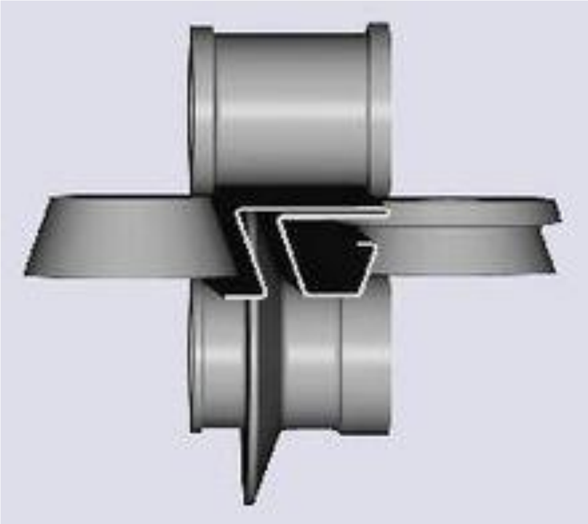
ME 3013
Manufacturing Processes I
2019
Lecture 3 – Cold Metal Forming

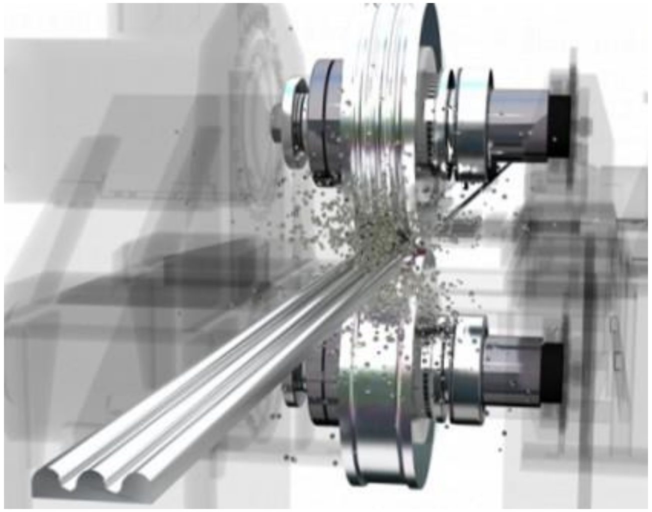
PHYSICAL QUANTITIES OF ROLLING

- Roll separating force (P_r) in N/mm.
- Roll pressure p in Pa.
- Coefficient of friction μ
- Width of the metal to be rolled w in mm.
- Radius of the work roll R and deformed radius of the work roll R' in mm.
- Contact length L in mm.
- Entry thickness h_{entry}, exit thickness h_{exit} and the difference Δh in mm.
- Shear stress τ in Pa.
- The angle between the vertical lines is ϕ
- The torque per width M in N.
- r is the reduction in %.

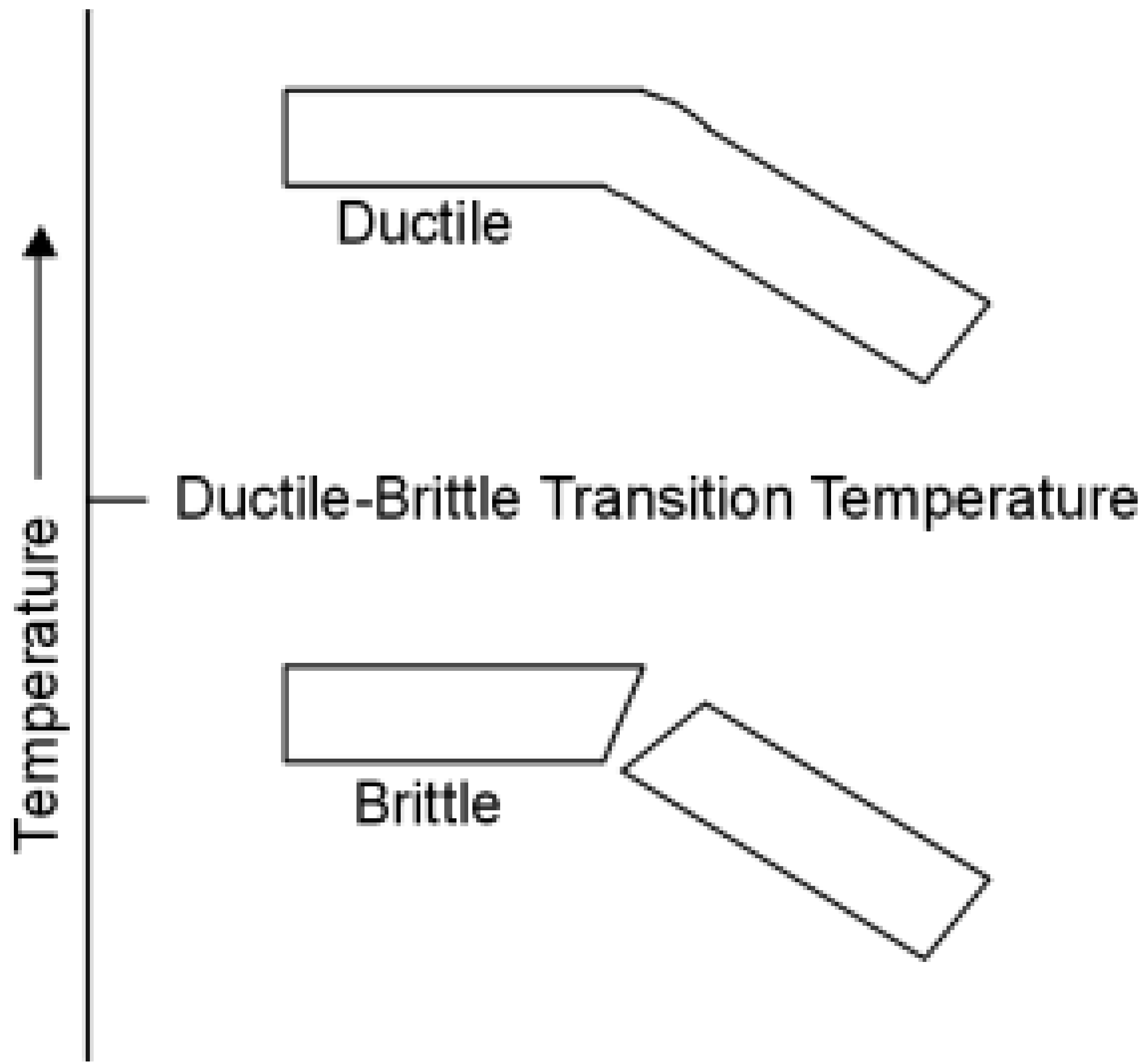
Outline

- Introduction
- Squeezing Processes
  - Forming
  - Joining
  - Surface improvement
- Bending
- Shearing
- Drawing
  - Bar, Rod, Tube, Wire
  - Sheet Metal
- Presses

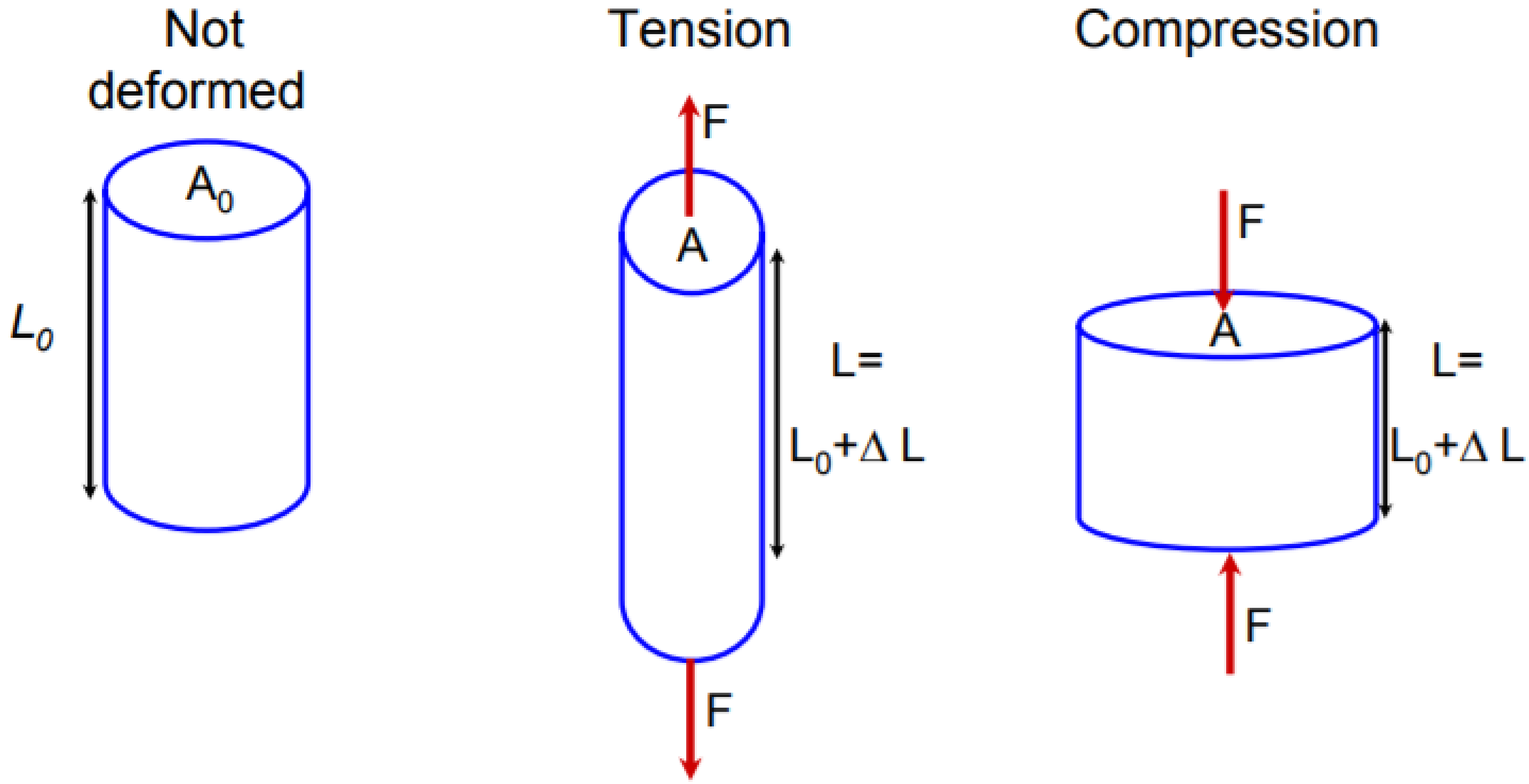




DUCTILE	BRITTLE
Ductile materials can be drawn into wires by stretching	Brittle materials break, crack or snap easily
Ductile materials show deformation	Brittle materials do not show deformation
Ductility is affected by temperature	Brittleness is affected by pressure (or stress)
Major examples for ductile materials are metals	Examples of brittle materials include ceramic and glass

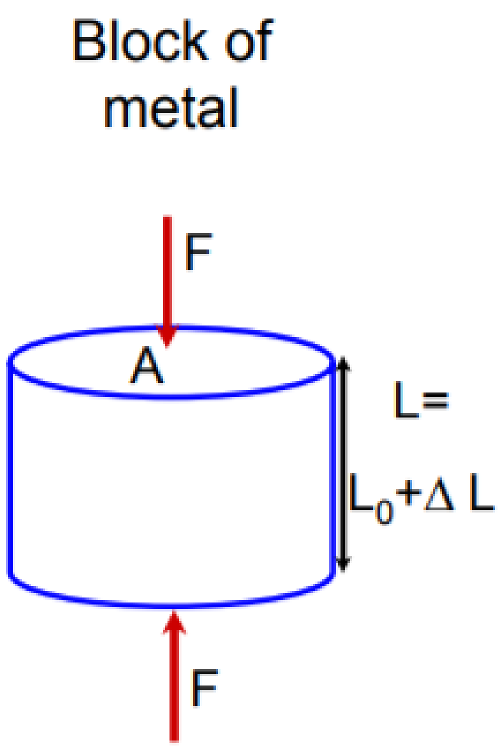

Ductile
Ductile-Brittle Transition Temperature
Brittle
Temperature

Load can be applied to the material by applying axial forces:



ΔL can be measured as a function of the applied force; area A_0 changes in response

Stress (σ) and Strain (ε)



Stress (σ)

- defining F is not enough (F and A can vary)
- Stress σ stays constant

$$\sigma = \frac{F}{A}$$

- Units

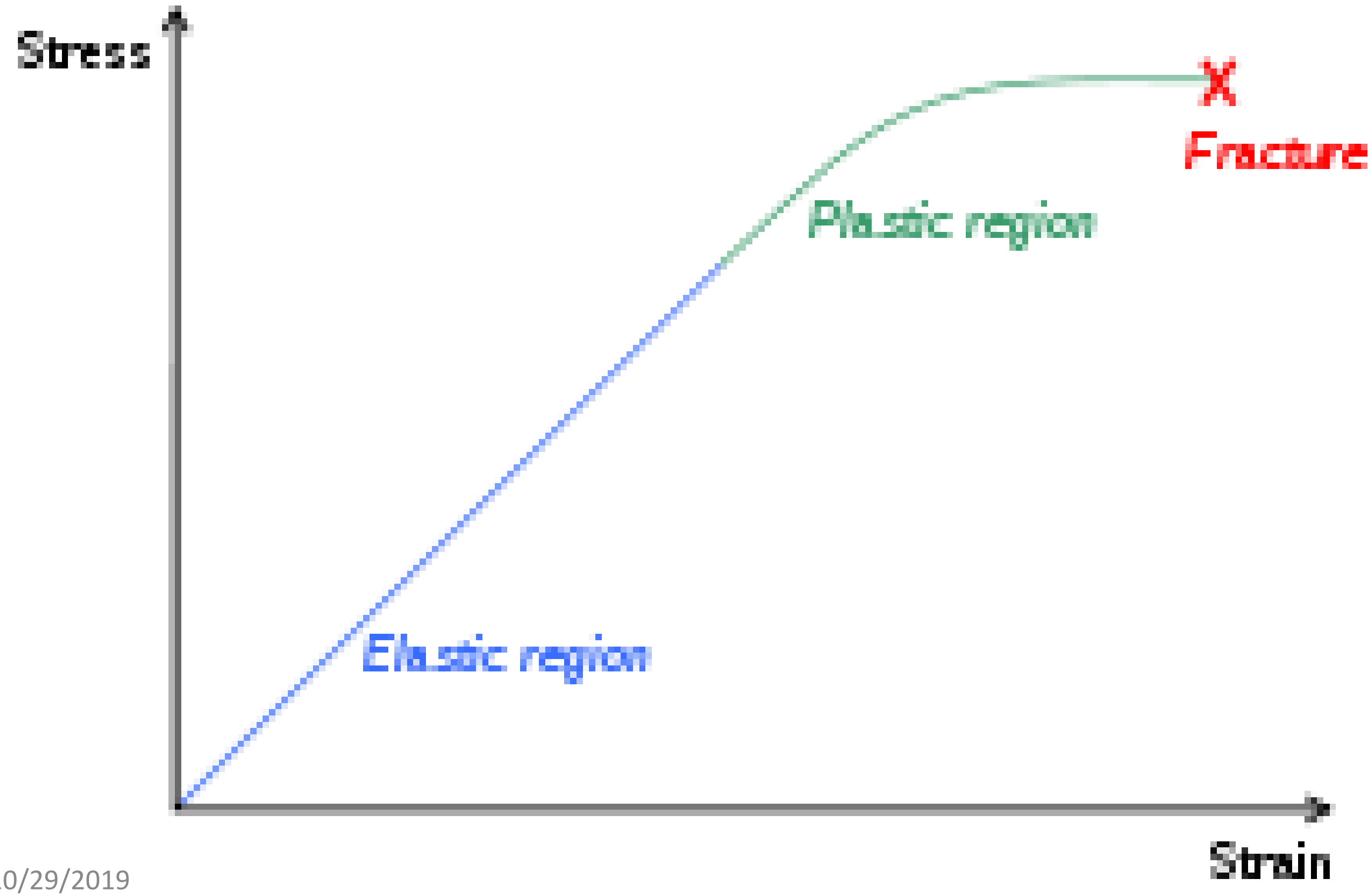
  Force / area = N / m^2 = Pa

  usually in MPa or GPa

Strain (ε) – result of stress

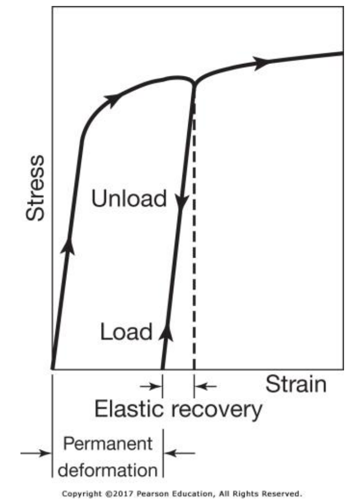
- For tension and compression: change in length of a sample divided by the **original** length of sample

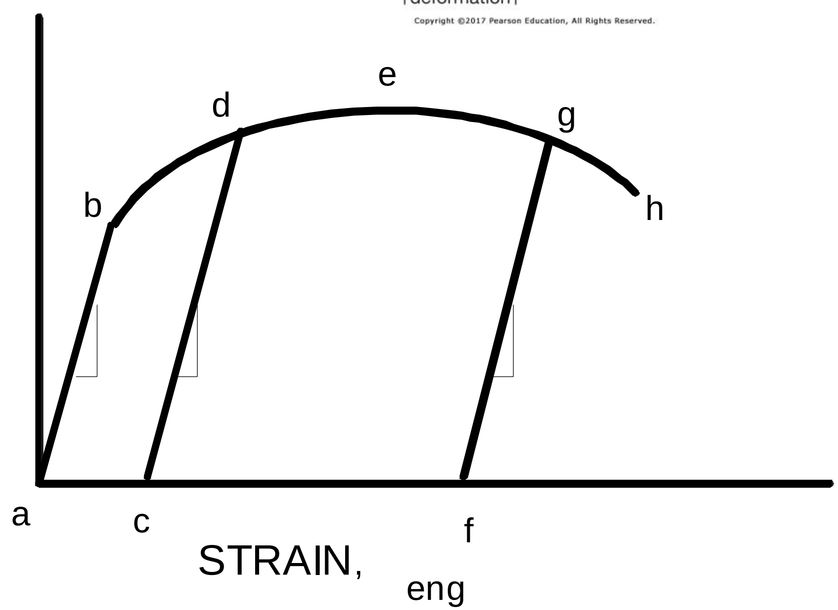
$$\varepsilon = \frac{\Delta L}{L}$$


Stress
Fracture
Plastic region
Elastic region
Strain

Strain Hardening

- Plastic deformation is a <u>permanent</u> deformation.
  - Obtained by applying large forces that exceed the elastic limit of the material.
- When metals are plastically deformed, their strength tends to *increase*.
- This is called *strain* or *work- hardening*.





