BMM3643 Manufacturing Processes
Sheet Metal Forming Processes

by
Dr Mas Ayu Bt Hassan
Faculty of Mechanical Engineering
masszee@ump.edu.my

Chapter Synopsis

This chapter will introduced students to a broad topic of sheet metal forming processes which involved a large amount of permanent (plastic) deformation. Permanent deformation of metals were formed under tension, compression, shear or a combination of loads. There are three major categories of sheet metal processes such as shearing/cutting, bending and drawing.

Chapter Information

Lesson Objectives:

Sheet Metal Forming Processes

Lesson Objective:

At the end of this lecture, students should be able to understand and explain the following:

- Understand the characteristics of sheet metals and formability
- Analyze the characteristics of sheet metal forming processes

Introduction

- Advantage in terms of light weight and versatile shape.
- File cabinets, appliances, car bodies, cans, roof etc.
- Commonly used materials is low-carbon steel because low cost, good strength & formability characteristics.
- There are 2 stages of sheet metal processes consists of cutting the large rolled sheets and then forming process into desired shape.
- Some characteristics of sheet metal will effects on the overall manufacturing process

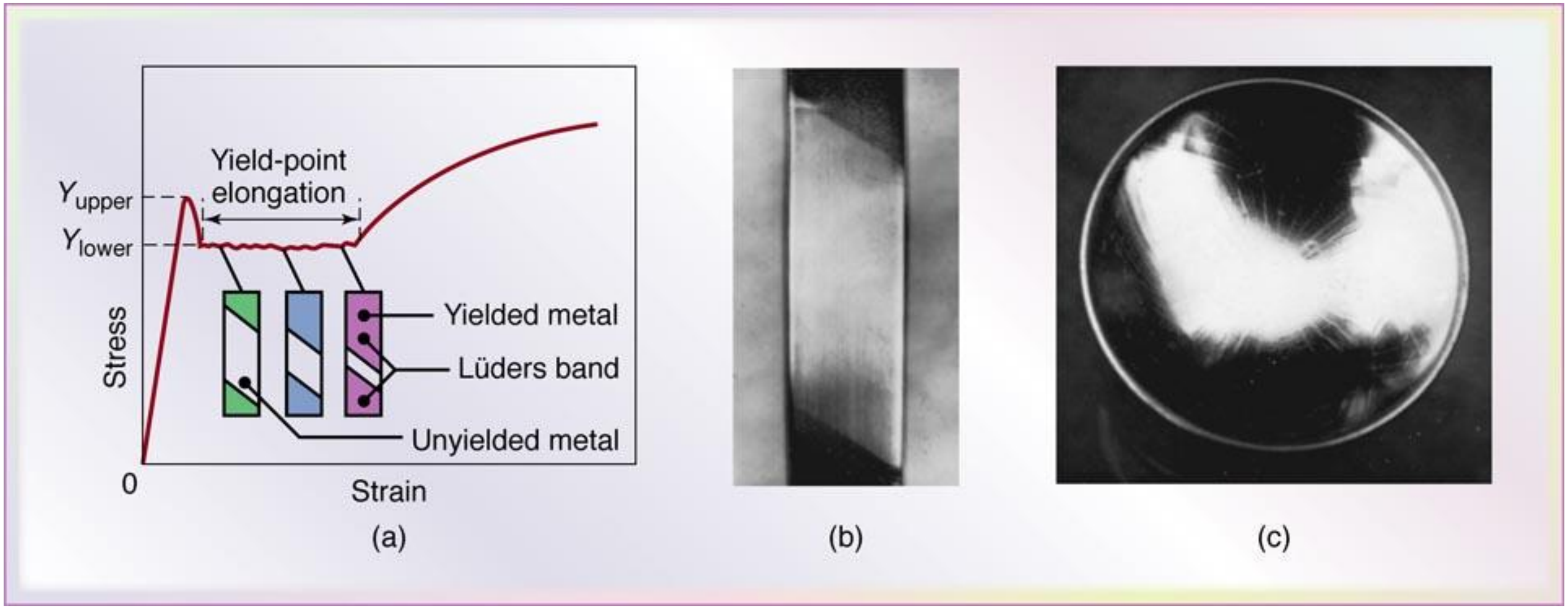
TABLE 16.2

Characteristics of Metals Important in Sheet-Forming Operations

Characteristic	Importance
Elongation	Determines the capability of the sheet metal to stretch without necking and failure; high strain-hardening exponent (n) and strain-rate sensitivity exponent (m) are desirable
Yield-point elongation	Typically observed with mild-steel sheets (also called L üder's bands or stretcher strains), flamelike depressions on the sheet surface, can be eliminated by temper rolling but sheet must be formed within a certain time after rolling
Anisotropy (planar)	Exhibits different behavior in different planar directions, present in cold-rolled sheets because of preferred orientation or mechanical fibering, causes earing in deep drawing, can be reduced or eliminated by annealing but at lowered strength
Anisotropy (normal)	Determines thinning behavior of sheet metals during stretching, important in deep drawing
Grain size	Determines surface roughness on stretched sheet metal, the coarser the grain—the rougher the appearance (orange peel), also affects material strength.
Residual stresses	Typically caused by nonuniform deformation during forming, results in part distortion when sectioned, can lead to stress-corrosion cracking, reduced or eliminated by stress relieving.
Springback	Due to elastic recovery of the plastically deformed sheet after unloading, causes distortion of part and loss of dimensional accuracy, can be controlled by techniques such as overbending and bottoming of the punch
Wrinkling	Caused by compressive stresses in the plane of the sheet, can be objectionable, depending on its extent, can be useful in imparting stiffness to parts by increasing their section modulus, can be controlled by proper tool and die design
Quality of sheared edges	Depends on process used; edges can be rough, not square, and contain cracks, residual stresses, and a work-hardened layer, which are all detrimental to the formability of the sheet; edge quality can be improved by fine blanking, reducing the clearance, shaving, and improvements in tool and die design and lubrication
Surface condition of sheet	Depends on sheet rolling practice; important in sheet forming as it can cause tearing and poor surface quality

Source by Kalpakjian Book, 2014

Illustration of Characteristics Metal Important in Sheet Metal



(a) Yield-point elongation in a sheet-metal specimen. (b) Luder's bands in a low-carbon steel sheet. (c) Stretcher strains at the bottom of a steel can for household products. *Source:* (b) Courtesy of Caterpillar Inc.

Formability of Sheet Metal

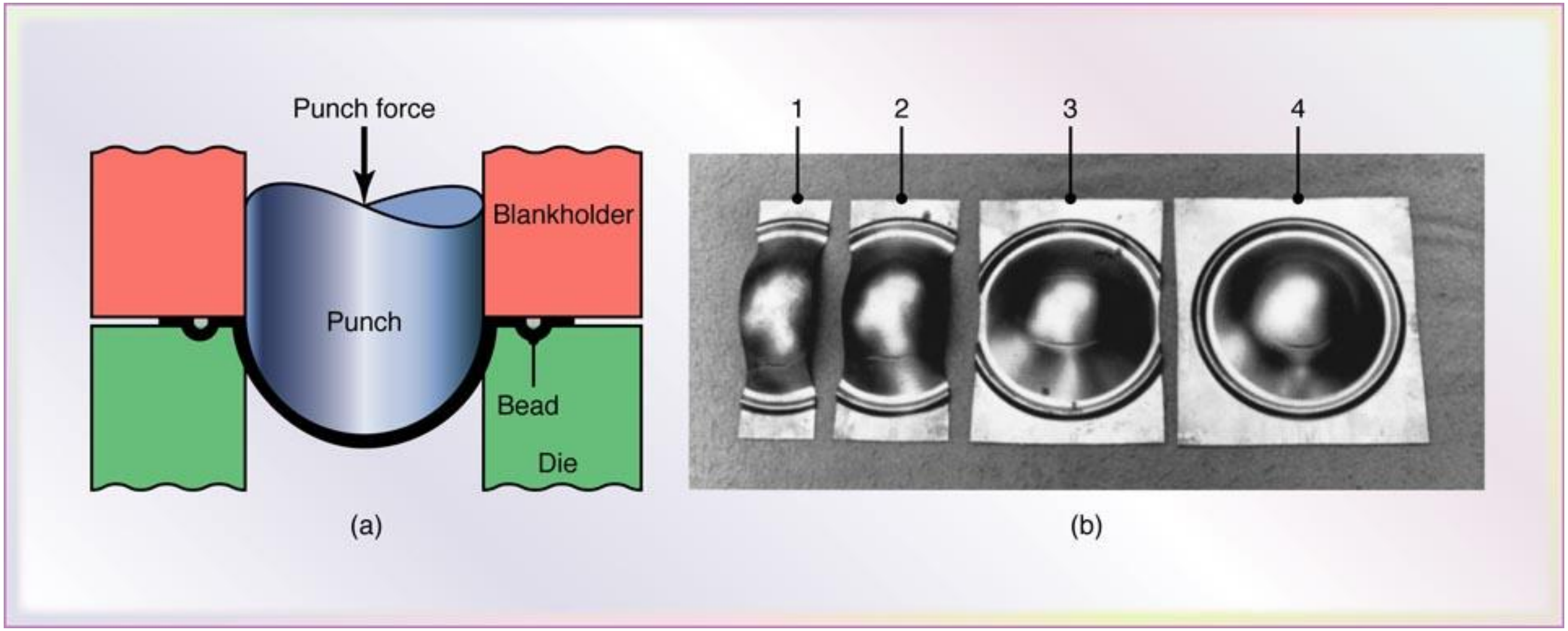
- Formability: The ability to undergo the desired shape change without failure such as necking or tearing
- Sheet metal undergoes two forms of deformation
  i. Stretching
  ii. Drawing

