Forming Processes
Chapters 13-16

Figure I.7b  Schematic illustration of various bulk deformation processes

Characteristics of Forming
- Metal flow through forming and shaping
- Little waste
- Higher capital cost
- Higher volume needed
- Tooling cost is expensive

Process Variables
- Starting material
- Starting work piece geometry
- Tool or die geometry
- Lubrication
- Starting temperature
- Speed of operation
- Amount of deformation

Dependent Variables
- Force or power required
- Nature of material flow
- Material properties
- Exit temperature
- Surface finish
**Outcome**

- Experience
- Experiment
- Theory

**Rolling Processes**

- Set of rolls
- Continuous or discrete
- Cold or hot
- Variety of shapes depend on rolling dies
- Part have uniform and dependable quality
- 2% to 5% dimensional tolerance

**Effects of Hot Rolling**

Figure 13.6 Changes in the grain structure of cast or of large-grain wrought metals during hot rolling. Hot rolling is an effective way to reduce grain size in metals for improved strength and ductility. Cast structures of ingots or continuous castings are converted to a wrought structure by hot working.

**Machined and Rolled Threads**

Figure 13.17 (a) Features of a machined or rolled thread. Grain flow in (b) machined and (c) rolled threads. Unlike machining, which cuts through the grains of the metal, the rolling of threads imparts improved strength because of cold working and favorable grain flow.
Roll Arrangements

Rolling Operations

- Video (Making Steel)
- Straightening
- Ring Rolling (video)

Forging of Metals (ch14)

- “Blacksmith” (video)
- Shaping operation
- Compressive forces
- Dies (mid to high cost)
- Discrete raw material
- Process variable (as above)
- Hot, warm, or cold

Characteristics of Forging

Forged Components

Microstructure of Parts

Figure 13.3

Figure 14.1 (a) Schematic illustration of the steps involved in forging a knife. (b) Landing-gear components for the CSA and CSB transport aircraft, made by forging. (c) General view of a 445 MN (50,000 ton) hydraulic press.

Figure 14.2 Schematic illustration of a part made by three different processes showing grain flow. (a) Casting by the processes described in Chapter 11. (b) Machining from a blank, described in Part IV of this book, and (c) forging. Each process has its own advantages and limitations regarding external and internal characteristics, material properties, dimensional accuracy, surface finish, and the economics of production. Source: Courtesy of Forging Industry Association.
Grain Flow in Forging

Figure 14.12 A pierced round billet showing grain-flow pattern (see also Fig 14.12c). Source: Courtesy of Ladish Co., Inc.

Open Die Forging

Figure 14.4 (a) Schematic illustration of a cogging operation on a rectangular bar. Blacksmiths use this process to reduce the thickness of bars by hammering the part on an anvil. Reduction in thickness is accompanied by barreling, as in Fig. 14.3c. (b) Reducing the diameter of a bar by open-die forging; note the movements of the dies and the workpiece. (c) The thickness of a ring being reduced by open-die forging.

Closed Die Forging

Heading

Forging vs. Casting Cost

Extrusion (ch15)
Direct-Extrusion

Figure 15.1 Schematic illustration of the direct-extrusion process.

Extruded Parts

Figure 15.2 Extrusions and examples of products made by sectioning off extrusions. Source: Courtesy of Kaiser Aluminum.

Types of Extrusion

Figure 15.3 Types of extrusion: (a) indirect; (b) hydrostatic; (c) lateral.

Metal Flow in Extrusion

Figure 15.6 Types of metal flow in extruding with square dies. (a) Flow pattern obtained at low friction or in indirect extrusion. (b) Pattern obtained with high friction at the billet-chamber interfaces. (c) Pattern obtained at high friction or with coiling of the outer regions of the billet in the chamber. This type of pattern, observed in metals whose strength increases rapidly with decreasing temperature, leads to a defect known as pipe (or extrusion) defect.

Extrusion Temperature Ranges

Table 15.1

Typical Extrusion Temperature Ranges for Various Metals and Alloys

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>200-250</td>
</tr>
<tr>
<td>Aluminum and its alloys</td>
<td>375-475</td>
</tr>
<tr>
<td>Copper and its alloys</td>
<td>650-975</td>
</tr>
<tr>
<td>Steels</td>
<td>875-1300</td>
</tr>
<tr>
<td>Refractory alloys</td>
<td>975-2200</td>
</tr>
</tbody>
</table>

Extrusion of Heat Sinks

Figure 15.10 (a) Aluminum extrusion used as a heat sink for a printed circuit board. (b) Die and resulting heat sink profiles. Source: Courtesy of Aluminum Extruders Council.
**Cold-Extruded Spark Plug**

Figure 15.12 Production steps for a cold-extruded spark plug. Source: Courtesy of National Machinery Company.