Load-strain curve plotted on Cartesian Coordinates

Cold Working

- Cold working is plastic deformation of metals below their *recrystallization* temperature.
- It is generally performed at *room* temperature.

Advantages:

- No heating
- Better *surface* finish
- Superior *dimension* control
- Improved *strength*
- Directional properties can be imparted (bestow a quality).
- *Contamination* problems are minimized.

Disadvantages:

- Higher forces for deforming the part
- Heavier and more powerful equipment
- Less ductility is available.
- Metal surfaces must be clean and scale-free.
- Strain hardening occur.
- Imparted directional properties may be detrimental (damaging).
- May produce undesirable residual stresses.

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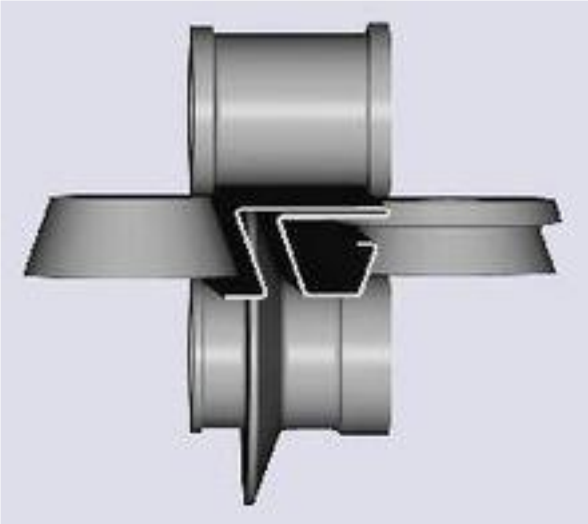
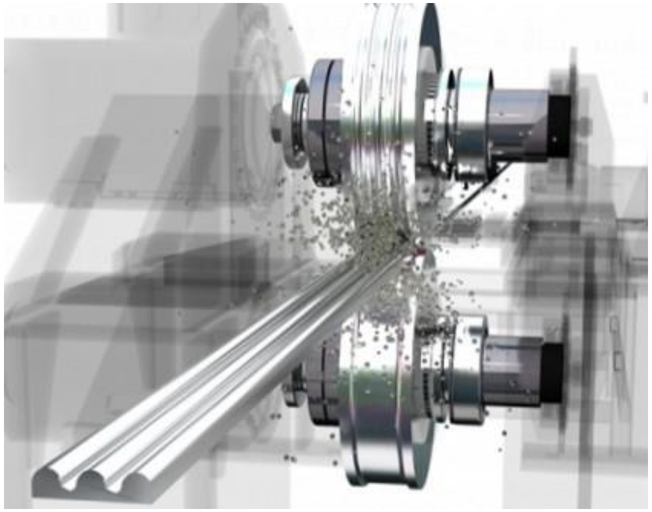




Squeezing Processes

- General Forming Techniques
  - Cold Rolling
  - Swaging
  - Cold Forging
  - Extrusion
  - Coining
- Joining Processes
  - Riveting (perçinleme)
  - Staking
- Surface Improvement
  - Peening
  - Burnishing

Products

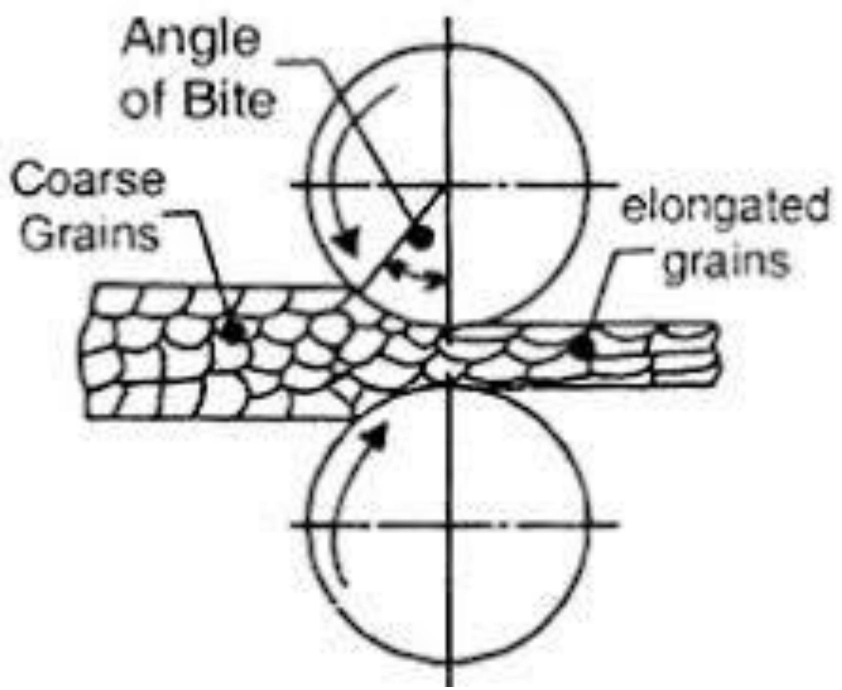
- Shapes
  - I-beams, railroad tracks
- Sections
  - door frames, gutters
- Flat plates
- Rings
- Screws

Rolling of Metals

- reducing the **thickness** or
- changing the **crosssection** of a long workpiece
- by **compressive** forces
- applied through a set of **rolls**
- Developed in late **1500s**
- Accounts for **90%** of all metals produced by metalworking processes
- Often carried out at elevated temperatures first (hotrolling)
- to change coarse-grained, brittle, and porous ingot structures
- to wrought structures with finer grain sizes and enhanced properties

Cold Rolling (Haddeleme)

- Used to have **smooth** surfaces and accurate dimensions.
- Generally cluster of rolls or **planetary** rolls are used.

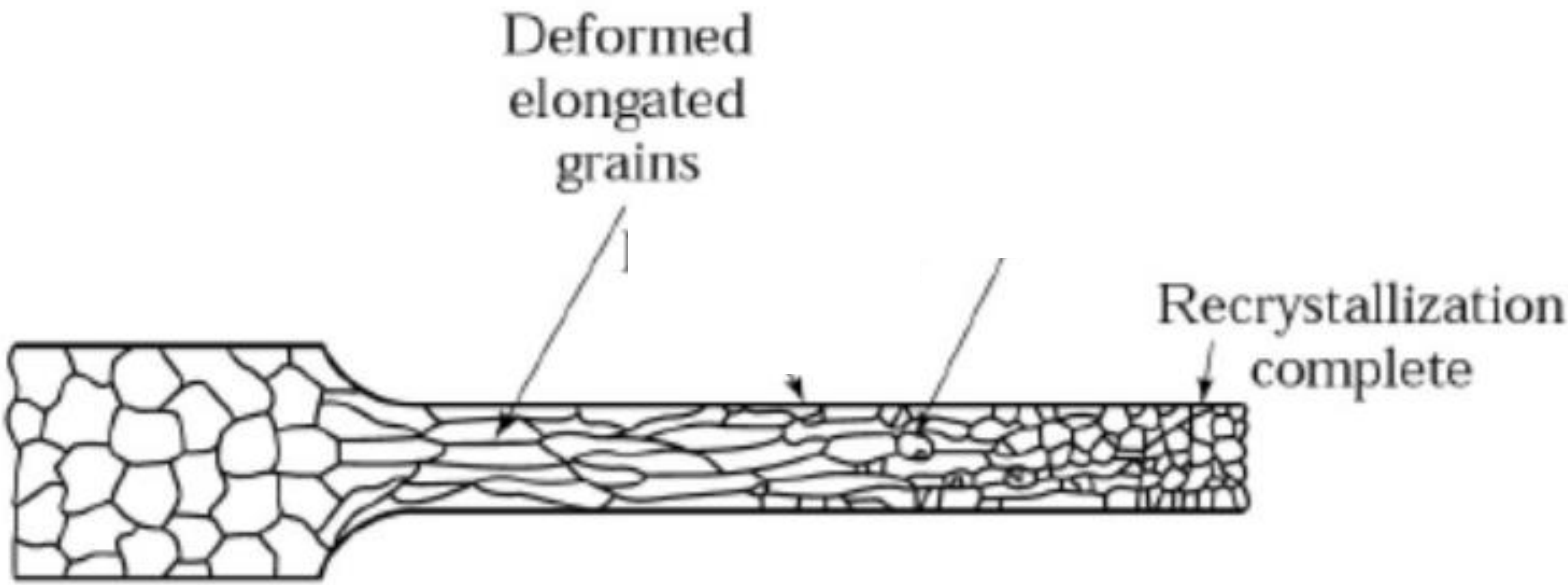


Plates – thickness greater than 6 mm (1/4 inch);

- boiler supports (0.3 m, 12 inch)
- reactor vessels (150 mm, 6 inch)
- battleships and tanks (100-125 mm, 4-5 inch)

Sheets – less than 6 mm thick; flat pieces, strips, and coils for beverage containers, automobile and aircraft bodies, appliances, kitchen and office equipment

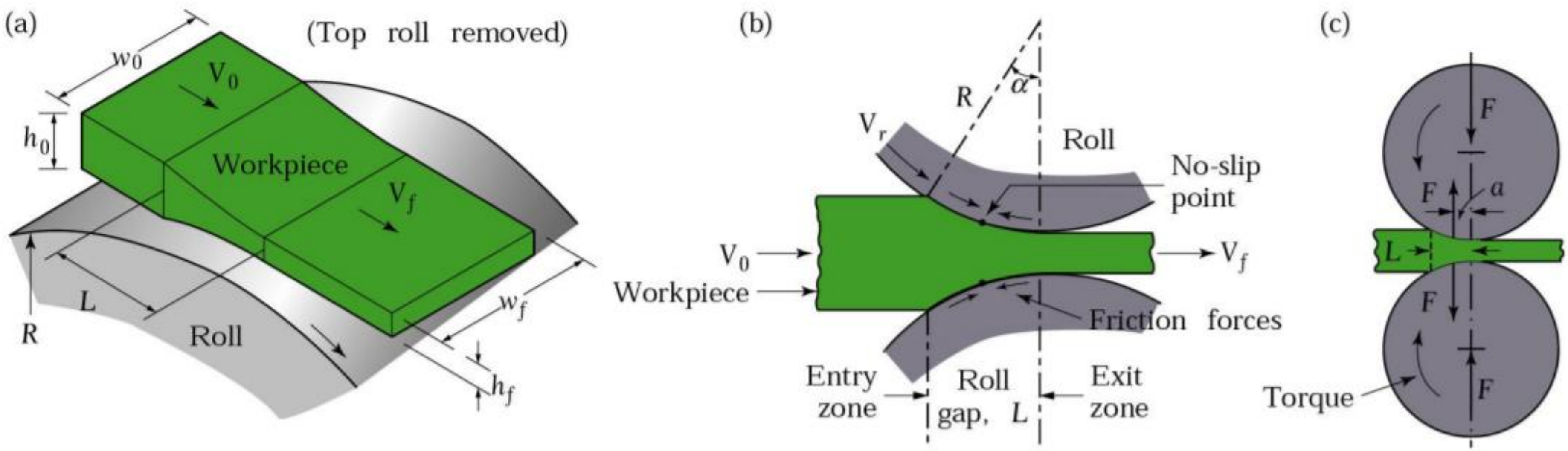
- Boeing 747 skin thickness – 1.8 mm (0.071 inch)
- Aluminum beverage cans – start as sheets that are 0.28 mm
- (0.011 inch) thick; later reduced to 0.1 mm (0.004 inch) by deep drawing
- Aluminum foil – 0.008 mm (0.0003 inch)



- Heavier and more powerful equipment
- Less ductility is available
- Strain hardening occur.
- Imparted directional properties may be detrimental (damaging).
- May produce undesirable residual stresses

Flat Rolling

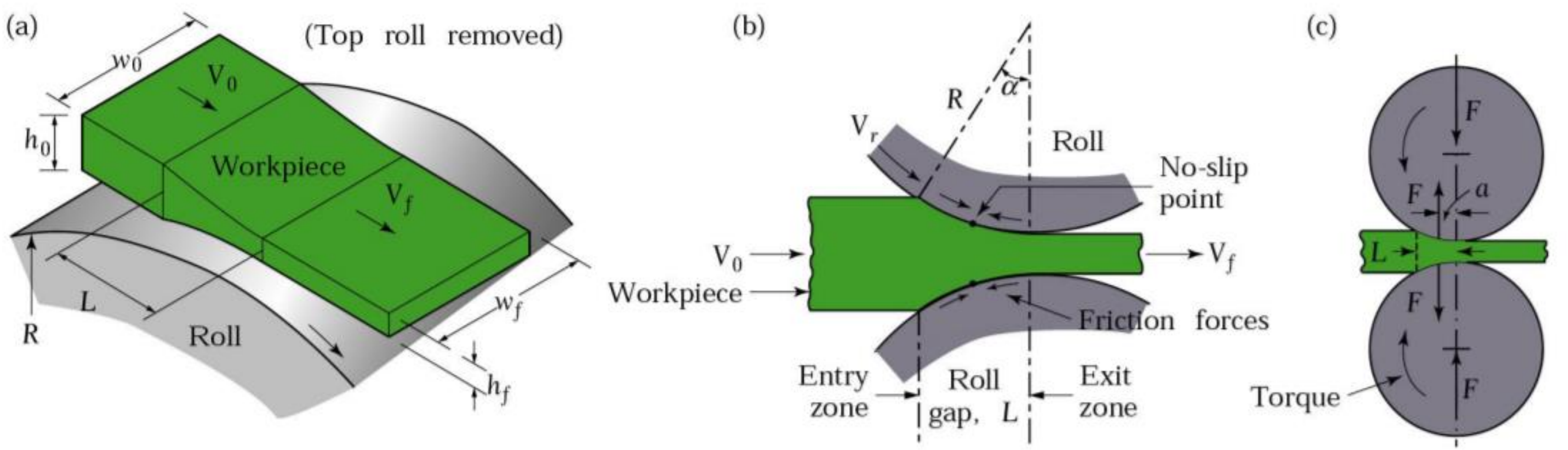
- Initial thickness h_o
- Final thickness h_f
- Roll gap L
- Surface speed of rolls V_r
- Entry velocity of strip V_o
- Final velocity of the strip V_f
- Neutral point, no-slip point – point along contact length where velocity of the strip equals velocity of the roll



Maximum Draft

$$h_o - h_f = \mu^2 R$$

- h_o is initial strip thickness,
- h_f final strip thickness,
- μ is friction coefficient, copper and roll can be taken as 0.1
- R is the roll radius.



LIMITATIONS OF FLAT ROLLING

- Minimum rollable thickness by Stone (1953)

$$h_{\min} = \frac{3.58 D \mu \sigma_{fm}}{E}$$

- D: roll diameter in mm
- E :elastic modulus in Pa,
- σ: average flow strength in Pa
- μ: coefficient of friction.