Test methods for formability of sheet metal (continue)

Cupping test

- The sheet metal specimen is clamped between two circular flat dies and a steel or round punch is pushed hydraulically into the sheet metal until a crack begins to appear on the stretched specimen

Cupping Test and Bulge-Test

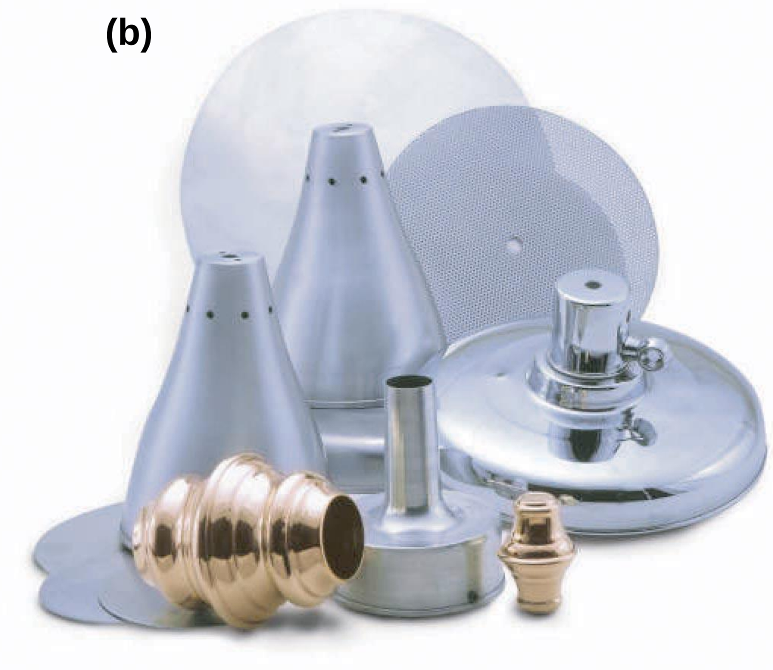


(a) **A cupping test** (the Erichsen test) to determine the formability of sheet metals. (b) **Bulge-test** results on steel sheets of various widths. The specimen farthest left is subjected to, basically, simple tension. The specimen farthest right is subjected to equal biaxial stretching. *Source:* Courtesy of Inland Steel Company.

Products from Sheet-Metal Process

(a)

(b)



Examples products made from sheet-metal process. (a) Die-formed and cut stamped parts. (b) Parts produced by spinning. *Source:* (a) Courtesy of Aphase II, Inc. (b) Courtesy of Hialeah Metal Spinning, Inc.

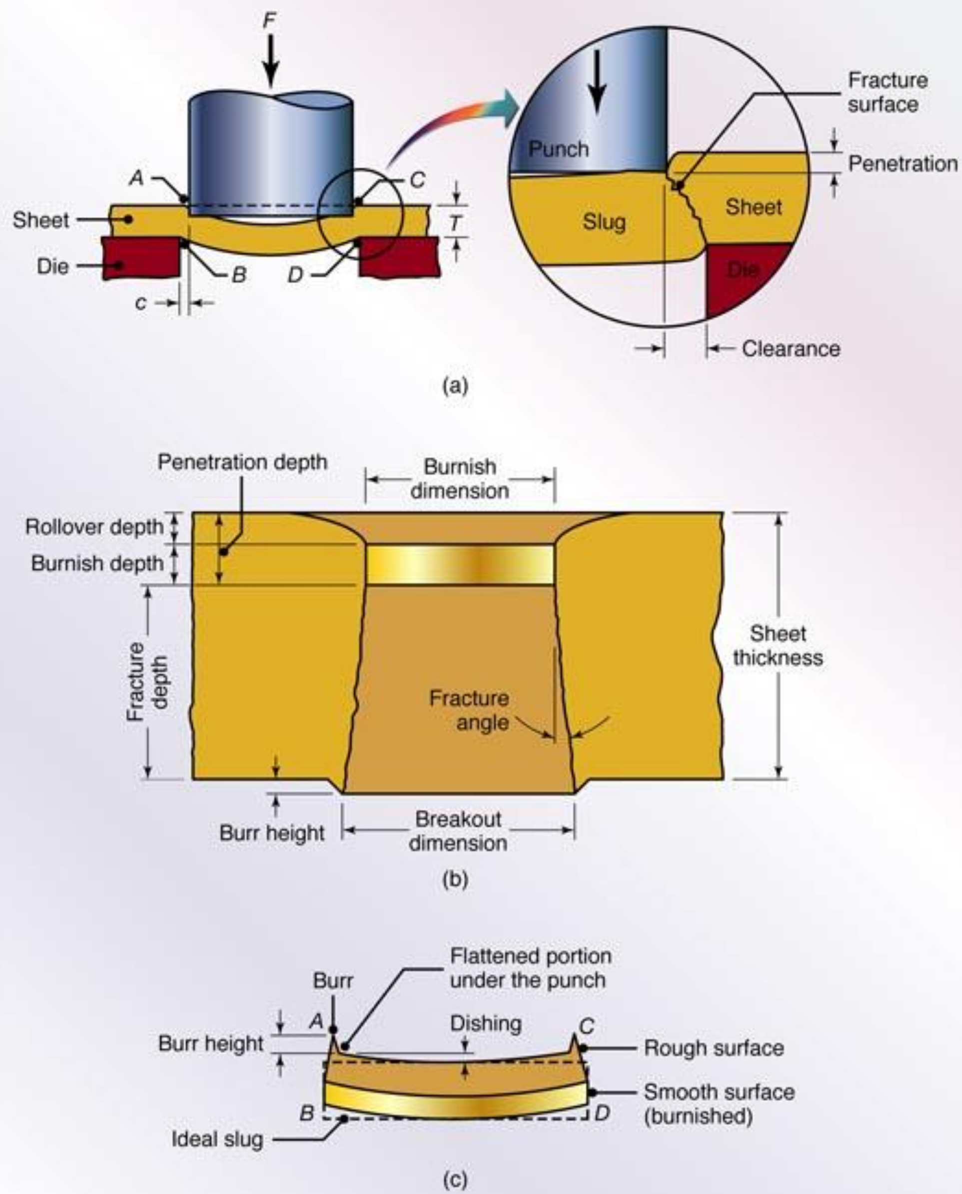
Categories in Sheet Metal Processes

1. Shearing/Cutting
   – Shearing to separate large sheets; or cut part perimeters or make holes in sheets
2. Bending
   – Straining sheet around a straight axis
3. Drawing
   – Forming of sheet into convex or concave shapes

1. Shearing/Cutting

- Sheet metal subjected to shear stress developed between a punch and a die is called shearing
- Shearing usually starts with formation of cracks on both the top and bottom edges of the work piece. These cracks meet each other and separation occurs
- Process parameters :
  - Shape of the material for the punch and die
  - Speed of the punching ,
  - Lubrication
  - Clearance between the punch and the die.

