ON THE SURFACE TO BE ETCHED.</p>
CUT OR DEPTH OF CUT	 <p>THE THICKNESS OF METAL REMOVED MEASURED IN THE DIRECTION NORMAL TO THE ORIGINAL METAL SURFACE.</p>	LAND	 <p>C IS A "LAND", A RELATIVELY NARROW STRIP OF UNETCHED METAL DIVIDING ADJACENT ETCHED AREAS.</p>
DISHED	 <p>THINNING OF THE CENTRAL PORTION OF THE WEB RESULTING FROM AN INCREASING ETCH RATE FROM SIDE TO CENTER OF A CUT; DUE TO IMPROPER AGITATION, RACKING OR TEMPERATURE CONTROL.</p>	PITTING	 <p>FORMATION OF PITS OR DEPRESSIONS IN THE ETCHED SURFACE.</p>
ETCH FACTOR (UNDERCUT RATIO)	 <p>ETCH FACTOR = <math>\frac{\text{UNDERCUT}}{\text{DEPTH OF CUT}} = \frac{A}{B}</math></p>	RIDGING	 <p>FORMATION OF A RAISED RIDGE AT THE BASE OF THE FILLET.</p>
FILLET, CHEMICAL MILLING	 <p>NOTE: THE RADIUS OF THE FILLET IS APPROXIMATELY EQUAL TO THE DEPTH OF THE CUT.</p> <p>THE CONCAVE SHOULDER BETWEEN THE ETCHED SURFACE AND THE NON-ETCHED SURFACE.</p>	STEP CUTS	 <p>MULTIPLE CUTS OF DIFFERENT DEPTHS IN THE SAME PIECE OF MATERIAL.</p>
FILLET NOTCH OR NOTCHING	 <p>A NOTCH AT THE BOTTOM OF THE FILLET RADIUS CAUSED BY SCRIBING TOO DEEPLY.</p>	WEB	 <p>A = WEB THICKNESS</p> <p>THE THINNED METAL REMAINING AFTER CHEMICAL MILLING.</p>

Figure 20.2 Chemical Milling Nomenclature

### Surface Finish

**Aluminum Alloys.** If the stock is in good condition before treatment, a finish of 125  $\mu$ -inches rms can be expected. No matter how poor the original surface is, the finished surface will not be rougher than 250  $\mu$ -inches rms.

**Magnesium Alloys.** Surface imperfections are washed out and finishes of 80  $\mu$ -inches rms can be obtained.

**Titanium Alloys.** Surface imperfections are washed out and extremely smooth finishes of approximately 40  $\mu$ -inches rms can be obtained.

**Steel Alloys.** If the cuts are shallow (less than 1/4 inch), finishes as low as 50  $\mu$ -inches can be obtained. If deeper cuts are made, the surface finish depends on the grain structure of the metal.

### Tolerances

On cuts of 0.125 inch or less, tolerances of plus or minus 0.003 inch are obtainable. On deeper cuts, tolerances are plus or minus 0.005 inch. If sheet thickness is being reduced, the tolerances are plus or minus 0.002 inch.

### Depth

The depth of cut in chemical milling can go fairly deep but for best results, it should be less than 1/2 inch.

### Size

The only limitation on the size of the part that can be treated by chemical milling is imposed by the size of the immersion tanks available.

### Tapering

By controlled withdrawal of a part from the solution, parts may be tapered to close tolerances.

### Warping

Warping is negligible because of the slow rate of etching and because of the virtual elimination of residual stresses.

### Fillet Radii

Fillet radii cannot be controlled. They are a function of the material and the depth of cut. The radius is almost exactly equal to the depth of cut.

### Overall Weight Reduction

Using no maskant or tooling, the part may be immersed and all surfaces equally reduced in weight and size.

### Wall thickness

Wall thickness may be reduced to 0.005 inch without warping or buckling.

### Surface irregularities

Surface irregularities such as dents, can be reproduced in the same degree as they are enlarged.

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