Edge cracking

Alligatoring

Roll Force and Power Equations

Rolling force can be estimated as in the following

$$F = LwY_{avg}$$

L is the roll-strip contact length, w is the width of the strip,

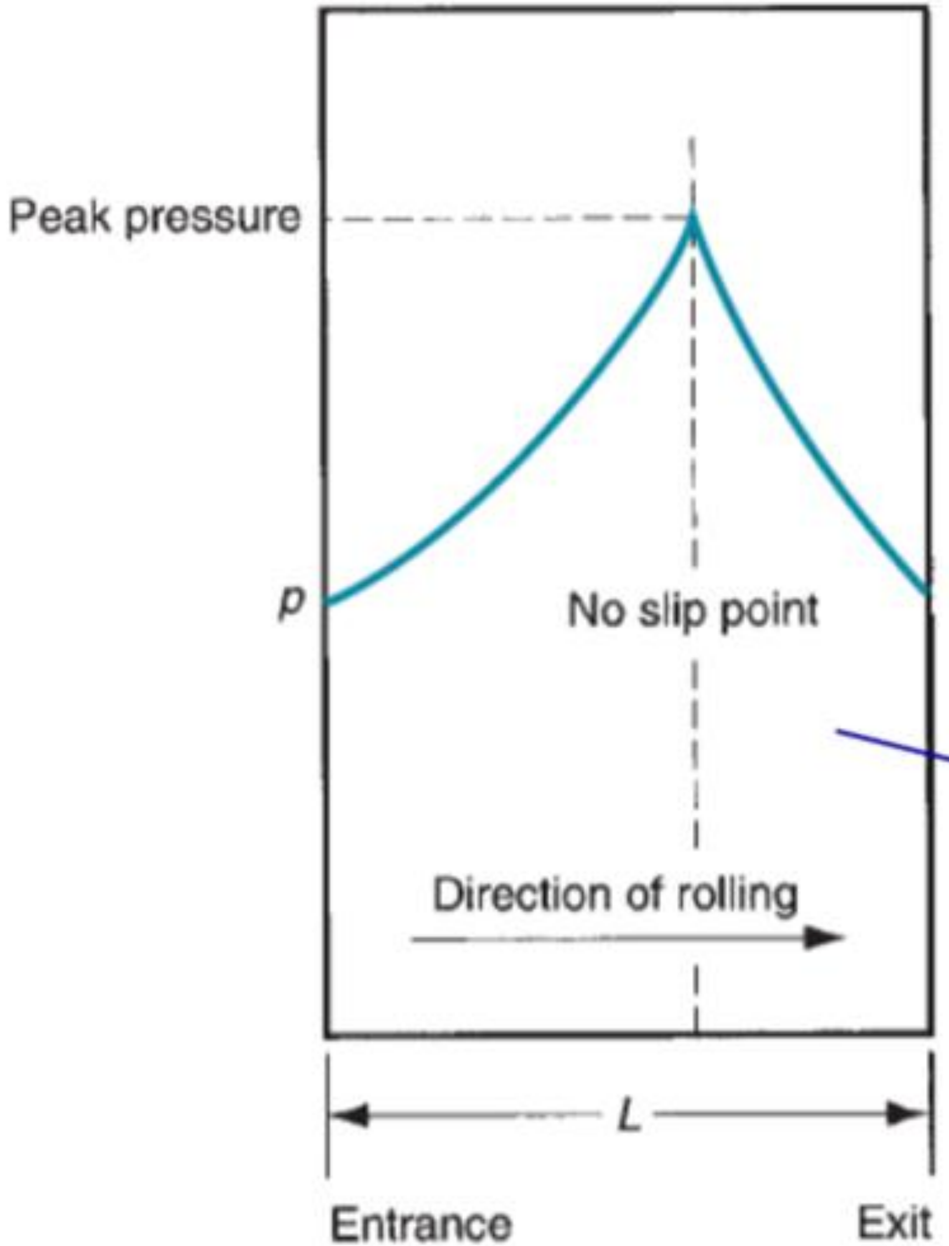
Y_{avg} is the average true stress.

The *torque* on the roll is the product of F and a. $a = L/2$.

$$Power\ (kW) = \frac{2\ \pi FLN}{60{,}000}$$

Where F is in Newtons, L is in meters, and N is rpm of roll

Typical variation in roll pressure along the contact length in flat rolling



$$F = w\int_0^L p\,dL$$

Area under the curve, rolling force, *F*,

Example

- w = 10 mm
- h_b = 2 mm
- height reduction = 30% ($h_f = 0.7\ h_b$)
- hf = 1.4 mm
- R = 75 mm
- v_R = 0.8 m/s
- mineral oil lubricant ($\mu = 0.1$)
- K = 720 MPa, n = 0.46
- Yavg = 425 MPa

Maximum draft:

$$\Delta h_{max} = \mu^2 R$$

$$= (0.1)^2 \bullet 75 = 0.75 \text{ mm}$$

$$\Delta h_{actual} = h_b - h_f = 2 - 1.4$$

$$= 0.6 \text{ mm}$$

Rolling force

$$L = (R\Delta h)^{0.5} = [75 \text{ x } (2\text{-}1.4)]^{0.5}$$

$$= 6.7 \text{ mm}$$

$$F = LwY_{avg}$$

$$w = 10 \text{ mm}$$

$$= 6.7 \times 10^{-3} \cdot 10 \times 10^{-3} \cdot 425 \times 10^{6}$$

$$= 28{,}392 \ N = 3.2 \ \ tons$$

The *torque* on the roll is the product of F and a. $a = L/2$.

$$Power\ (kW) = \frac{2\ \pi FLN}{60{,}000}$$

$$Power\ (kW)\Big/_{roller} = T \times \omega = \frac{F \cdot L \cdot V_R}{2 \cdot R}$$

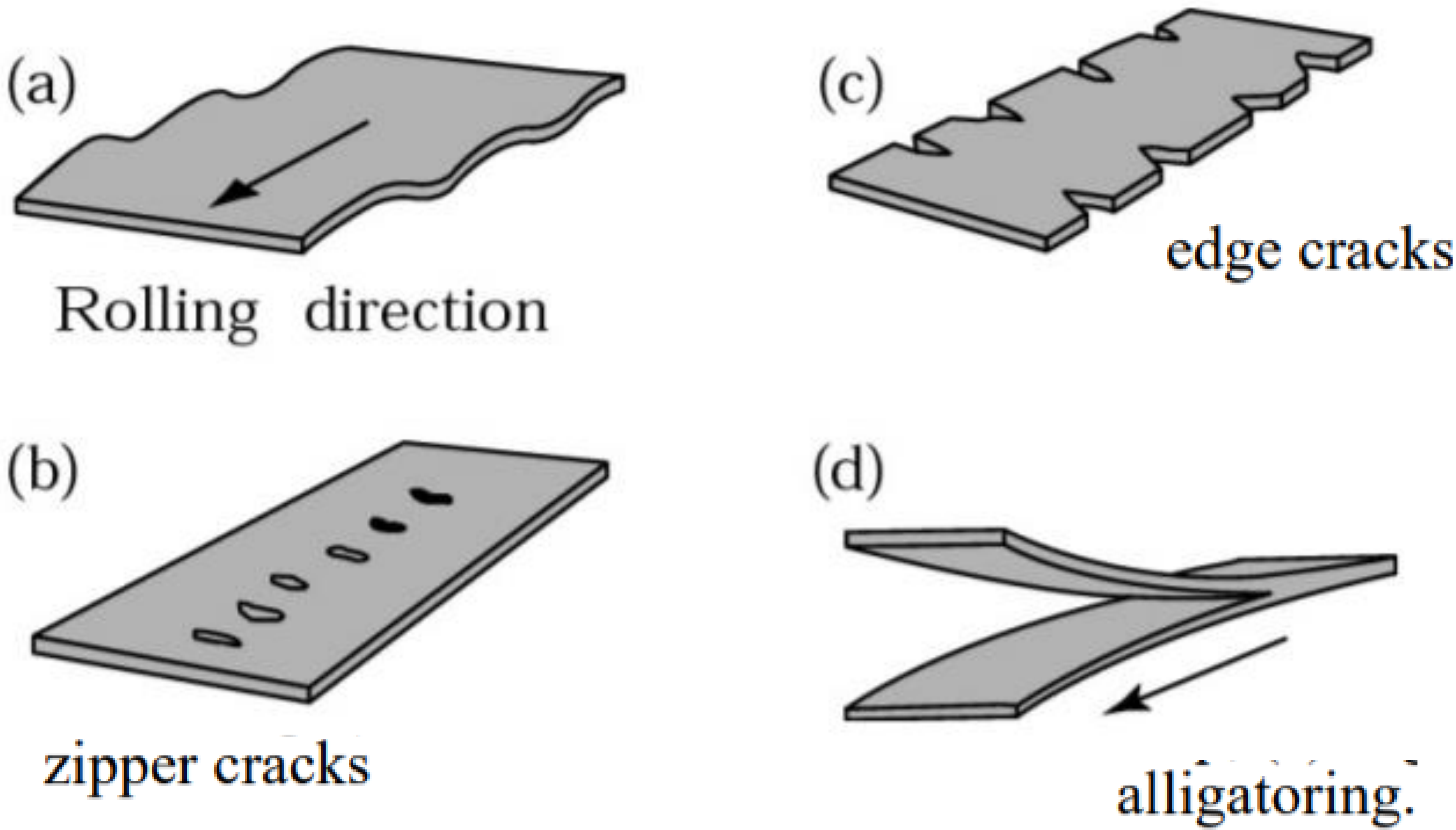
$$Power\ (kW)/\ roll = \frac{28{,}392 \cdot 6.7 \times 10^{-3} \cdot 0.8}{2 \cdot 0.075}$$

$$= 1.01\, kW\ /\ roll = 1.35\, hp$$

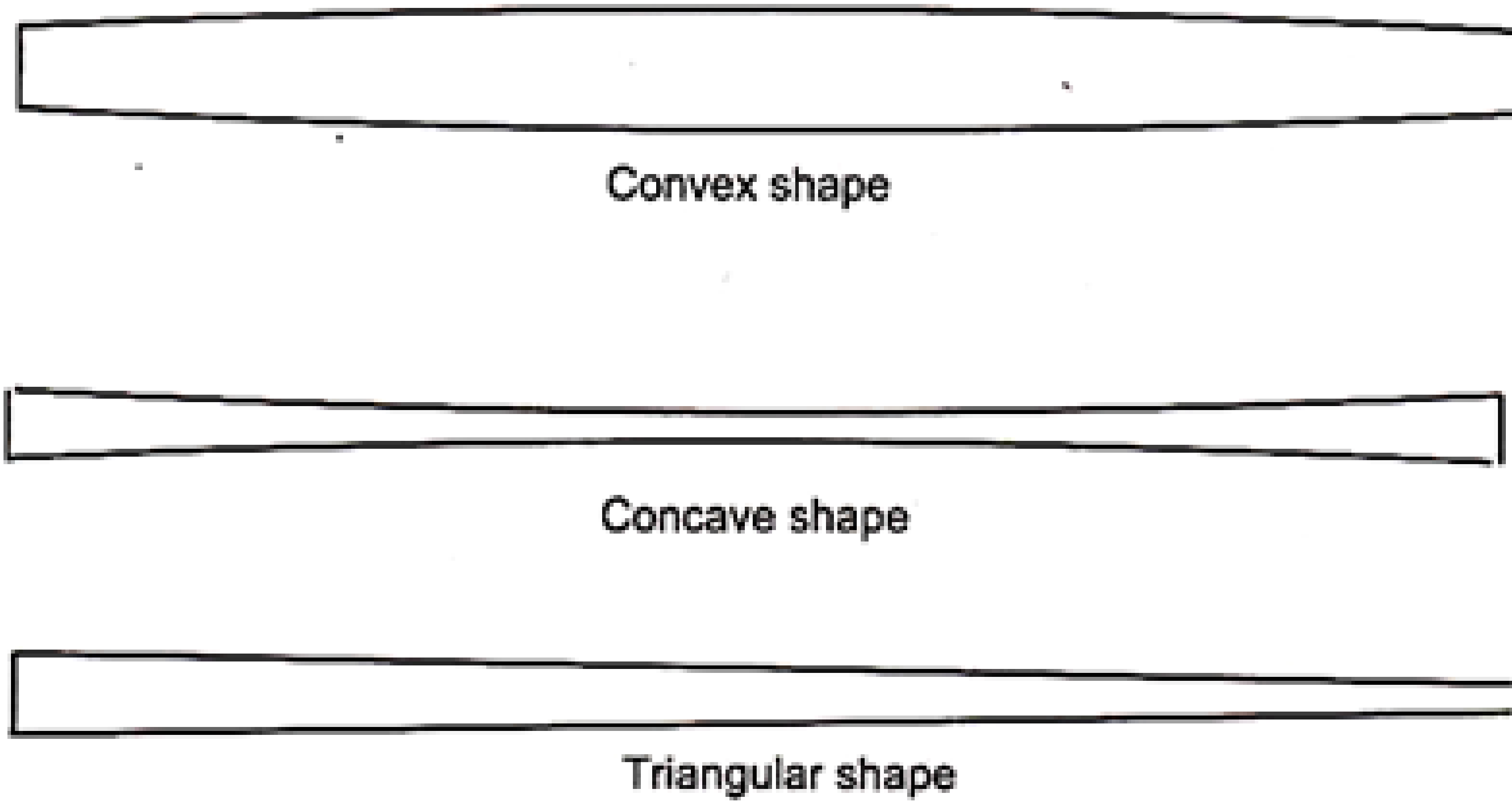
Defects in Rolling

- **Surface defects** – scale, rust, scratches, gouges, pits, and cracks
- **Wavy edges** – due to roll bending
- **Alligatoring** – complex phenomenon that may be due to non-uniform deformation or defects in the billet

wavy edges;

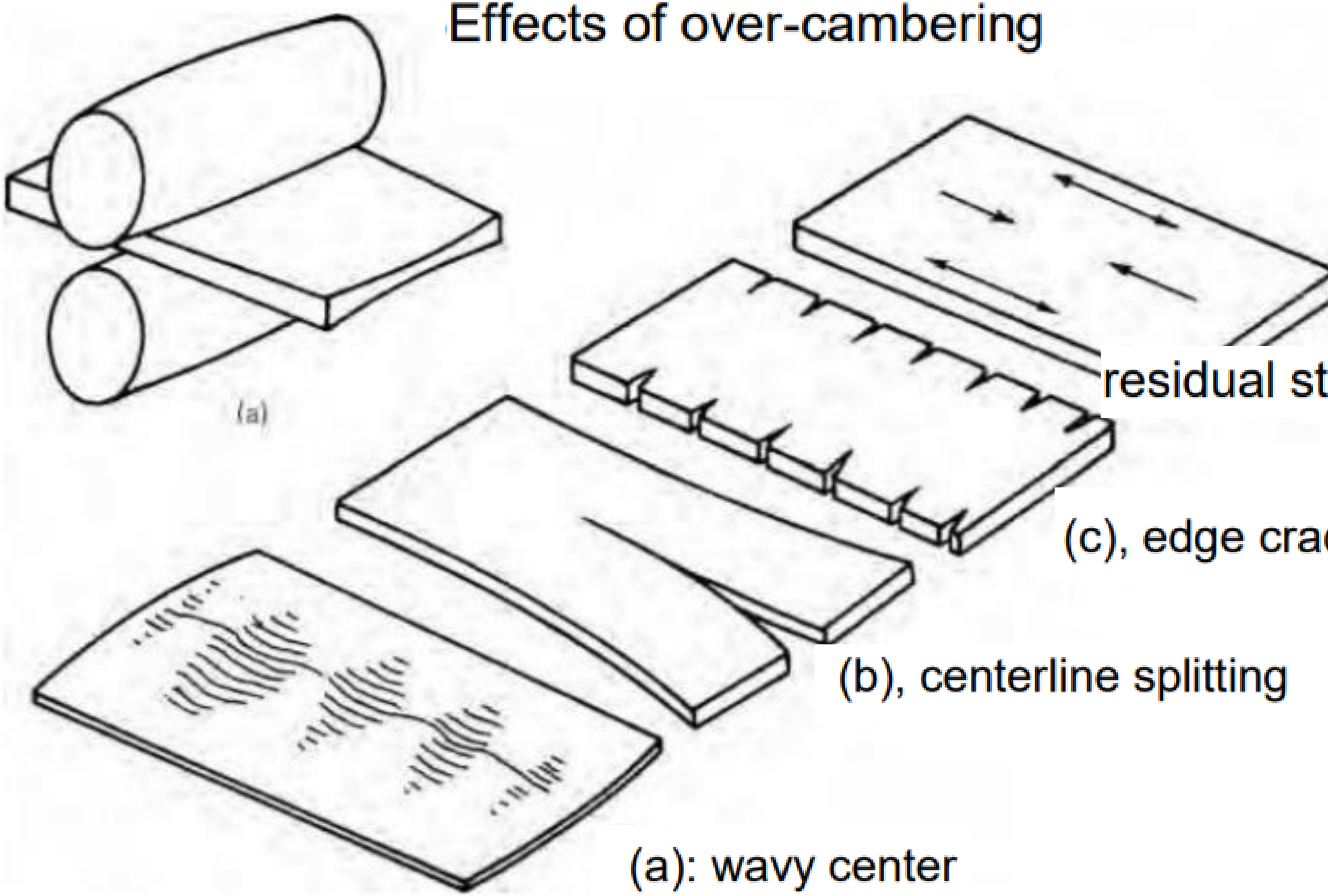


(a)
Rolling direction
(b)
zipper cracks
(c)
edge cracks
(d)
alligatoring.



Cambers observed on sheet

Effects of over-cambering



residual stresses.