Shearing: Punch and Die



Source by Kalpakjian Book, 2014

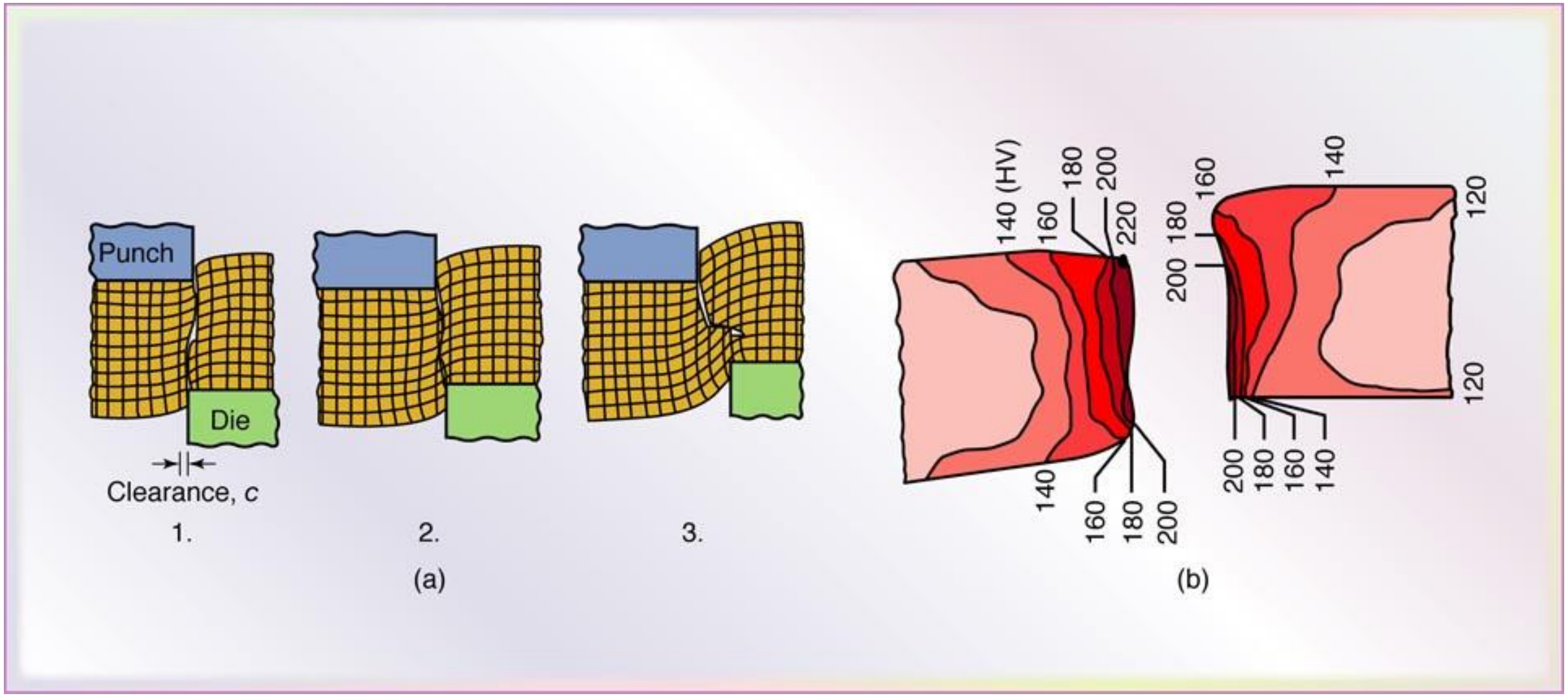
$$\text{Punch force,} \quad F = 0.7TL(\text{UTS})$$

T = sheet thickness

L = total length sheared

(a) Schematic illustration of shearing with a punch and die, indicating some of the process variables. Characteristic features of (b) a punched hole and (c) the slug. (*Note:* The scales of the two figures are different.)

Illustrations Effect of Shearing

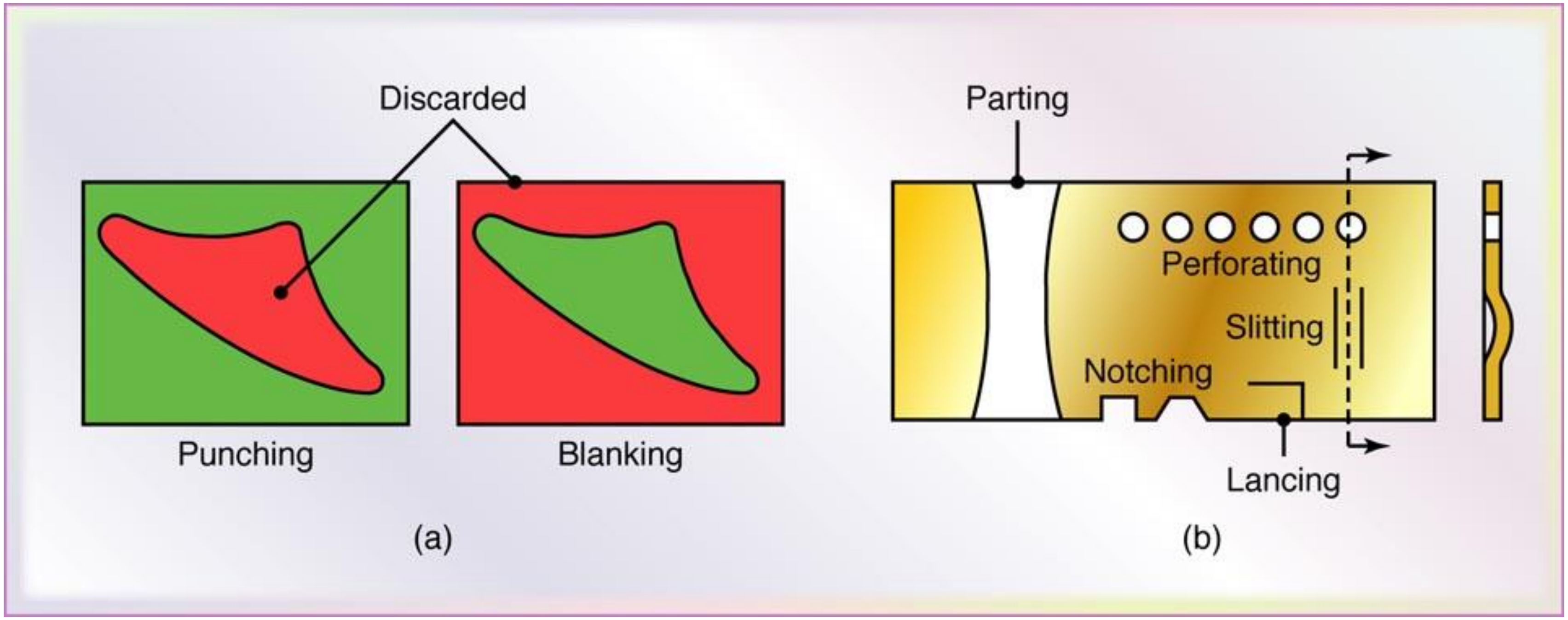


(a) Effect of the clearance, *c*, between punch and die on the deformation zone in shearing. As the clearance increases, the material tends to be pulled into the die rather than be sheared. In practice, clearances usually range between 2 and 10% of the thickness of the sheet. (b) Microhardness (HV) contours 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.

Shearing Operation

- Several operations based on shearing performed
  - Punching – sheared slug discarded
  - Blanking – Slug is the part and the rest is scrap
- Others example of shearing operations are:
  - Die cutting: Perforating, parting, notching, lancing
  - Fine blanking
  - Slitting
  - Steel rules
  - Nibbling
  - Tailor welded blanks

Examples of Shearing Operations

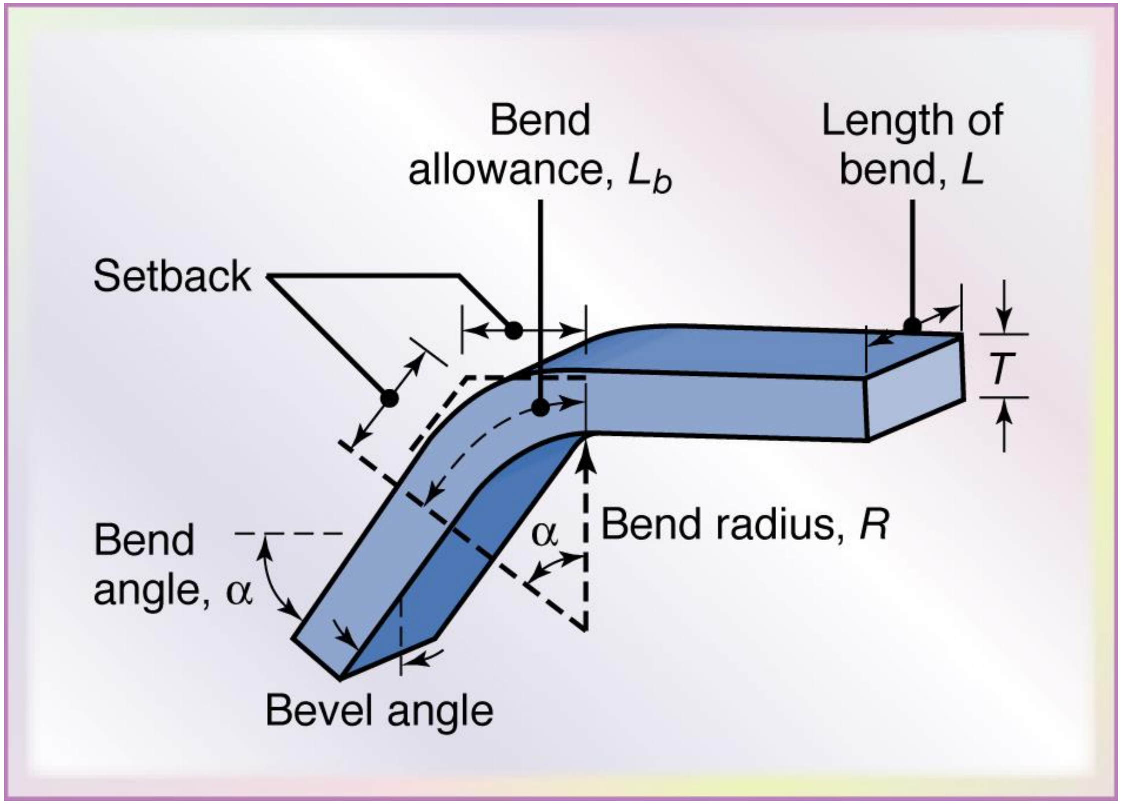


(a) Punching (piercing) and blanking. (b) Examples of various die-cutting operations on sheet metal.