**Sheet Metal Processes - Ch16**

Figure 15.13 A cross-section of the metal part in Fig 15.12 showing the grain-flow pattern. Source: Courtesy of National Machinery Company.

**Process Overview**

- Make a variety of parts from sheets of metal by cutting and bending them into shape
- Examples

**Sheet-Metal Parts**

**Wastebasket**

**Design with Joints**

Page 6
Can Manufacture

Figure 16.31  The metal-forming processes involved in manufacturing a two-piece aluminum beverage can.

Forming Video

Sheet-Metal Forming Processes

Table 16.10  General characteristics of sheet-metal forming processes (no alphanumeric data)

<table>
<thead>
<tr>
<th>Process</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending</td>
<td>Requires two dies.</td>
</tr>
<tr>
<td>Deep Drawing</td>
<td>Requires three dies.</td>
</tr>
<tr>
<td>Stamping</td>
<td>Requires three dies.</td>
</tr>
<tr>
<td>Roll Forming</td>
<td>Requires five dies.</td>
</tr>
<tr>
<td>Hydroforming</td>
<td>Requires five dies.</td>
</tr>
</tbody>
</table>

Engineering Problems

- Shape design and materials
- Size of equipment (force)
- Nesting
- Minimum bend radius
- Springback
- Bend allowance

Shearing

Figure 16.3  (a)  Effect of the clearance, c, between punch and die on the deformation zone in shearing. As the clearance increases, the material tends to be pulled into the die rather than be sheared. In practice, clearances usually range between 2% and 10% of the thickness of the sheet. (b) Microhardness (HV) contours for a 6.4-mm (0.25-in.) thick AISI 1020 hot-rolled steel in the sheared region. Source: After H.P. Weaver and K.J. Weinmann.

Punch Force

\[ F = 0.7TL(UTS) \]

- \( T \) = thickness
- \( L \) = total length sheared
- \( UTS = \) ultimate tensile strength

Example from book

- 1 in. dia., 1/8 in. thick, 140,000 psi UTS
- \( F = 0.7\pi(1/8)\times140,000 = 19.25 \text{ tons} \)
Die-Cutting Operations

Figure 16.4 (a) Punching (piercing) and blanking. (b) Examples of various die-cutting operations on sheet metal.

Nesting

- Optimal arrangement of parts on a piece of sheet metal

Bending Operations

Figure 16.22 Examples of various bending operations.

Press Brake

Figure 16.23 (a) through (e) Schematic illustrations of various bending operations in a press brake. (f) Schematic illustration of a press brake. Source: Courtesy of Verson Allsteel Company.

Bending Terminology

Figure 16.16 Bending terminology. Note that the bend radius is measured to the inner surface of the bent part.

Springback in Bending

Figure 16.19 Springback in bending. The part tends to recover elastically after bending, and its bend radius becomes larger. Under certain conditions, it is possible for the final bend angle to be smaller than the original angle (negative springback).
Reducing Springback (Dies)

Figure 16.20 Methods of reducing or eliminating springback in bending operations. Source: After V. Cukuła, T. Nakagawa, and H. Tyamoto.

Minimum Bend Radius

Figure 16.17 (a) and (b) The effect of elongated inclusions (stringers) on cracking as a function of the direction of bending with respect to the original rolling direction of the sheet. (c) Cracks on the outer surface of an aluminum strip bent to an angle of 90 degrees. Note also the narrowing of the top surface in the bend area (due to Poisson effect).

Minimum Bend Radius

Figure 16.18 Relationship between $R/T$ ratio and tensile reduction of area for sheet metals. Note that sheet metal with 50% tensile reduction of area can be bent over itself in a process like the folding of a piece of paper without cracking. Source: After J. Datsko and C. T. Yang.

Bend Allowance Equation

- Length of part when unfolded
- $L_b = \alpha (R + kT)$, where
  - $k$ is a constant between .33 to .5
  - $T$ = thickness of sheet metal
  - $R$ = bend radius
  - $\alpha$ = bend angle

Understanding Bend Allowance

- (Instructor Notes)