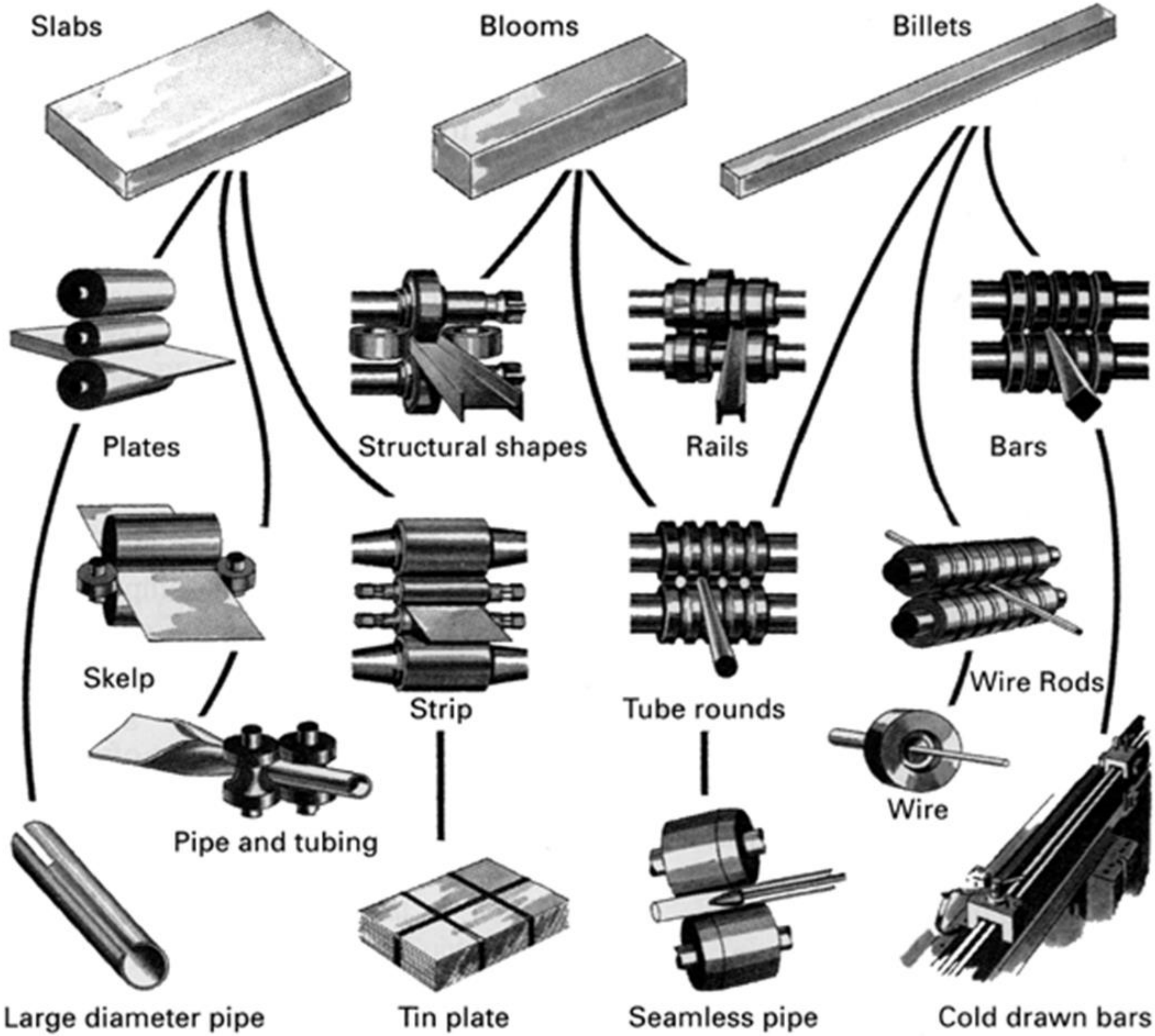
(c), edge cracking

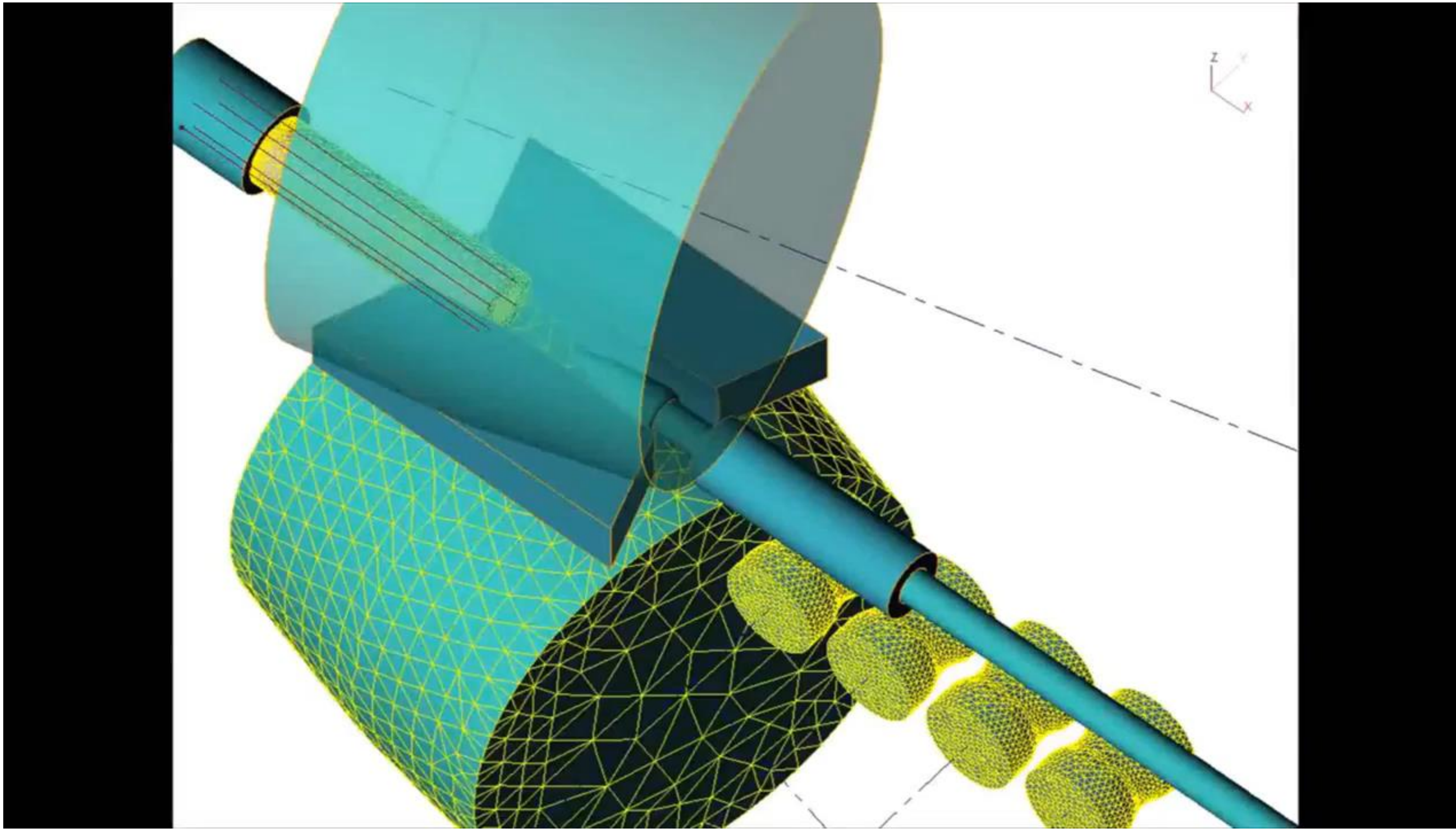
(b), centerline splitting

(a): wavy center

Rolled Metal Characteristics

- Residual stresses
- Dimensional tolerances for cold-rolled sheet thicknesses
- +/- 0.1 mm to 0.35 mm (0.004 to 0.014 inch)
- Flatness tolerances to within +/- 15 mm/m (3/16 inch/foot) for cold rolling,
- +/- 55 mm/m (5/8 inch/foot) for hot rolling
- Hot rolling and sand casting produce similar ranges fo rsurface finish
- Cold rolling produces a very fine surface finish

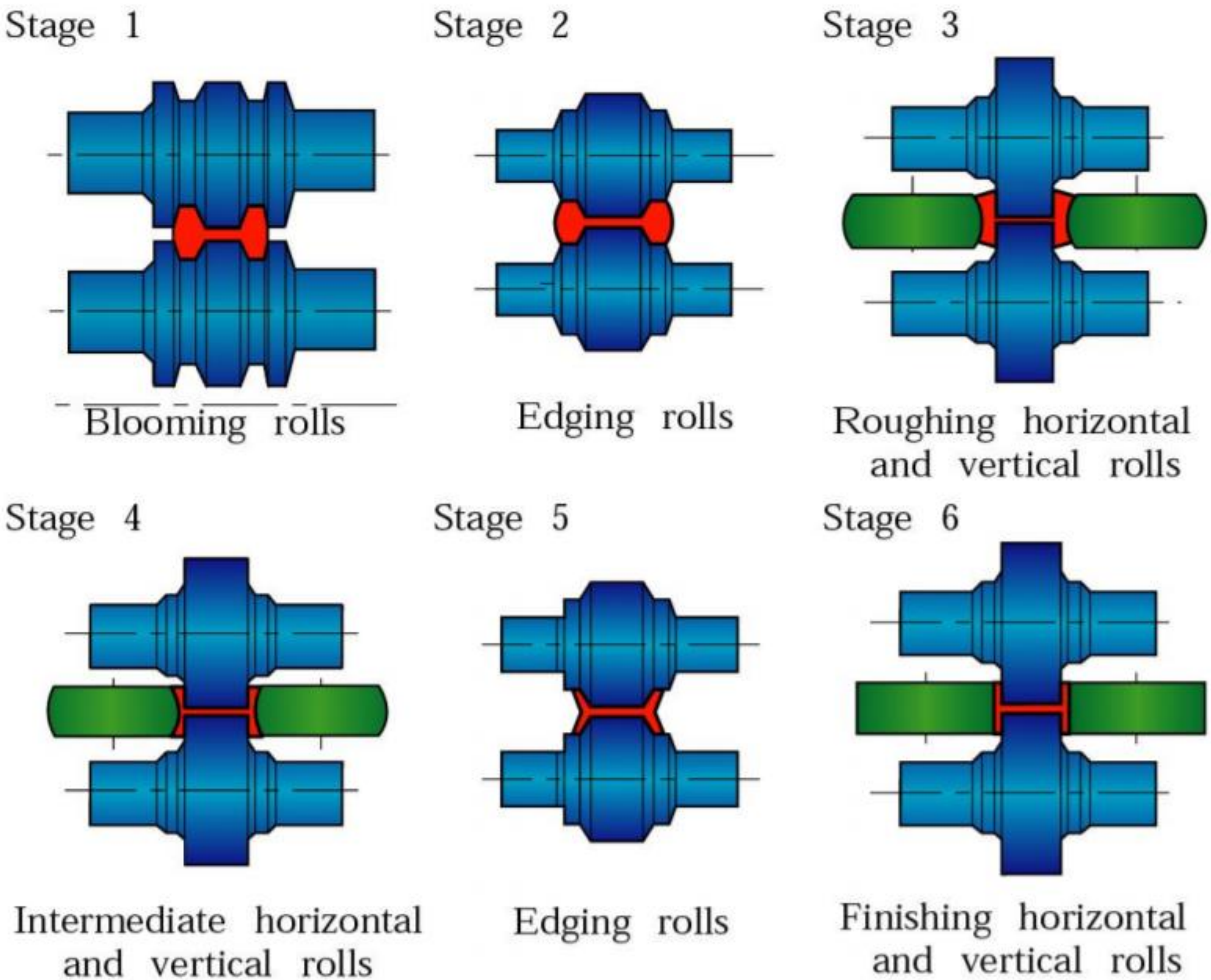

Slabs
Blooms
Billets
Plates
Structural shapes
Rails
Bars
Skelp
Strip
Tube rounds
Wire Rods
Pipe and tubing
Wire
Large diameter pipe
Tin plate
Seamless pipe
Cold drawn bars



Defects in Rolled Plates and Sheets

- on the **surfaces** of rolled plates and sheets,
- **internal** structural defects.
- compromise surface **appearance**,
- adversely affect **strength**, formability, and other manufacturing characteristics.
- surface defects (scale, rust, scratches, gouges, pits, and cracks)

Shape Rolling



Ring Rolling

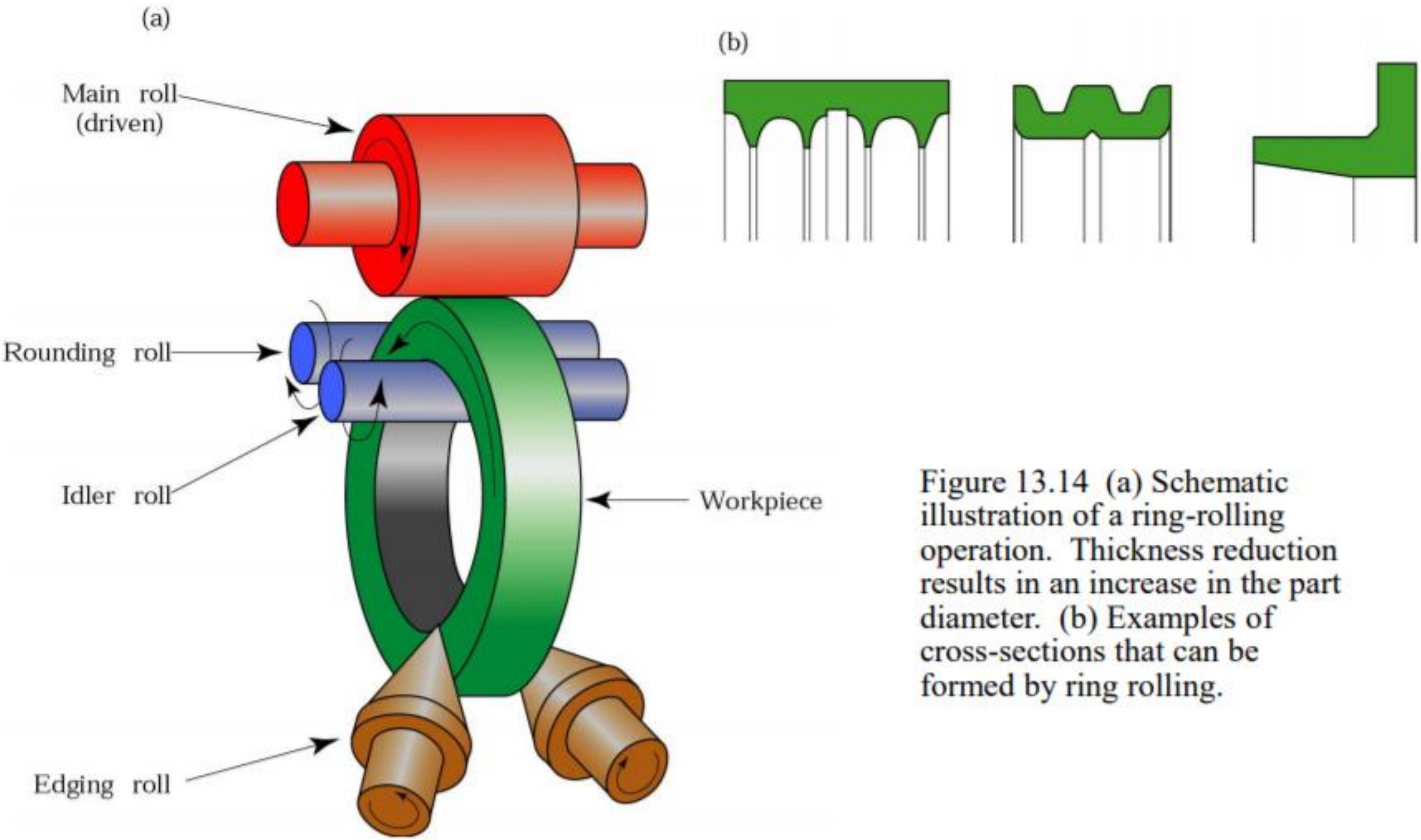


Figure 13.14 (a) Schematic illustration of a ring-rolling operation. Thickness reduction results in an increase in the part diameter. (b) Examples of cross-sections that can be formed by ring rolling.

Ring Rolling – Seamless Rings

Thread Rolling

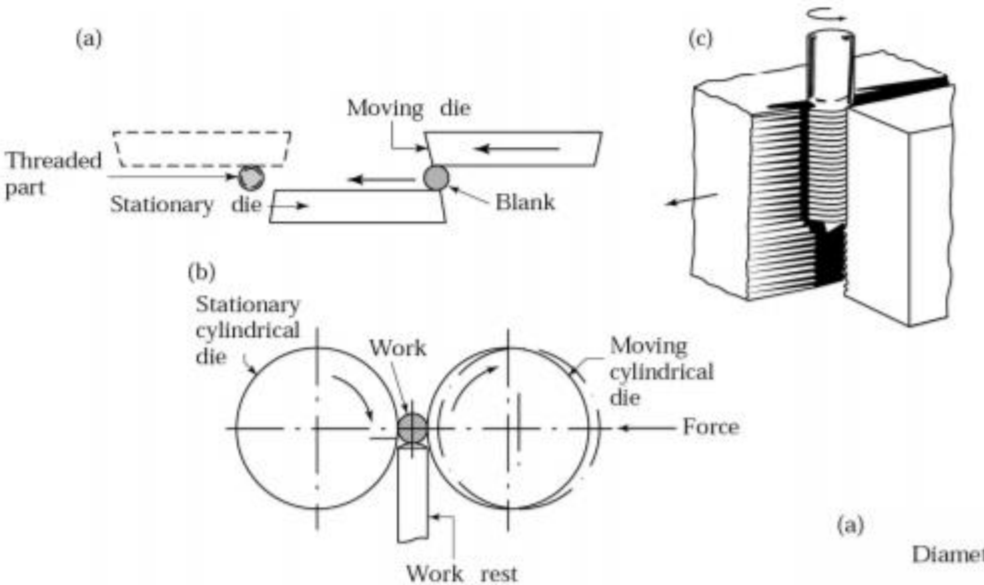


Figure 13.15 Thread-rolling processes: (a) and (c) reciprocating flat dies; (b) two-roller dies. Threaded fasteners, such as bolts, are made economically by these processes, at high rates of production.