2. Bending

- It is one of the most widely used for forming operations.
- Example products are components in automobile or an appliance, e.g. paper clip, flanges, seams.
- In bending, the outer fibres of the materials are in tension and the inner fibres are in compression.

Bending Terminology



Schematic of bending process. Note that the bend radius is measured to the inner surface of the bent part.

Source by Kalpakjian Book, 2014

Bending Terminology (continue)

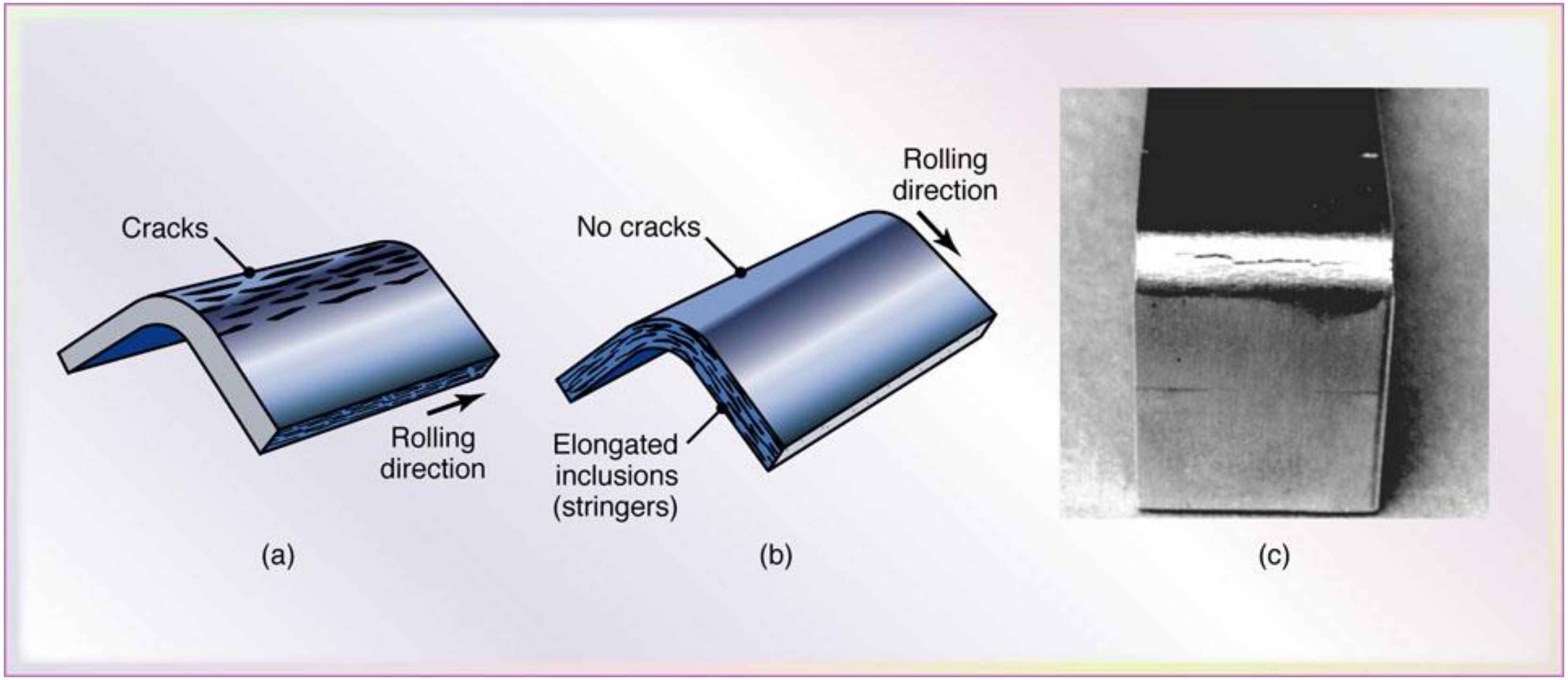
- Bend allowance, L_b, - the length of the neutral axis, used to determine the length of the blank to be bent.
- Approximately, $L_b = \alpha (R + kT)$
  - α – bend angle, T – sheet thickness, R – bend radius, k – constant (~0.33 for R < 2T and 0.5 for R > 2T).
- For ideal case, the neutral axis at the centre of the sheet thickness, k = 0.5,

$$L_b = \alpha (R + 0.5T)$$

Bending Terminology (continue)

- The ratio at which a crack appears on the outer surface of the bend is referred to as minimum bend radius
- It is expressed in terms of thickness such as 2T, 3T, and so on.
- 3T minimum bend radius indicates that the smallest radius to which the sheet can be bent, without cracking.

Effect of Elongated Inclusions



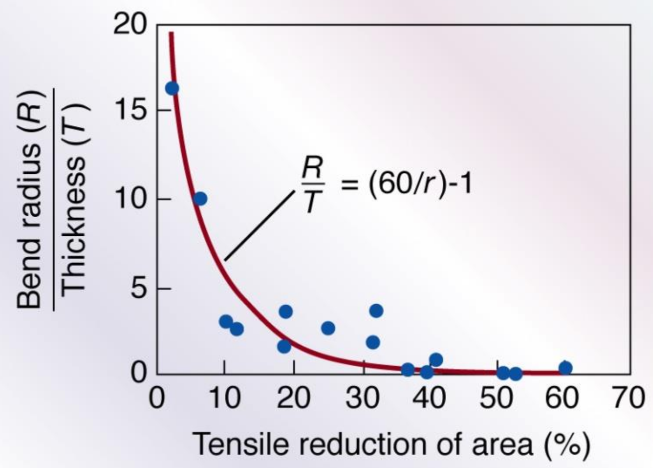
(a) and (b) The effect of elongated inclusions stringers on cracking as a function of the direction of bending with respect to the original rolling direction of the sheet. (c) Cracks on the outer surface of an aluminum strip bent to an angle of 90 degrees. Note also the narrowing of the top surface in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

Minimum Bend Radius

TABLE 16.3

Minimum Bend Radius for Various Materials at Room Temperature

Material	Condition: Soft	Condition: Hard
Aluminum alloys	0	6*T*
Beryllium copper	0	4*T*
Brass (low-leaded)	0	2*T*
Magnesium	5*T*	13*T*
Steels		
Austenitic stainless	0.5*T*	6*T*
Low-carbon, low-alloy, and HSLA	0.5*T*	4*T*
Titanium	0.7*T*	3*T*
Titanium alloys	2.6*T*	4*T*



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.

Minimum Bend Radius (continue)

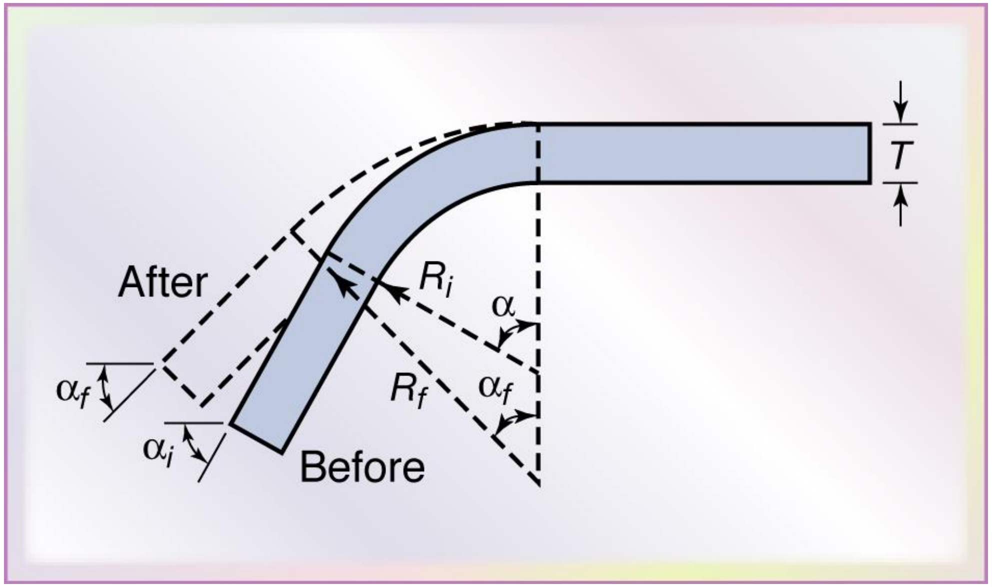
- The minimum bend radius, R,

$$R \approx T\,((50/r) - 1)$$

  - r = tensile reduction of area of sheet metal
- **Factors** that determine the bend radius include:
  - Ductility of materials
  - Working temperature
  - Thickness of sheet metals

Springback

- It is an elastic recovery of material after plastic deformation when the load is removed.
- Can be easily observed in bending.
- Occurs not only in flat sheets and plates, but also in solid or hollow bars and tubes.