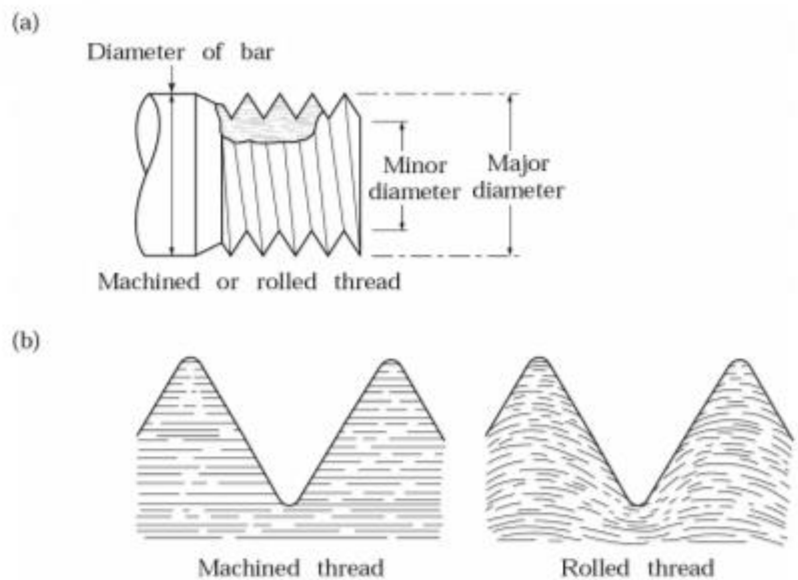
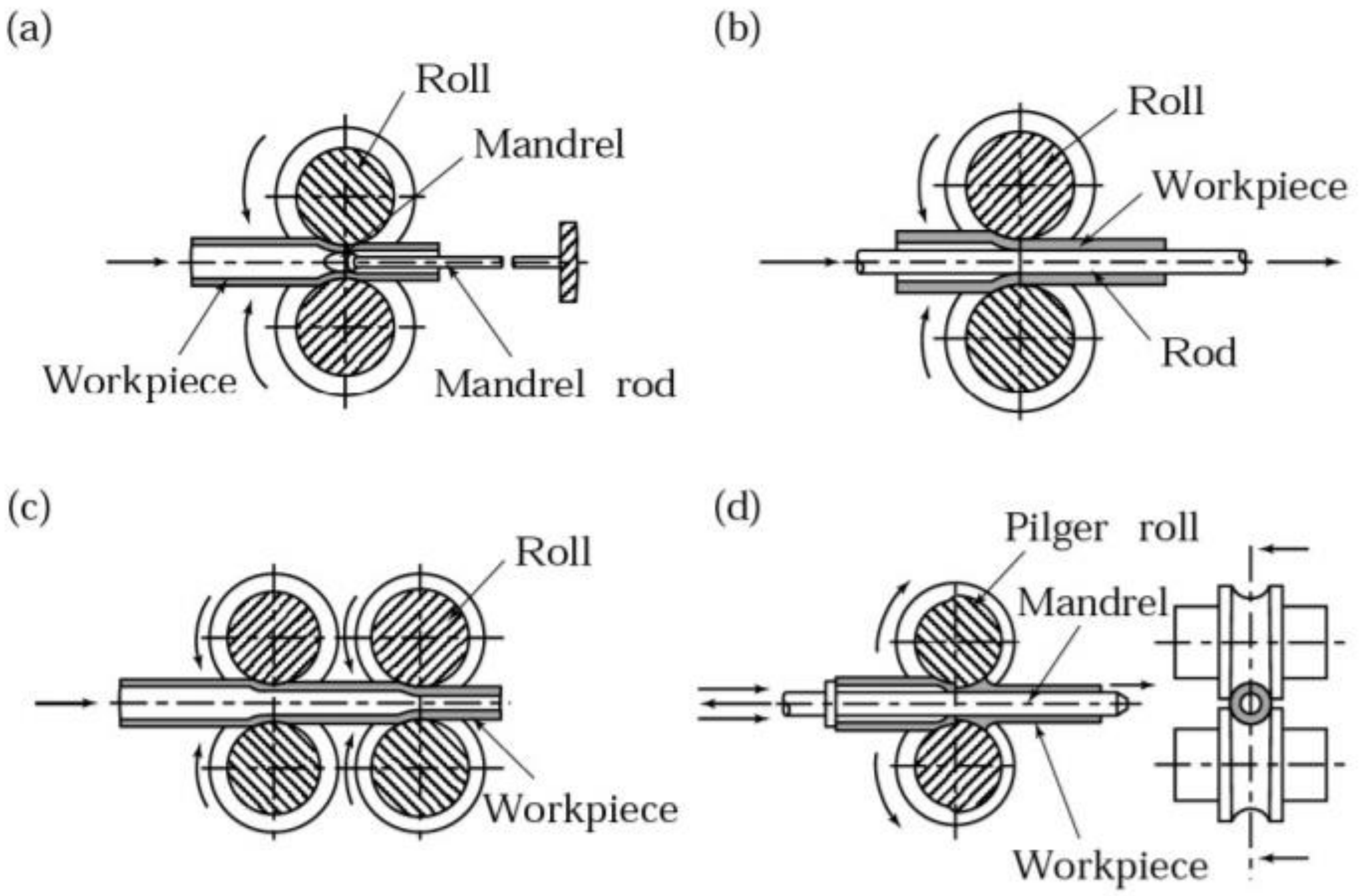


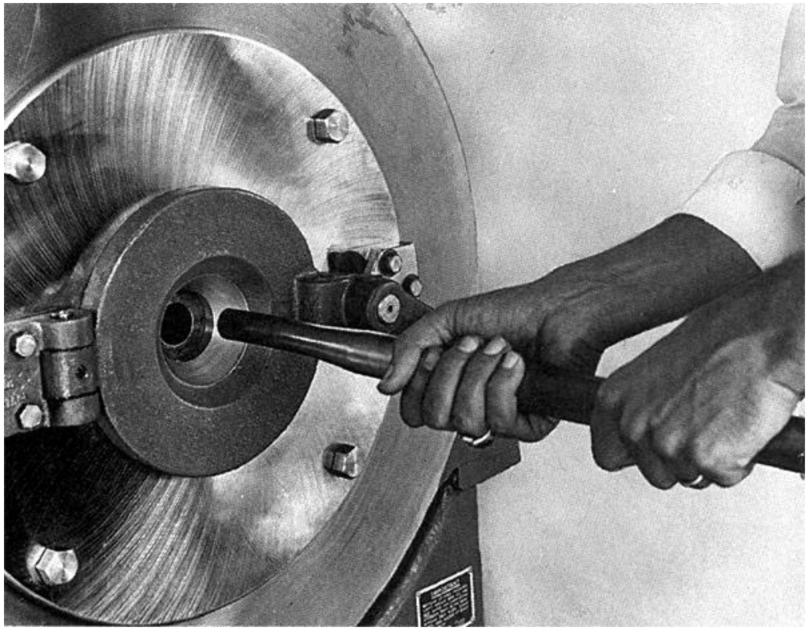
Figure 13.16 (a) Features of a machined or rolled thread. (b) Grain flow in machined and rolled threads. Unlike machining, which cuts through the grains of the metal, the rolling of threads causes improved strength, because of cold working and favorable grain flow.

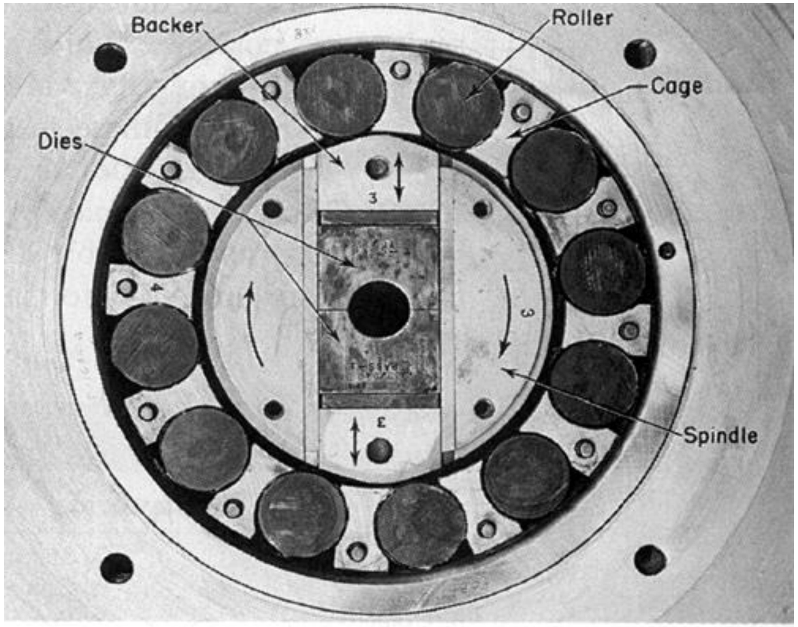
Tube Rolling



Swaging (dövme, çekiçleme, tokaçlama)

- reducing the diameter, tapering, or pointing round bars or tubes by **external hammering**





https://www.youtube.com/watch?v=ma2nPMl92bQ

Swaging (Tokaçlama)

- Involves hammering or forcing tube or rod into a confining die to *reduce* its diameter.
- Die plays the role of a *hammer*.
- Repeated blows cause the metal to flow *inward*.

Tube Swagging

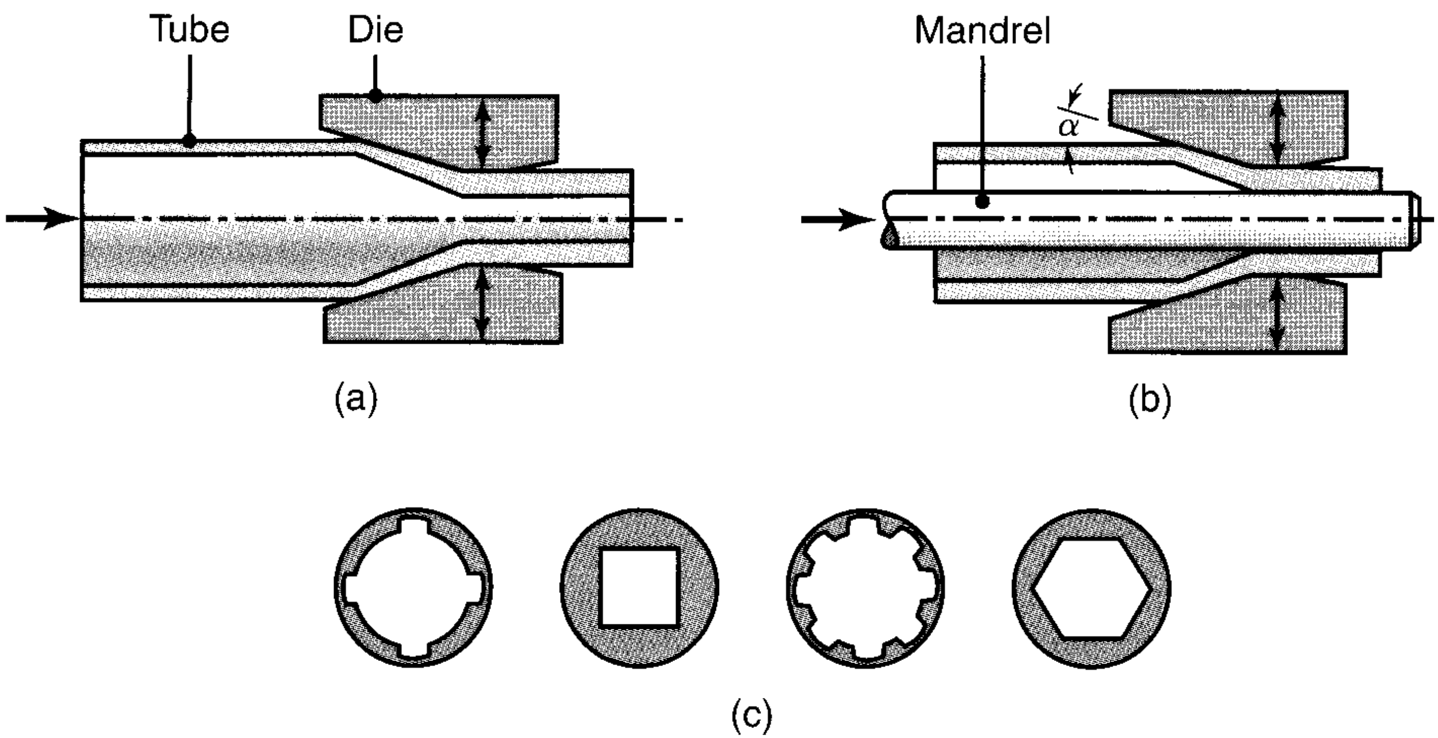
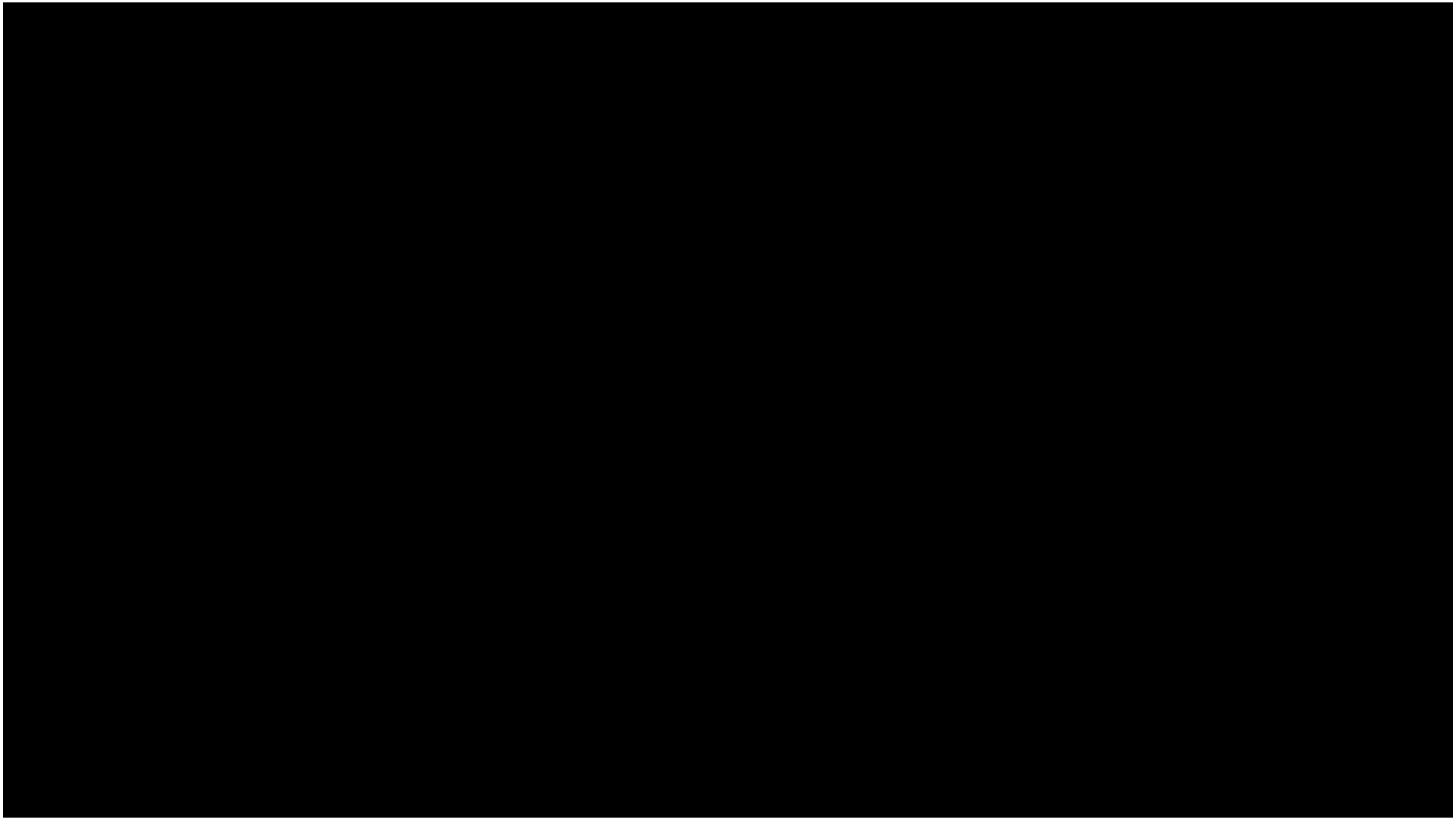
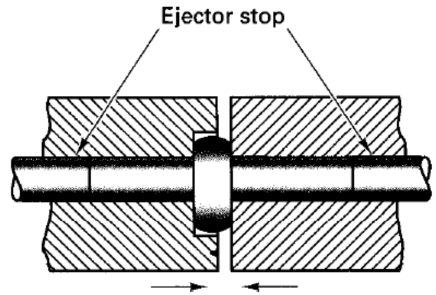


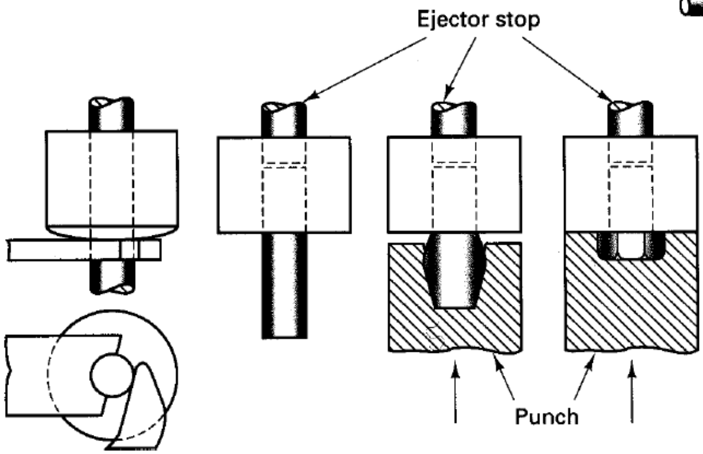
FIGURE 14.15 (a) Swaging of tubes without a mandrel; note the increase in wall thicknes the die gap. (b) Swaging with a mandrel; note that the final wall thickness of the tube depend: the mandrel diameter. (c) Examples of cross sections of tubes produced by swaging on sha mandrels. Rifling (internal spiral grooves) in small gun barrels can be made by this process.

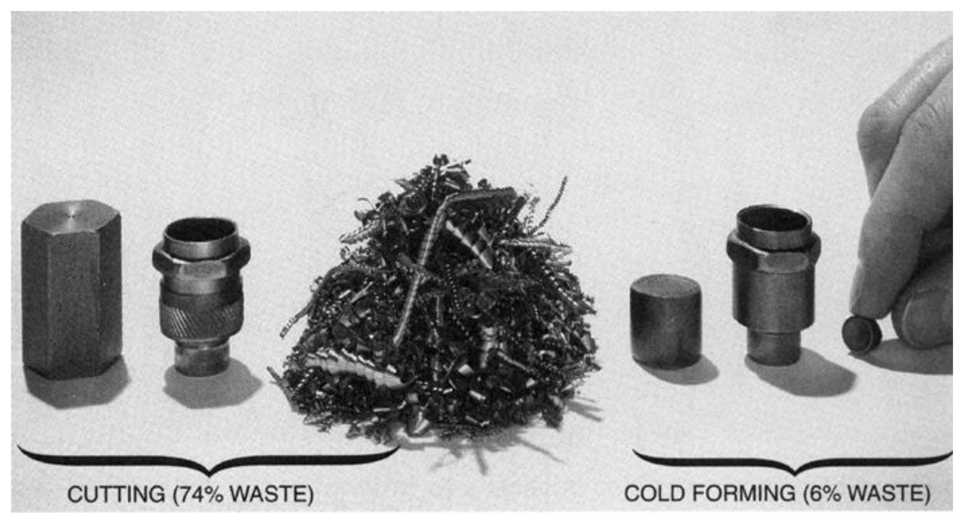


Cold Forging

- The metal is squeezed into a die cavity.





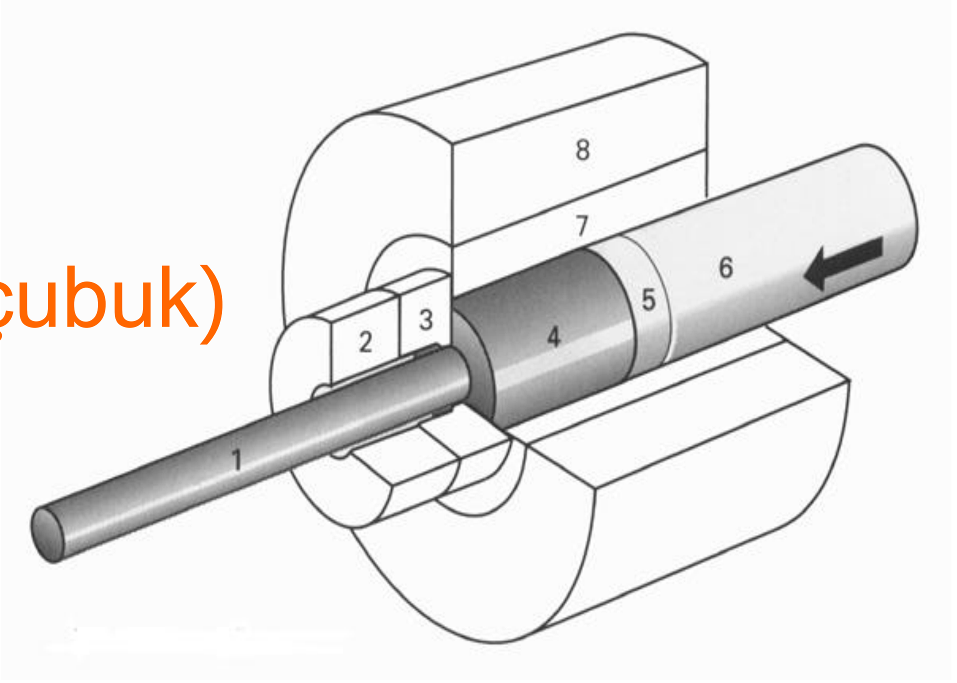


Forgeability of Metals;

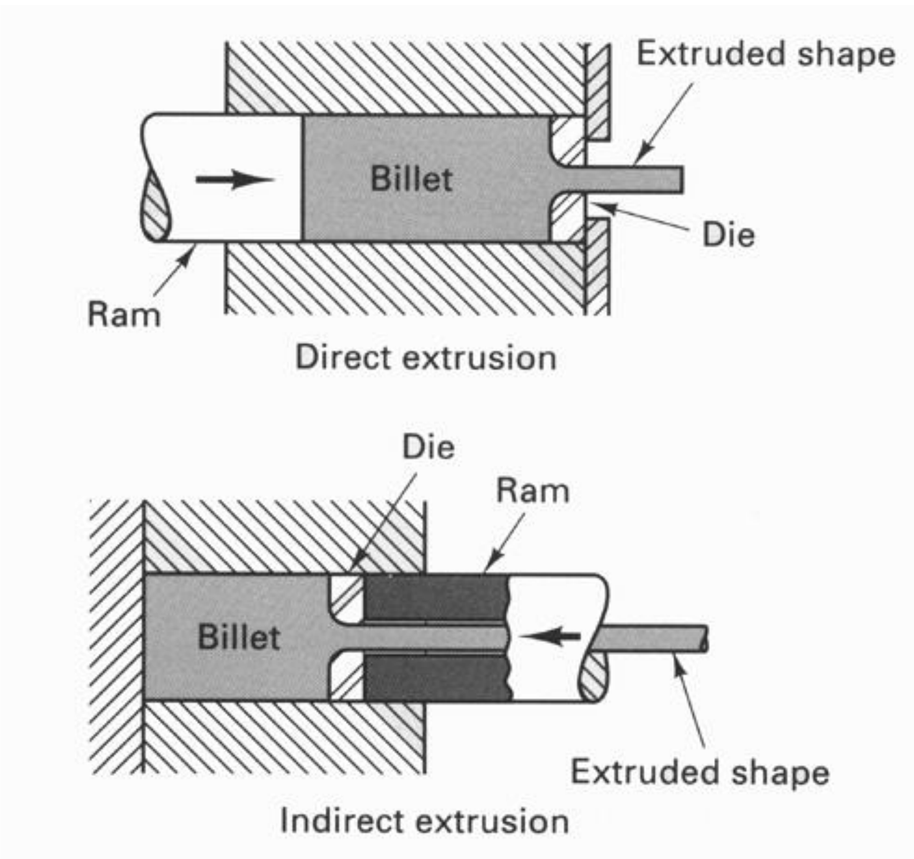
- capability of a material to undergo **deformation without cracking**.
- tests to quantify **forgeability**;
- **upsetting test**, a solid, cylindrical specimen is upset between flat dies,
- reduction in height at which cracking on the barreled surfaces begins is noted.
- The greater the deformation prior to cracking, the greater the forgeability of the metal.
- **hot-twist test**, in which a round specimen is twisted continuously in the same direction until it fails.
- This test is performed on a number of specimens and at different temperatures,
- The temperature at which the maximum number of turns occurs then becomes the forging temperature for maximum forgeability.
- The hot-twist useful particularly for steels.

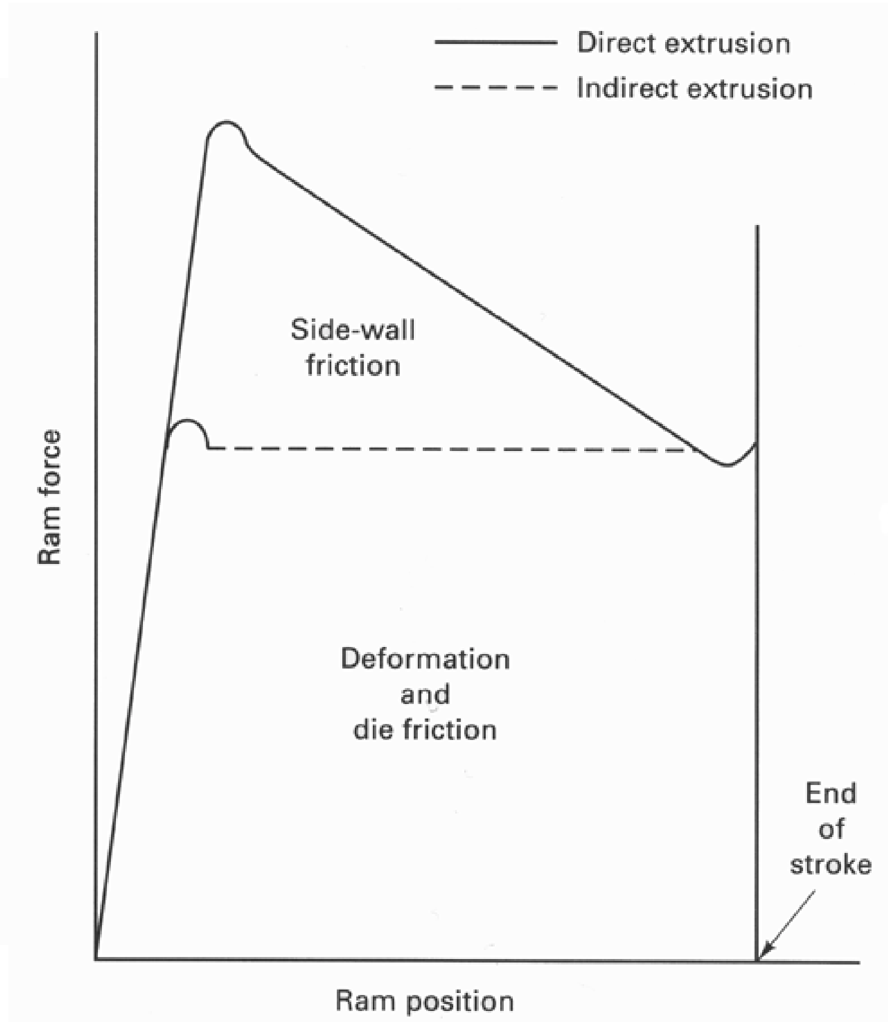
Extrusion (ekstrüzyon, kalıptan basma)

1. Extrusion
2. Die Backer
3. Die
4. Billet (ham demir çubuk)
5. Dummy Block
6. Pressing Stem
7. Container Liner
8. Container Body

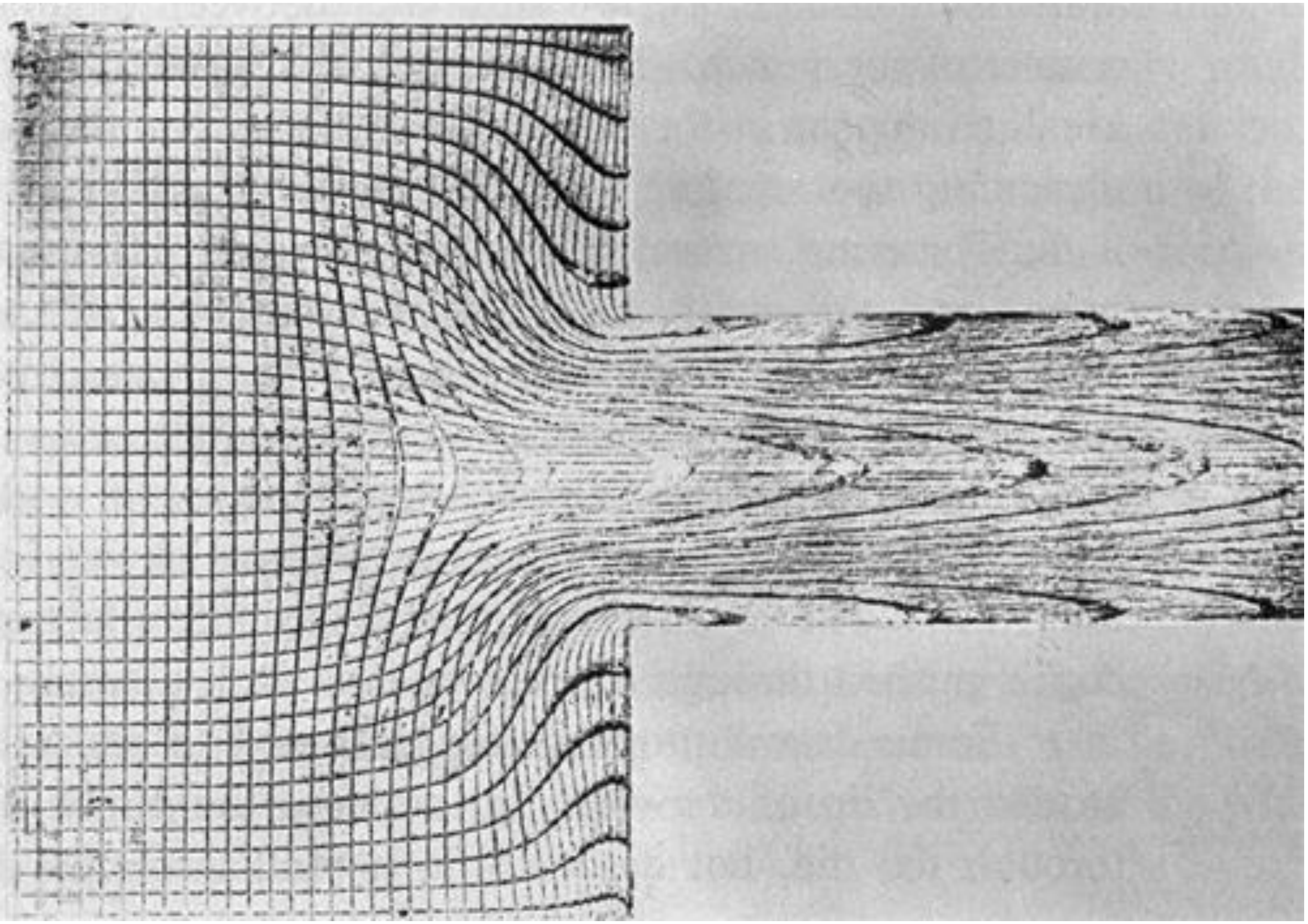


Direct- and Indirect Extrusion



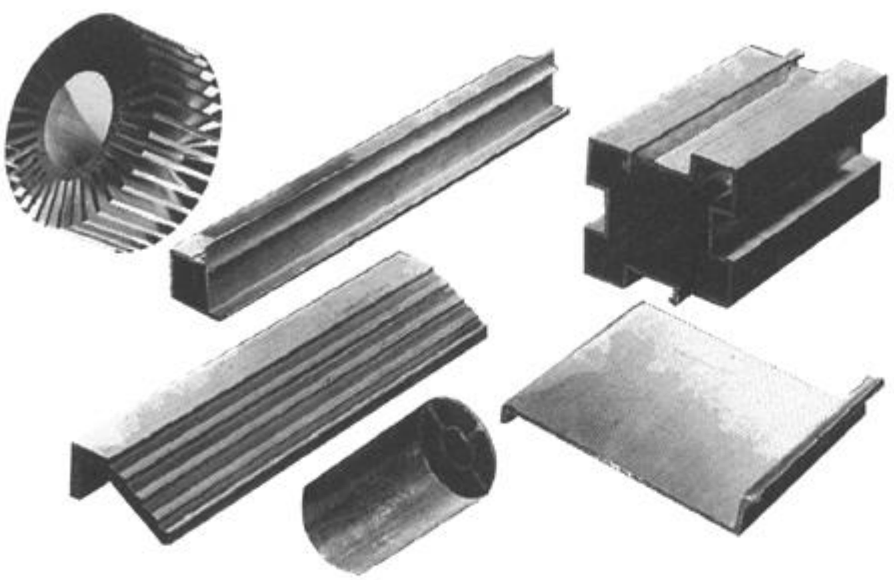


Metal Flow in Extrusion



Extrusion Samples

Aluminum



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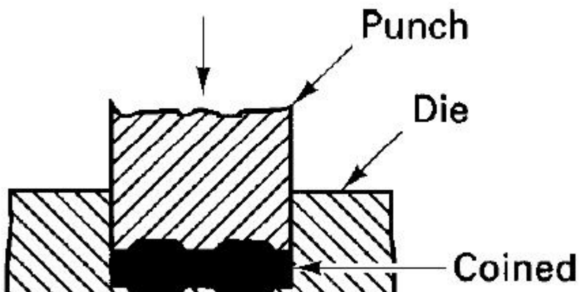
Properties of Extrusion

- Almost *any* cross-section can be extruded.
- The amount of reduction in a single step is only limited by the *capacity* of the equipment.
- Extrusion dies are relatively *inexpensive*.
- Product changes require only a *die* change:
  - Small quantities can be produced economically.
- Cross-section must be the *same* throughout the length.
- The *dimensional* tolerances are very good:
  - A minimum of ±0.07 mm is easily attainable.