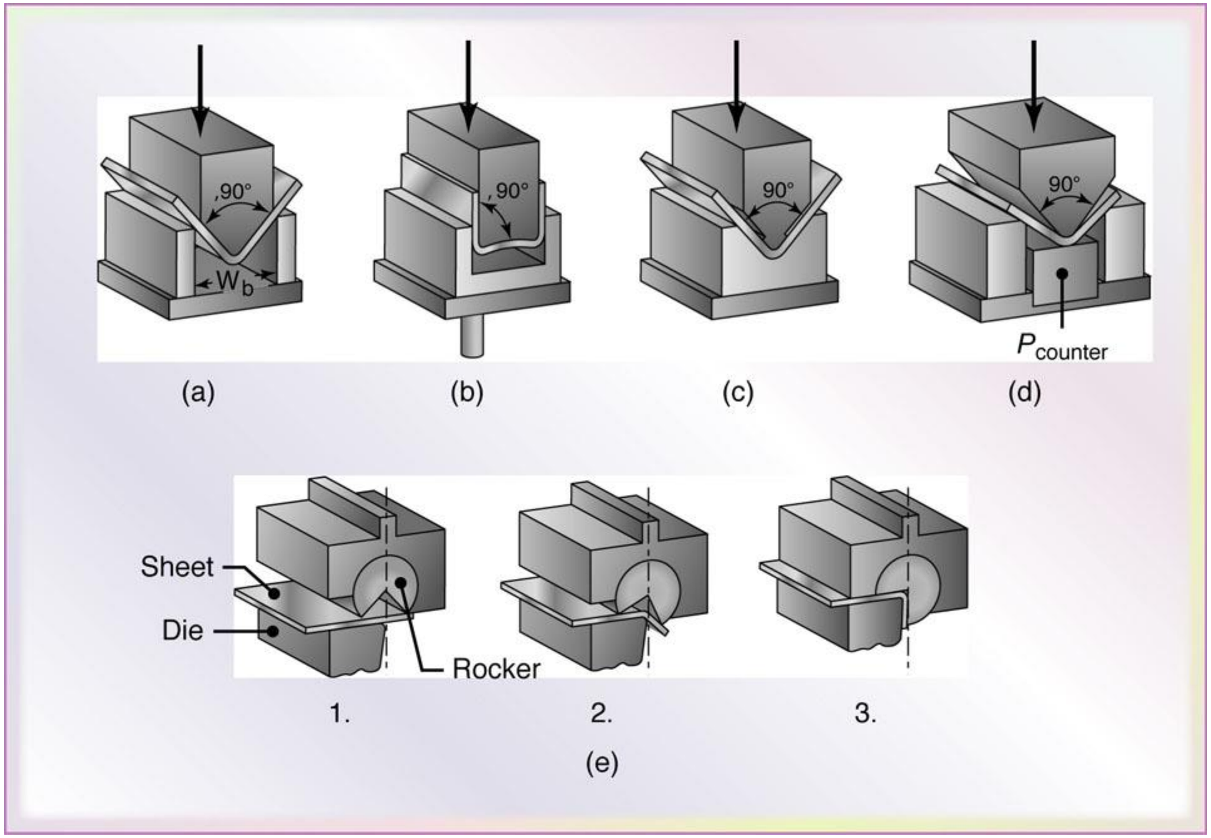


Springback in bending. The part tends to recover elastically after bending, and its bend radius becomes larger. Under certain conditions, it is possible for the final bend angle to be smaller than the original angle (negative springback).

Compensation for Springback

- Few ways to compensate them:
  - Over bending of part
  - Bottoming the punch – coin the bend area by subjecting it to high localized compressive between the technique tip of the punch and the die surface.
  - Stretch bending: part is subjected to tension while being bent (stretch forming)
  - In order to reduce spring back bending may also be carried out at elevated temperatures

Compensation for springback (continue)

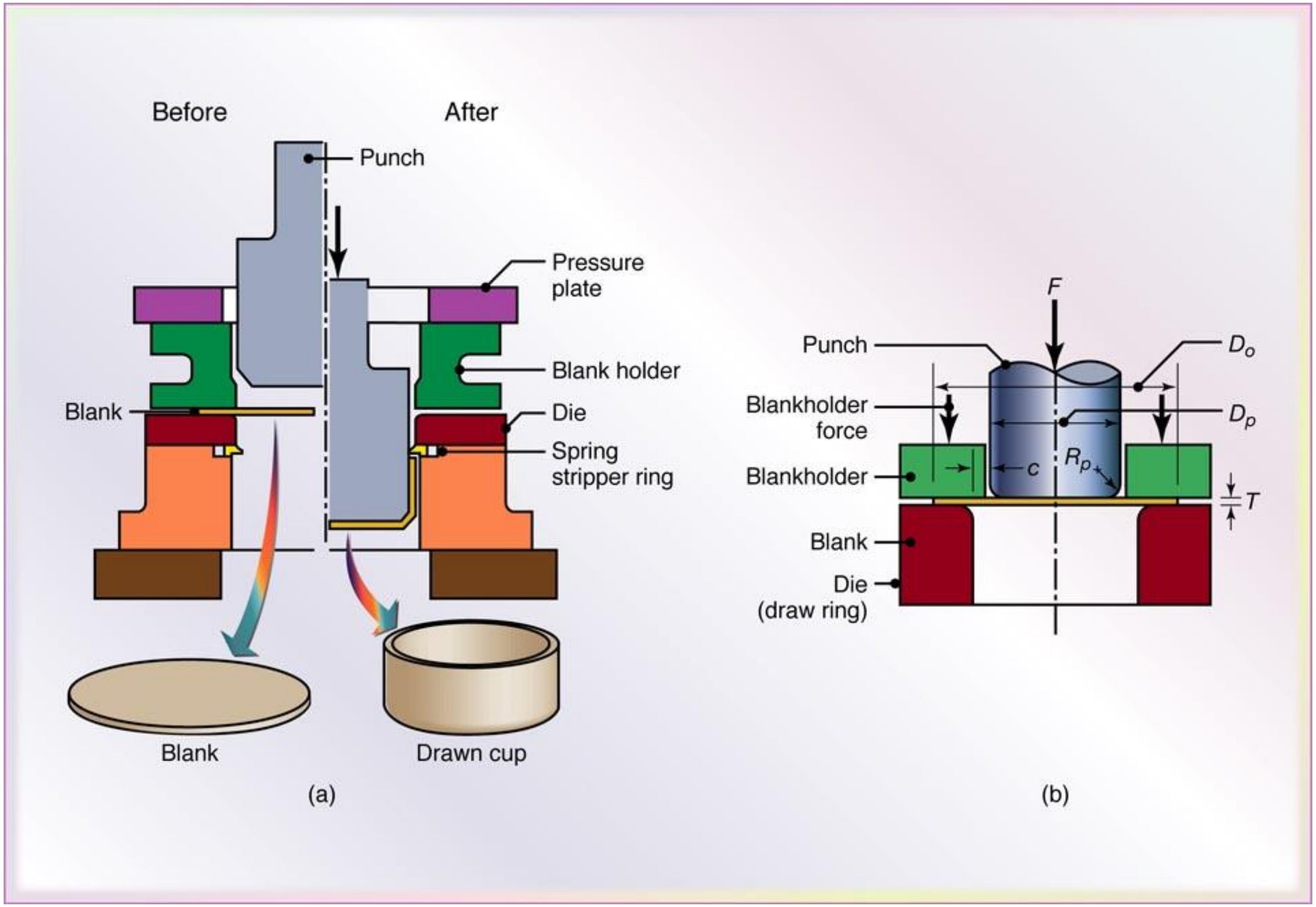


Methods of reducing or eliminating springback in bending operations.
Source: After V. Cupka, T. Nakagawa, and H. Tyamoto.