Coining & Hobbing

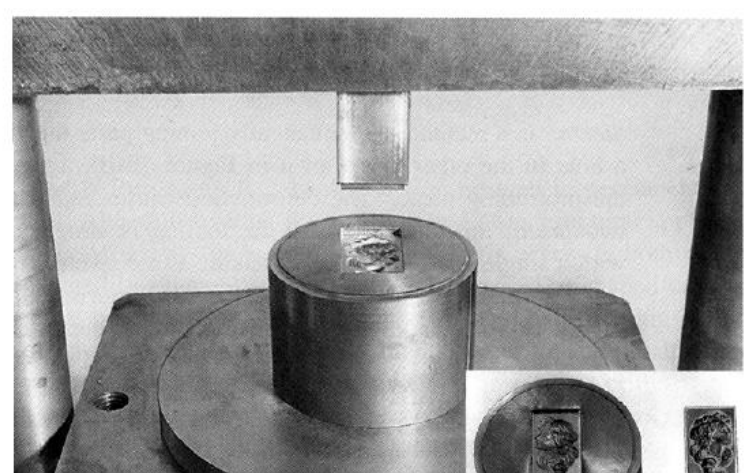
Coining: (Darp)

- producing **coins, medals**,
- where exact **size and fine detail** are required
- in a **variable** thickness.
- Very **high pressures** are needed.



Hobbing\Hubbing:

- A hardened **hob** is slowly pressed into an annealed **die** block
- Using a **hydraulic press**
- until the desired **impression** is produced.



Anneal: heat (metal or glass) and allow it to cool slowly, in order to remove internal stresses and toughen it.

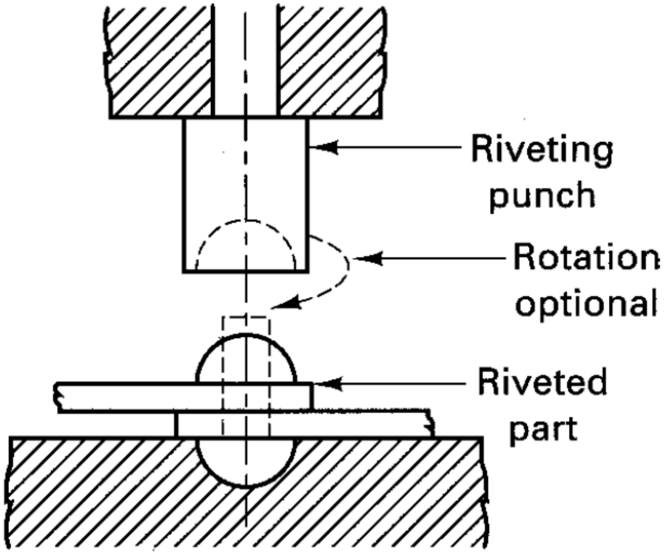
Making Coins

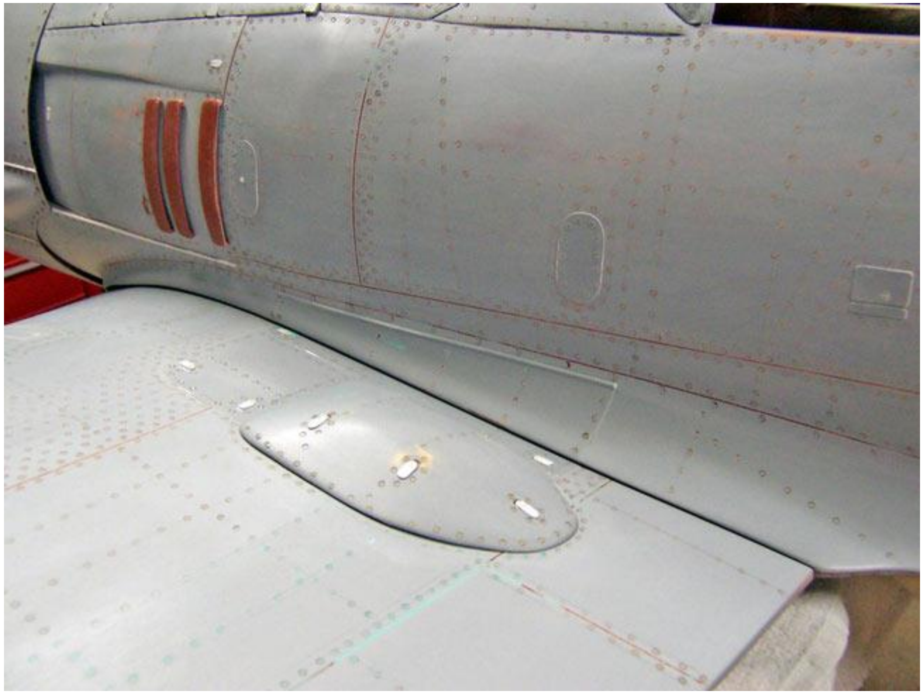
Squeezing Processes

- General Forming Techniques
  - Cold Rolling
  - Swaging
  - Cold Forging
  - Extrusion
  - Coining
- Joining Processes
  - Riveting
  - Staking
- Surface Improvement
  - Peening
  - Burnishing

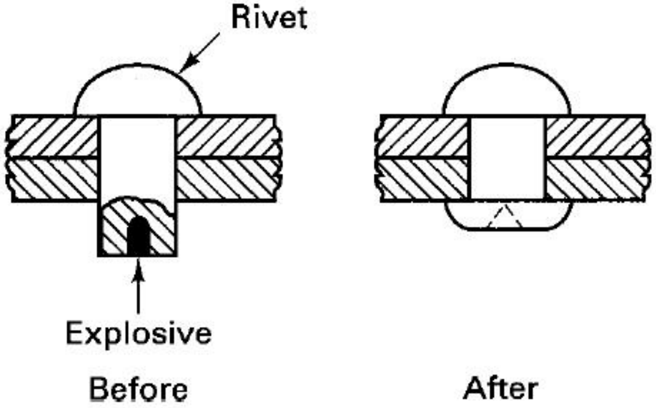
Riveting (Perçinleme)

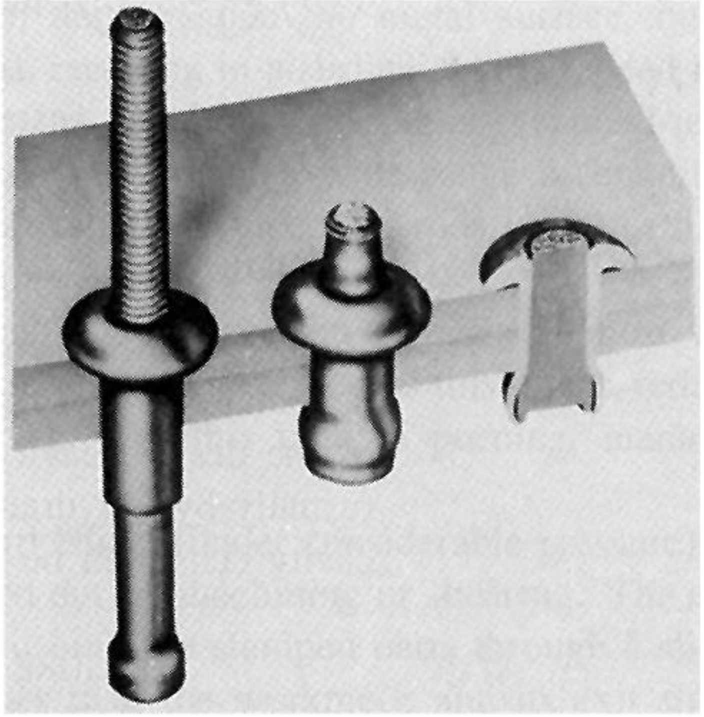
a **head** is formed on the shank end of a fastener to provide a **permanent** method of **joining** **sheets** or **plates** of metal together.





Riveting



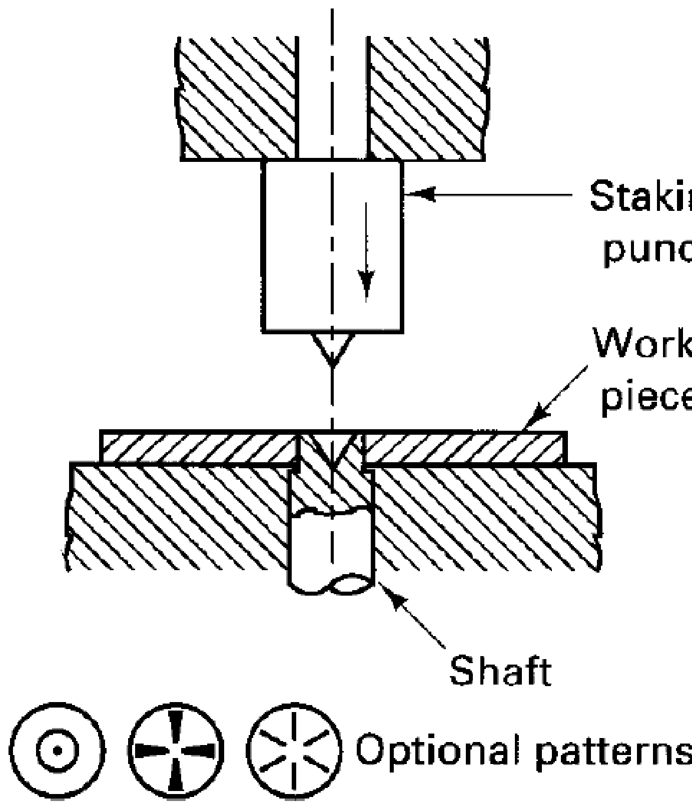


Riveting

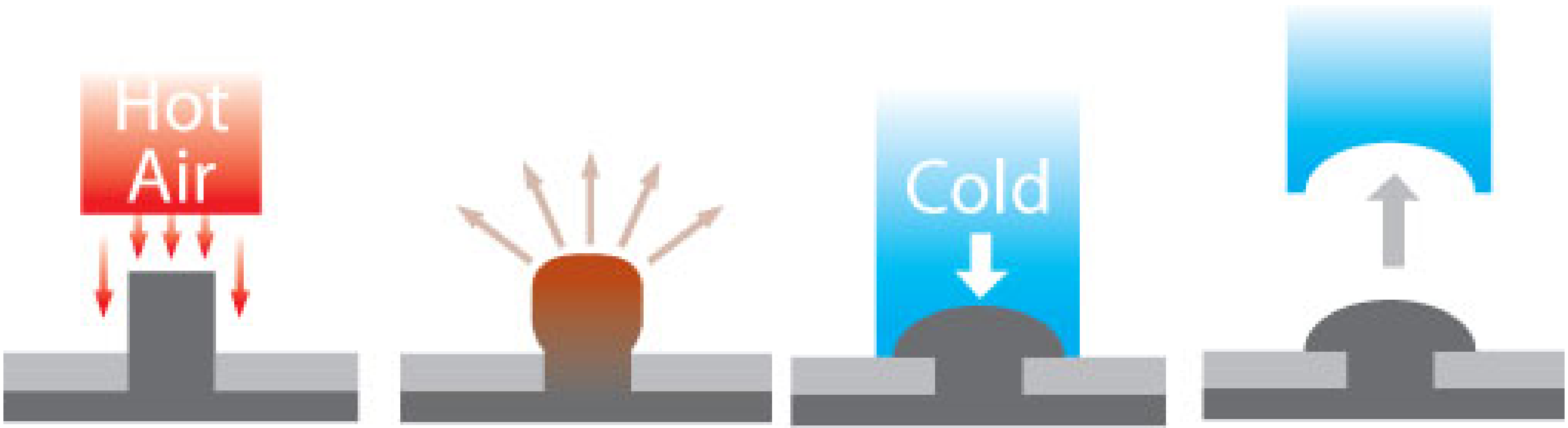
Staking

Staking is used to permanently fasten two parts together where one protrudes through a hole in the other.

extend beyond or above a surface.



Staking



Phasa Process using Hot Air to heat selected Parts

No contact with parts being heated the process is clean

Cold tools used to FORM, CLAMP and Chill the Stakes

The stakes have been heated then cooled under pressure

Squeezing Processes

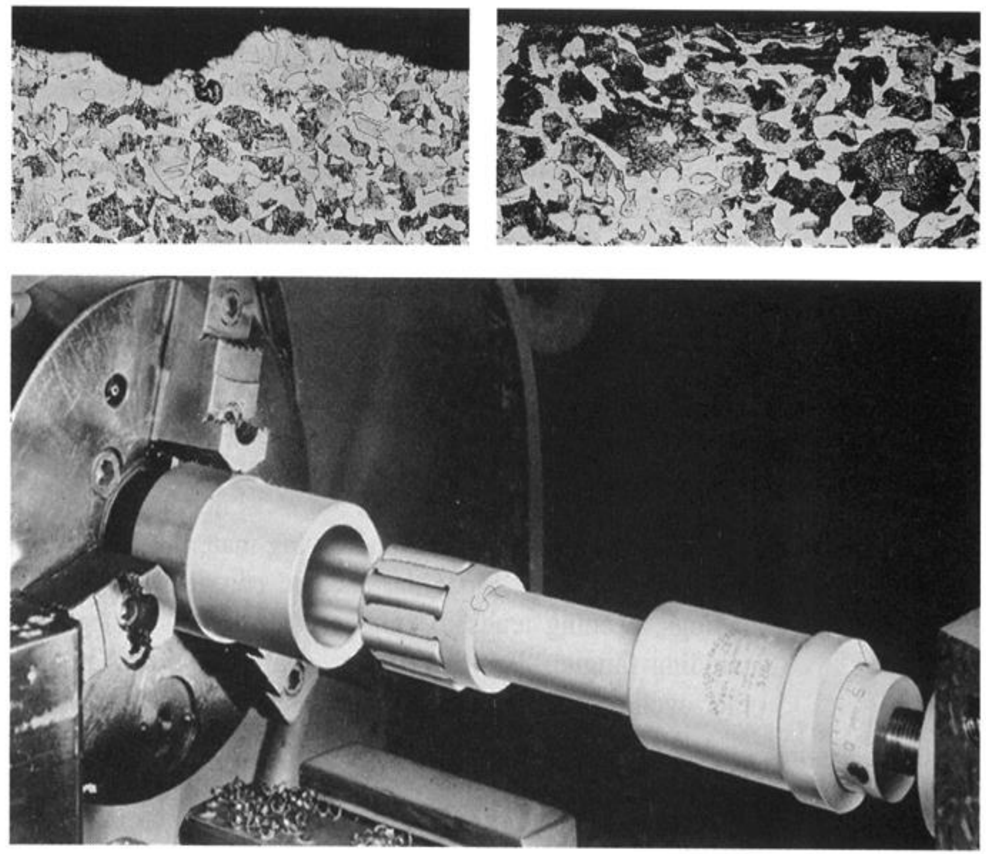
- General Forming Techniques
  - Cold Rolling
  - Swaging
  - Cold Forging
  - Extrusion
  - Coining
- Joining Processes
  - Riveting
  - Staking
- Surface Improvement
  - Peening
  - Burnishing

Peening (Yüzey Dövme)

- striking the surface repeated blows by impelled shot or a round-nose tool.
- Highly favorable to resist cracking under fatigue.