3. Deep Drawing

- Punch forces a flat sheet metal into a deep die cavity
- Round sheet metal block is placed over a circular die opening and held in a place with blank holder & punch forces down into the die cavity

DEEP DRAWING PRINCIPLE



Schematic illustration of deep drawing process.

Source by Kalpakjian Book, 2014

DEEP DRAWING (CONTINUE)

Equation to calculate maximum punch force

$$F_{max} = \pi D_p T(\text{UTS})\left[\left(\frac{D_o}{D_p}\right) - 0.7\right]$$

- The important variables in deep drawing are:
  - The properties of sheet metal
  - The blank diameter, D_o
  - The punch diameter, D_p
  - The clearance, c
  - The punch corner radius, R_p
  - The die corner radius, R_d

Deep Drawability

- Deep drawability is expressed in LDR
- Limiting drawing ratio (LDR) ;

$$LDR = \text{Max blank } \text{Ø}/\text{punch } \text{Ø} = D_o/D_p$$

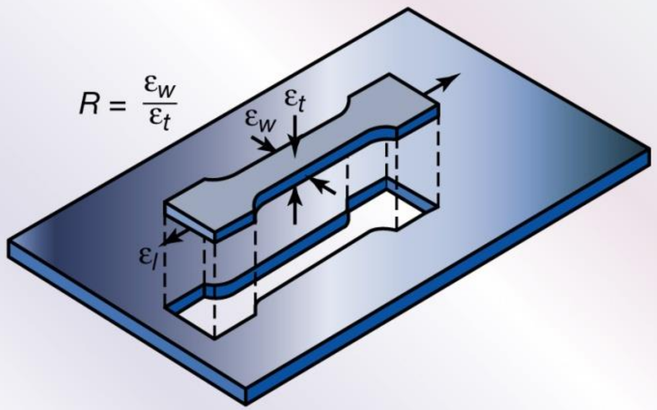
- Drawability of metal is determined by normal anisotropy (R) or plastic anisotropy;

$$R = \text{width strain / thickness strain} = E_w/E_t$$

- R value is get from tensile test.

$$Ravg = (R0 + 2R45 + R90) / 4$$

Normal and Average Anisotropy



$$\text{Normal anisotropy}, R = \frac{\text{Width strain}}{\text{Thickness strain}} = \frac{\varepsilon_w}{\varepsilon_t}$$

$$\text{Average anisotropy}, R_{avg} = \frac{R_0 + 2R_{45} + R_{90}}{4}$$

Strains on a tensile-test specimen removed form a piece of sheet metal. These strains are used in determining the normal and planar anisotropy of the sheet metal.

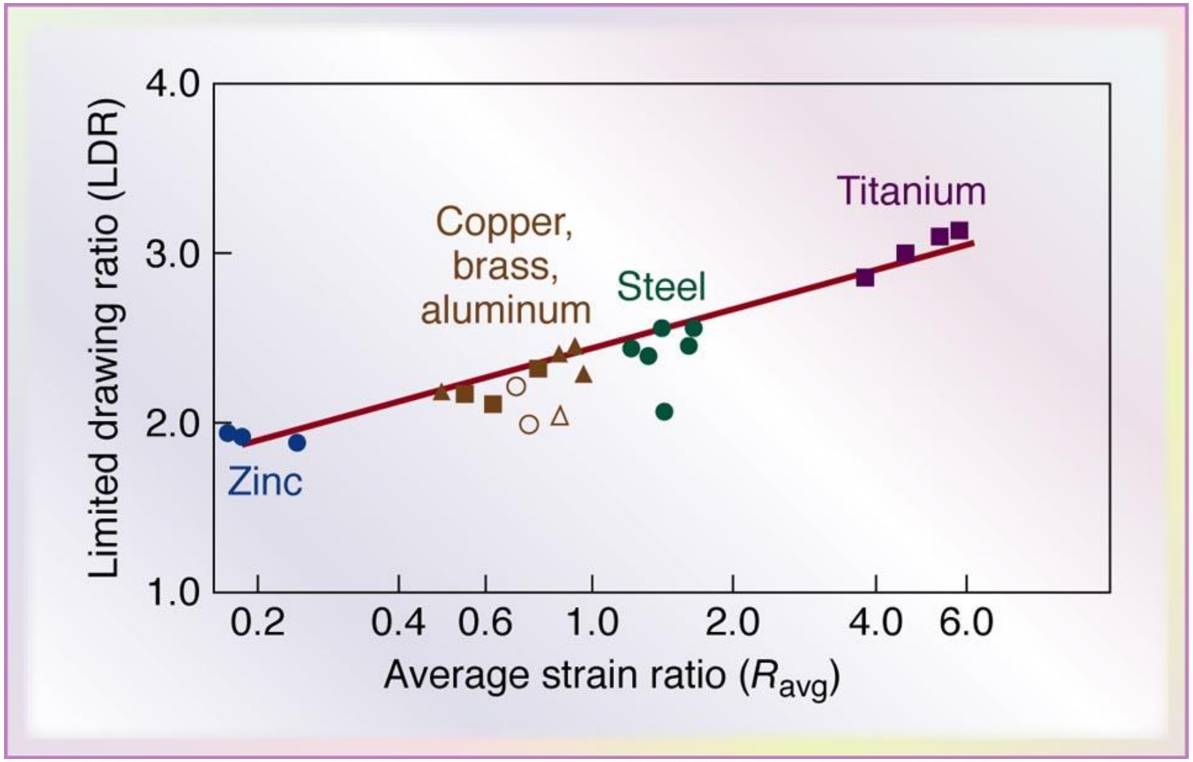
TABLE 16.4

Typical Ranges of Average Normal Anisotropy, R_{avg}, for Various Sheet Metals

Zinc alloys	0.4–0.6
Hot-rolled steel	0.8–1.0
Cold-rolled, rimmed steel	1.0–1.4
Cold-rolled, aluminum-killed steel	1.4–1.8
Aluminum alloys	0.6–0.8
Copper and brass	0.6–0.9
Titanium alloys (α)	3.0–5.0
Stainless steels	0.9–1.2
High-strength, low-alloy steels	0.9–1.2

Source by Kalpakjian Book, 2014

Relationship between Average Normal Anisotropy and the Limiting Drawing Ratio



The relationship between average normal anisotropy and the limiting drawing ratio for various sheet metals. *Source:* After M. Atkinson.

Deep Drawing Practice

- Blank holder pressure: 0.7-1.0 % of Yield strength + UTS
- Clearance usually: 7 -14 % > sheet thickness
- Lowers forces and increases drawability
- Commonly used lubricants are mineral oils, heavy duty emulsions and soap solutions.

DEEP DRAWING: BEVERAGE CAN MANUFACTURE

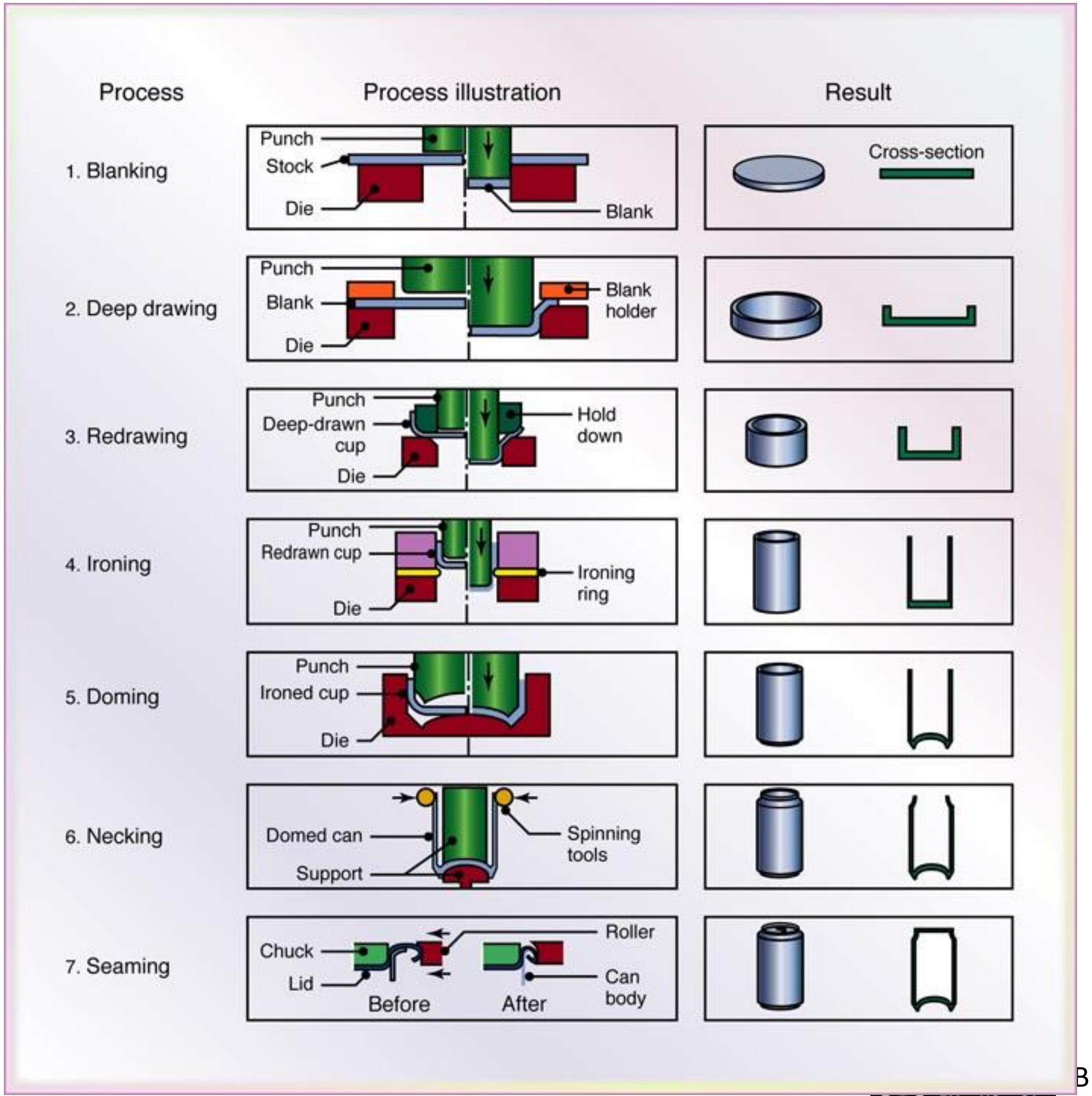
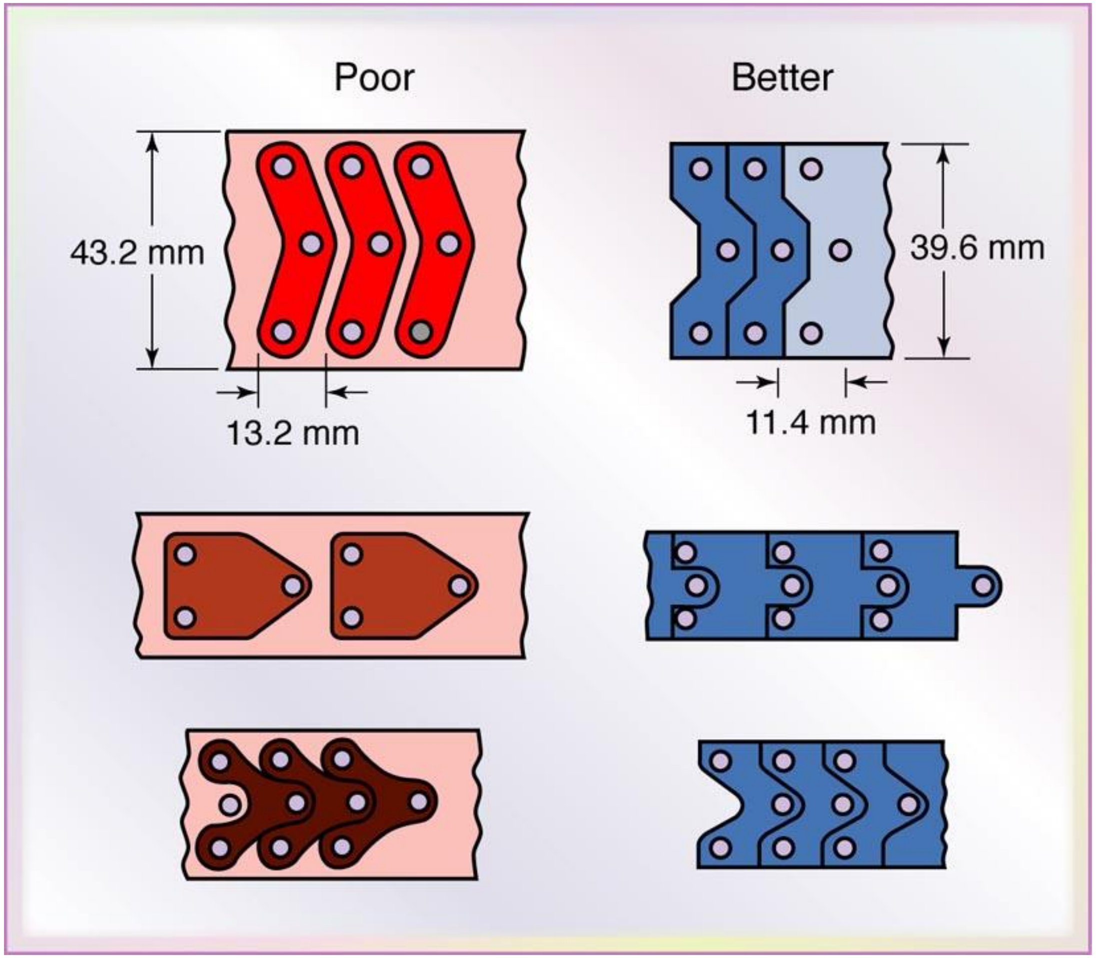


Illustration of beverage can manufacture. The metal-forming processes involved in manufacturing a two-piece aluminum beverage can.

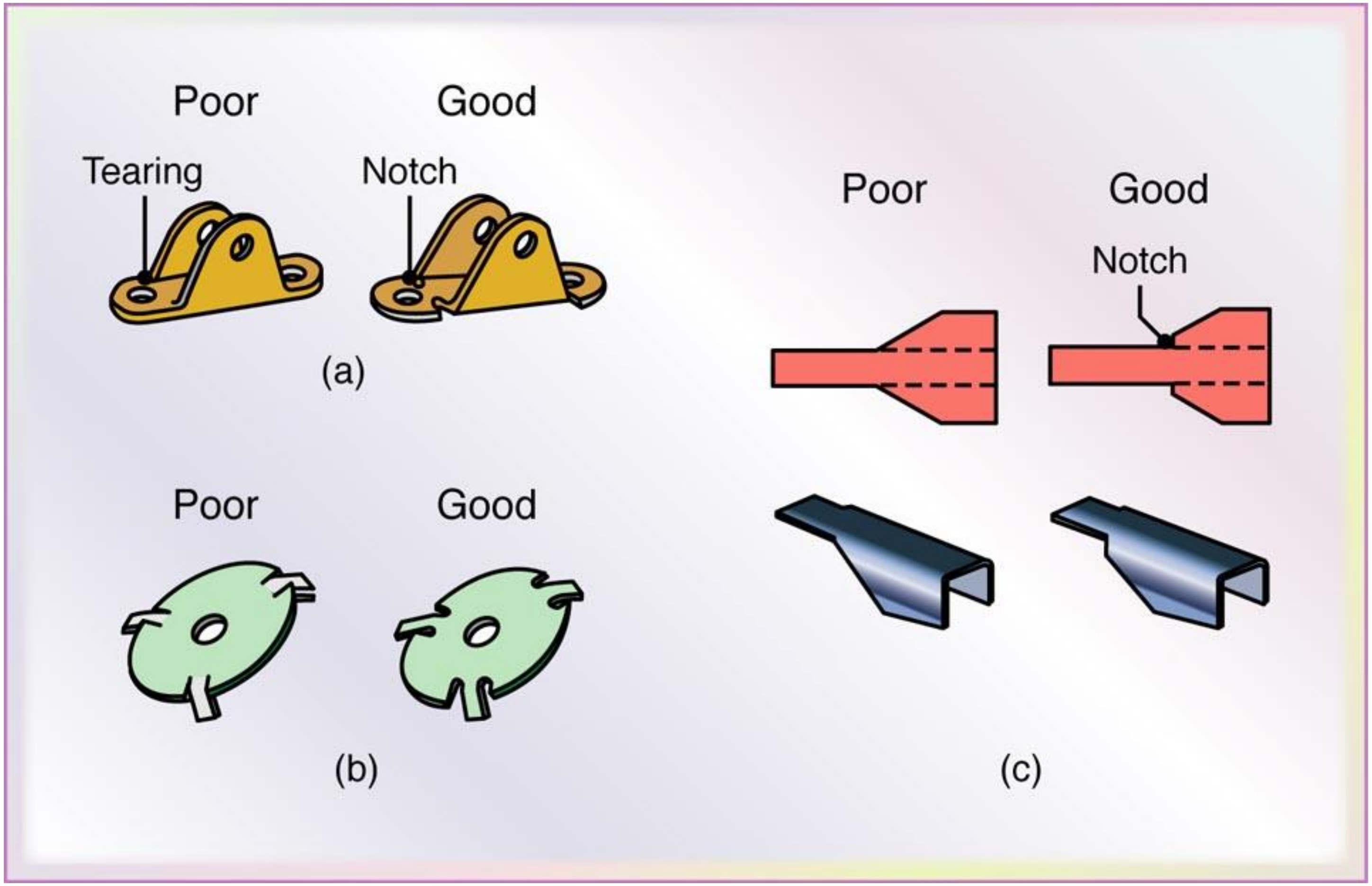
Source by Kalpakjian Book, 2014

DESIGN CONSIDERATION IN SHEET-METAL FORMING



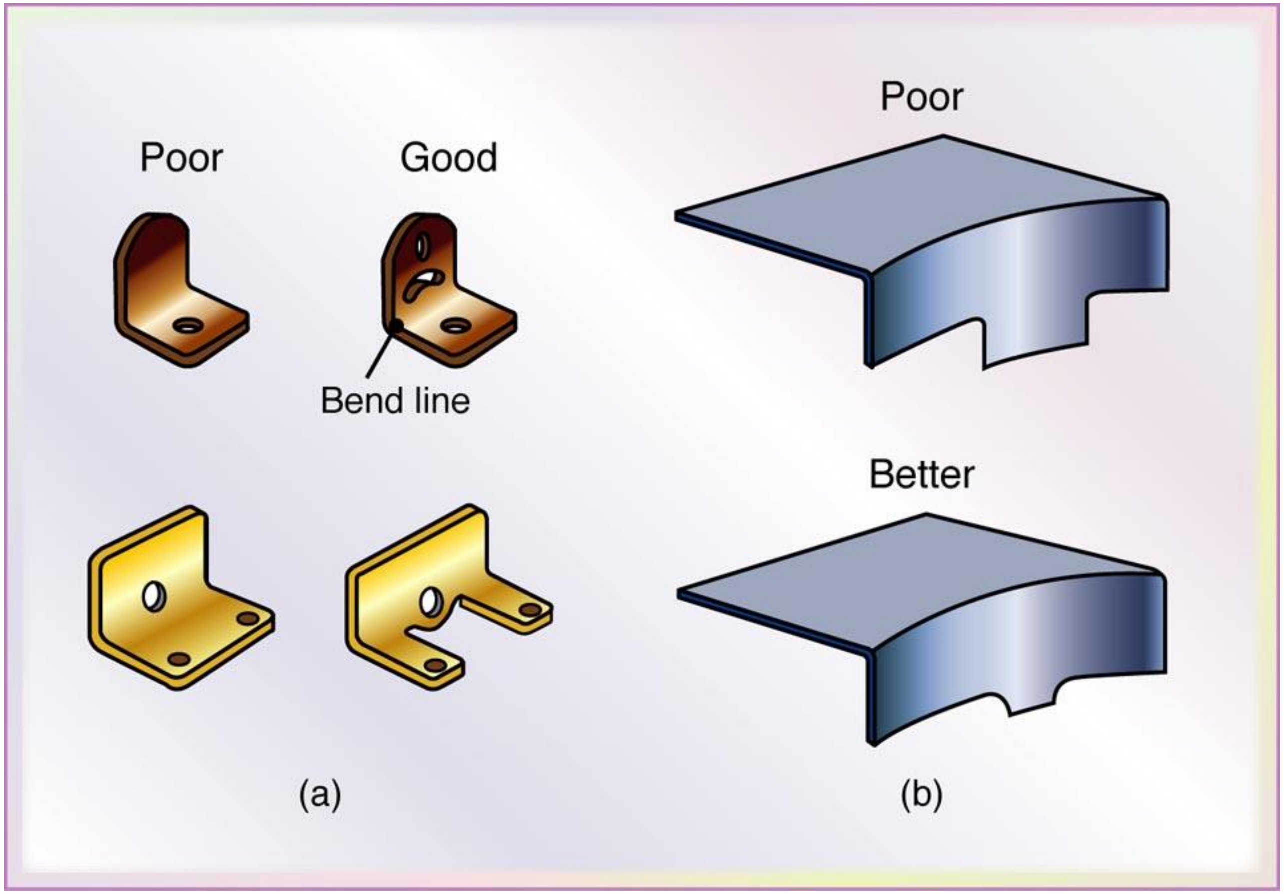
Efficient nesting of parts for optimum material utilization in blanking. *Source*: Courtesy of Society of Manufacturing Engineers.

APPLICATION OF NOTCHES



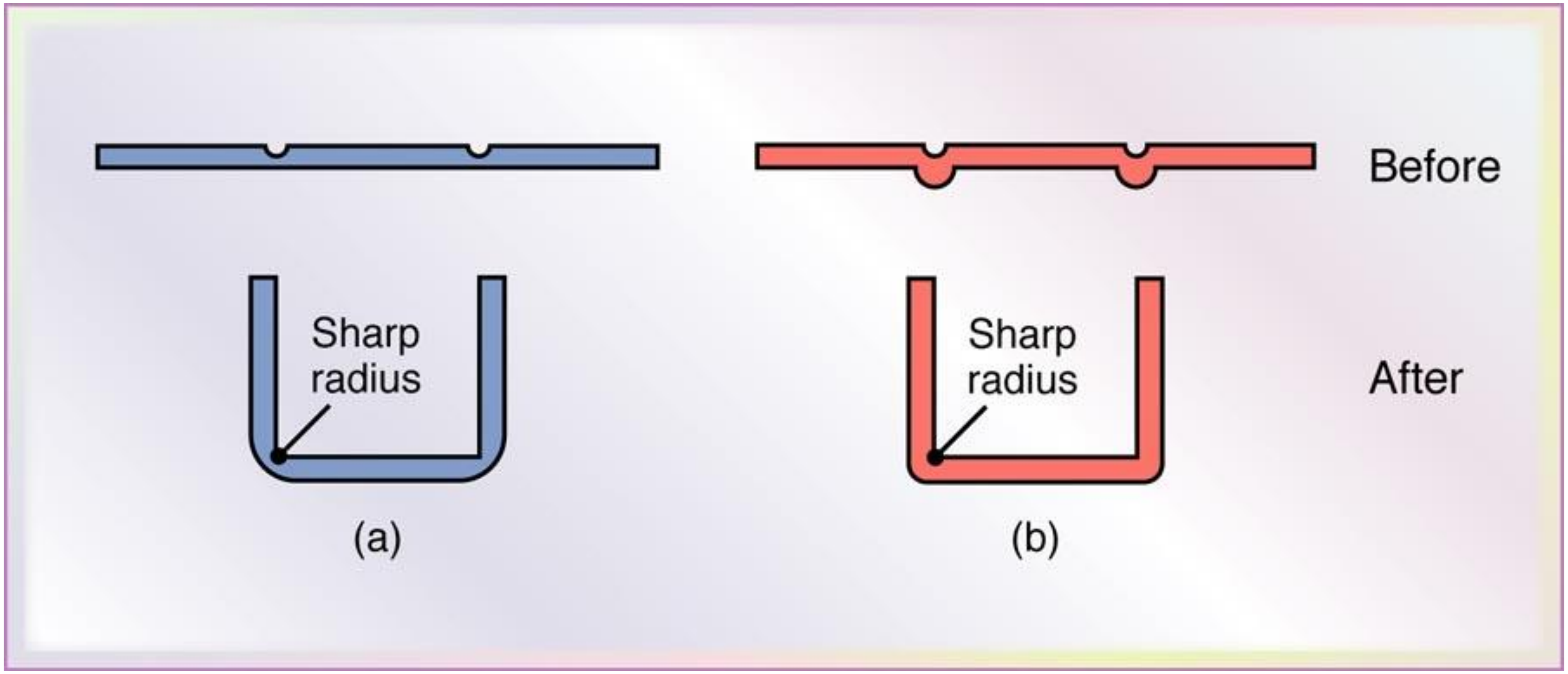
Application of notches to avoid tearing and wrinkling in right-angle bending operations. *Source*: Courtesy of Society of Manufacturing Engineers.

STRESS CONCENTRATION NEAR BENDS



Stress concentration near bends. (a) Use of a crescent or ear for a hole near a bend. (b) Reduction of severity of tab in flange. *Source*: Courtesy of Society of Manufacturing Engineers.

OBTAINING A SHARP RADIUS IN BENDING



Application of scoring or embossing to obtain a sharp inner radius in bending. Unless properly designed, these features can lead to fracture. *Source*: Courtesy of Society of Manufacturing Engineers.

End of chapter

Sheet Metal Forming Processes