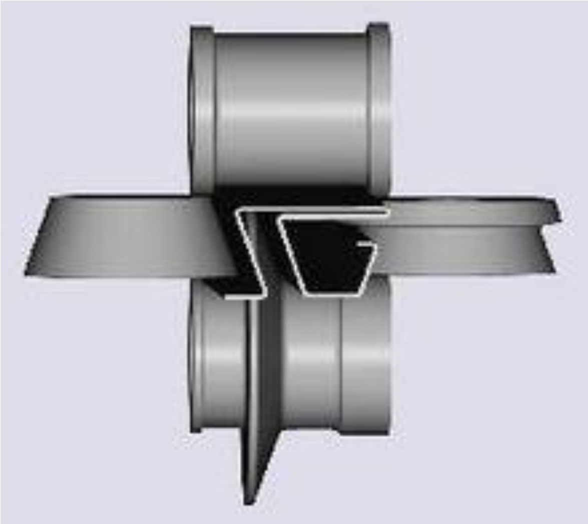
Burnishing (Çapak Temizleme)

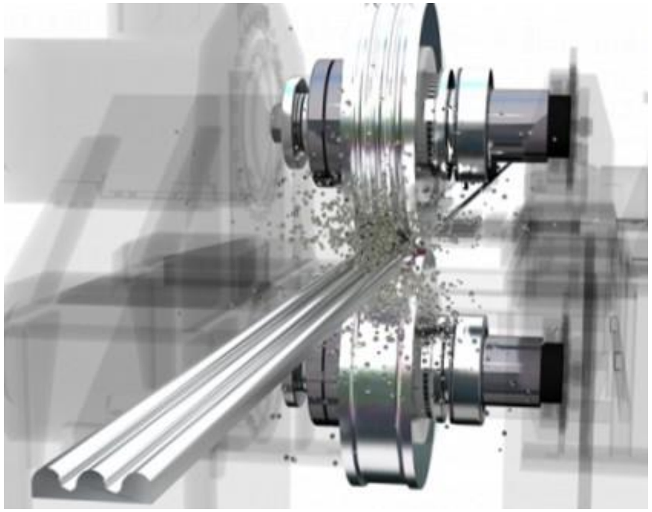
- **rubbing** a smooth hard object under considerable pressure
- over the minute surface protrusions that are formed on a metal surface
- during machining or shearing,
- reducing their depth and sharpness through plastic flow.



Outline

- Introduction
- Squeezing Processes
  – Forming
  – Joining
  – Surface improvement
- Bending
- Shearing
- Drawing
  – Bar, Rod, Tube, Wire
  – Sheet Metal
- Presses





Bending Mechanics

Bend allowance

$$L_b = \alpha(R + kT)$$

L_b: length of the neutral axis

α: the bend angle

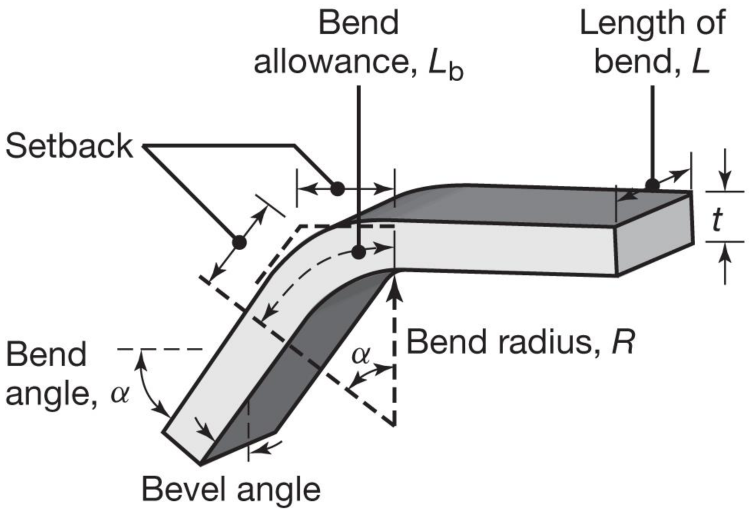
T: sheet thickness

R: bend radius

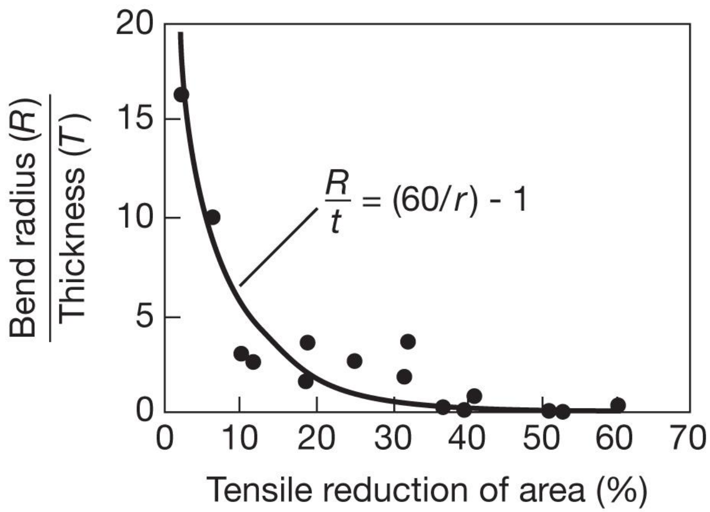
k: constant 0.33 for R<2T and 0.5 for R>2T

r: tensile reduction of area

$$R_{min} = T(\frac{50}{r} - 1)$$



(a)



(b)

Example

A 20 mm wide and 4 mm thick C 20 steel sheet is required to be bent at 60 deg. at bend radius 10 mm. Determine the bend allowance.

Solution.

Here, bend radius $R = 10$ mm

Sheet thickness $t = 4$ mm

Since $R > 2t$, $k = 0.5$

Bend allowance

$$= \left(2\pi \times \frac{60}{360}\right)(10 + 0.5 \times 4)$$

$$= 12.56 \text{ mm}$$

Springback

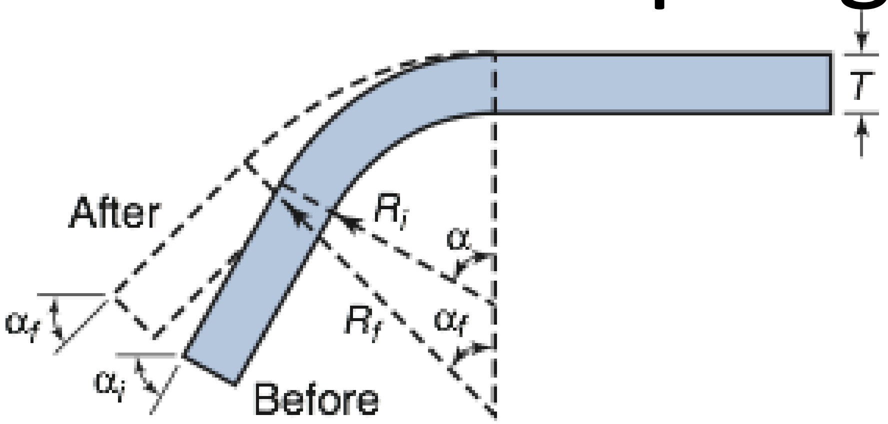


FIGURE 7.18 Terminology for springback in bending. Note that the bend angle has become smaller. There are situations whereby the angle becomes larger, called negative springback (see Fig. 7.20).

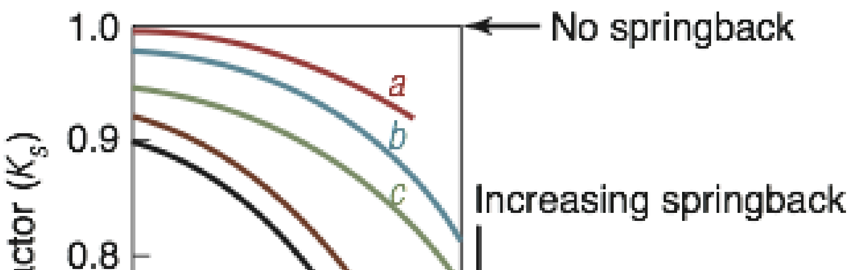


FIGURE 7.19 Springback factor, K_s, for various materials: (a) 2024-0 and 7075-0 aluminum; (b) austenitic stainless steels; (c) 2024-T aluminum; (d) 1/4-hard austenitic stainless steels; and (e) 1/2-hard to full-hard austenitic stainless steels. A factor of $K_s = 1$ indicates that there is no springback. *Source:* After G. Sachs.

Springback factor:

$$K_s = \frac{\alpha_f}{\alpha_i} = \frac{(2R_i/t)+1}{(2R_f/t)+1}$$

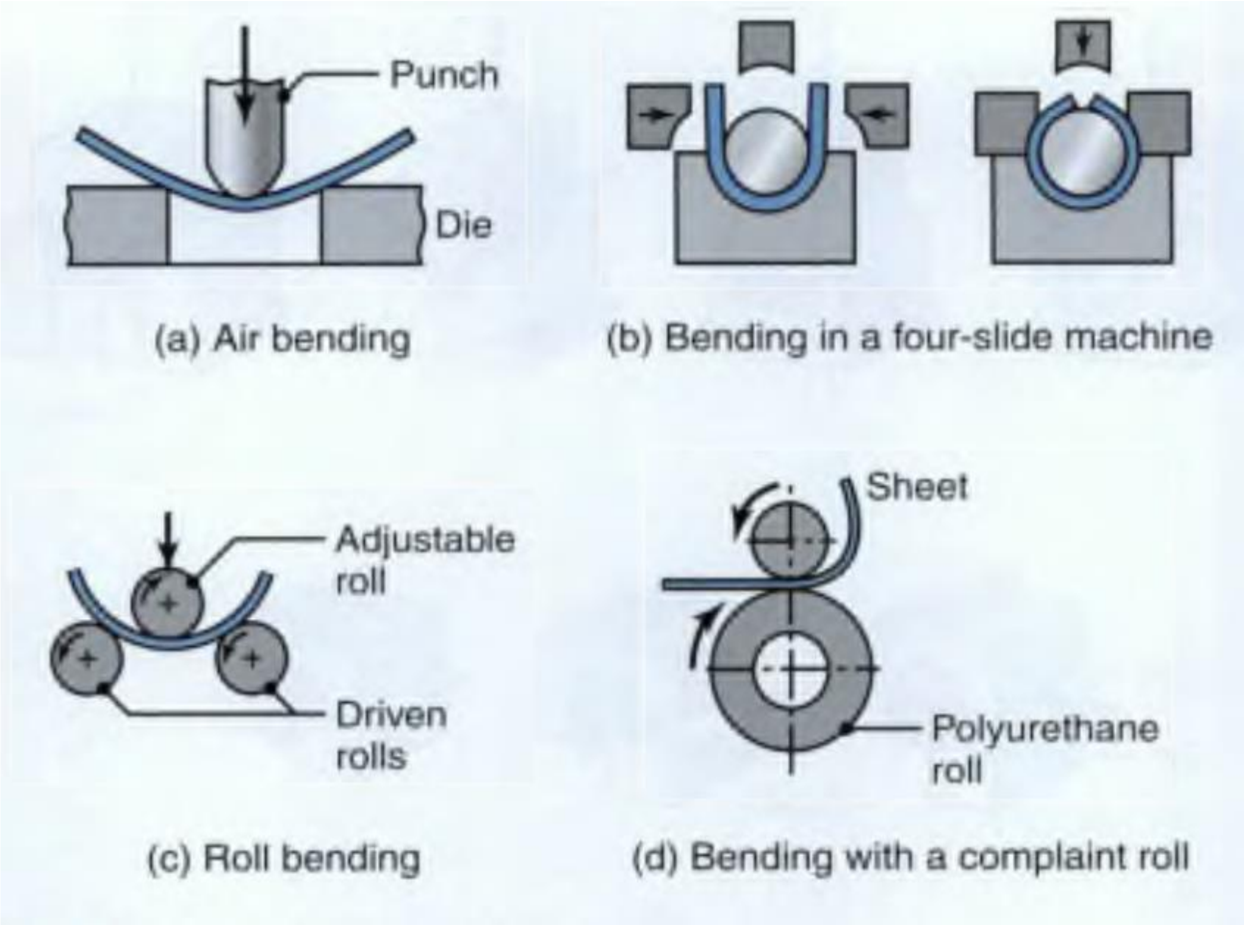
Springback estimation:

$$\frac{R_i}{R_f} = 4\left(\frac{R_i Y}{Et}\right)^3 - 3\left(\frac{R_i Y}{Et}\right) + 1$$

Maximum Bending Force

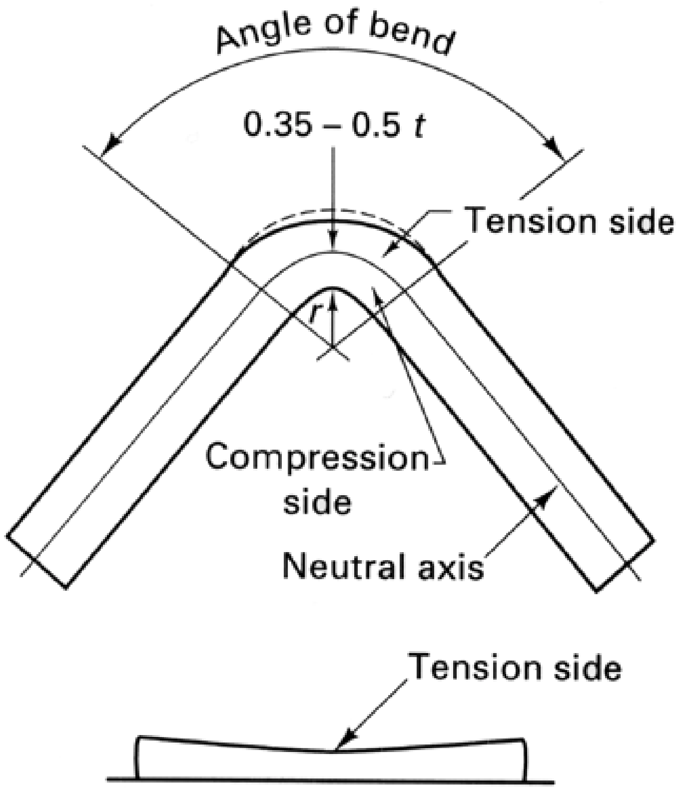
L= length of the bend
T= thickness of the sheet
W= die opening
Y= yield stress
k= constant varies depending on dies

$$P = \frac{kYLT^2}{W}$$



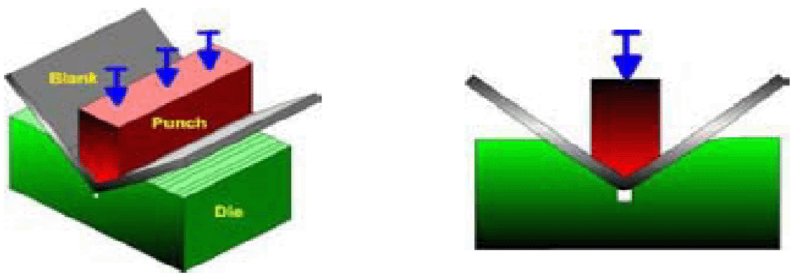
Bending (Bükme, Eğme)

- plastic deformation of metals about a linear axis
- with little or no change in the **surface area**.
- Types:
  - Angle bending
  - Draw bending
  - Stretch bending
  - Roll bending
  - Cold-roll forming
  - Seaming

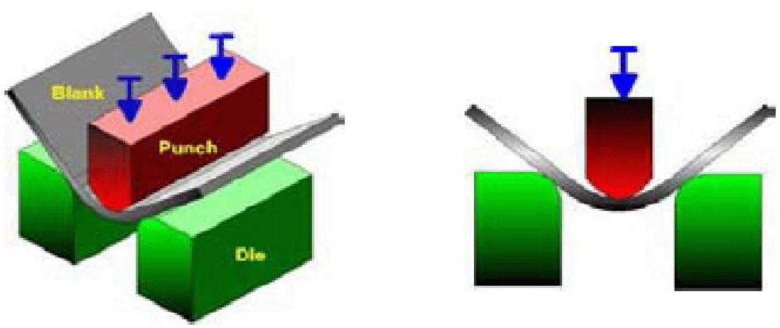


Angle Bending

V Bending:

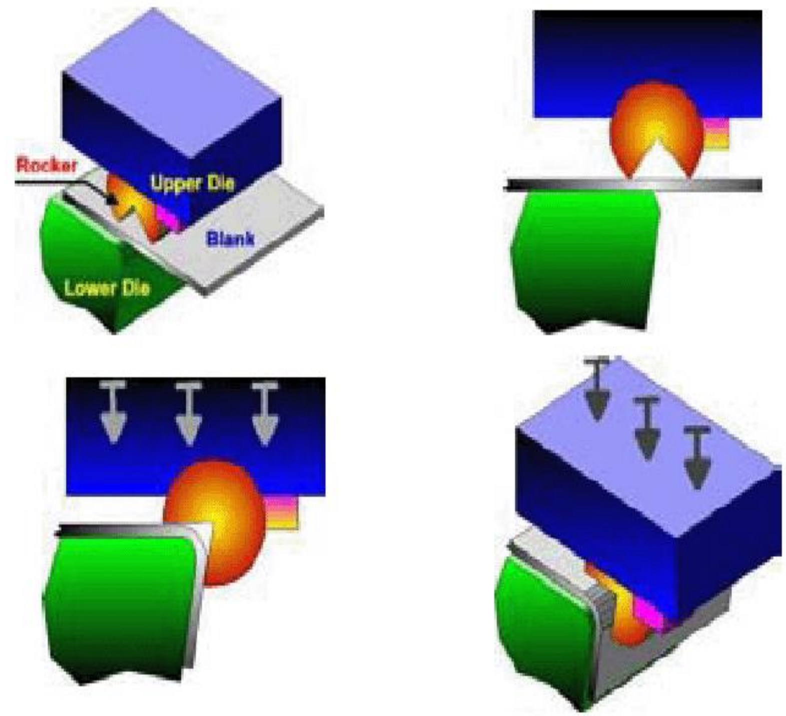


V shaped punch or die

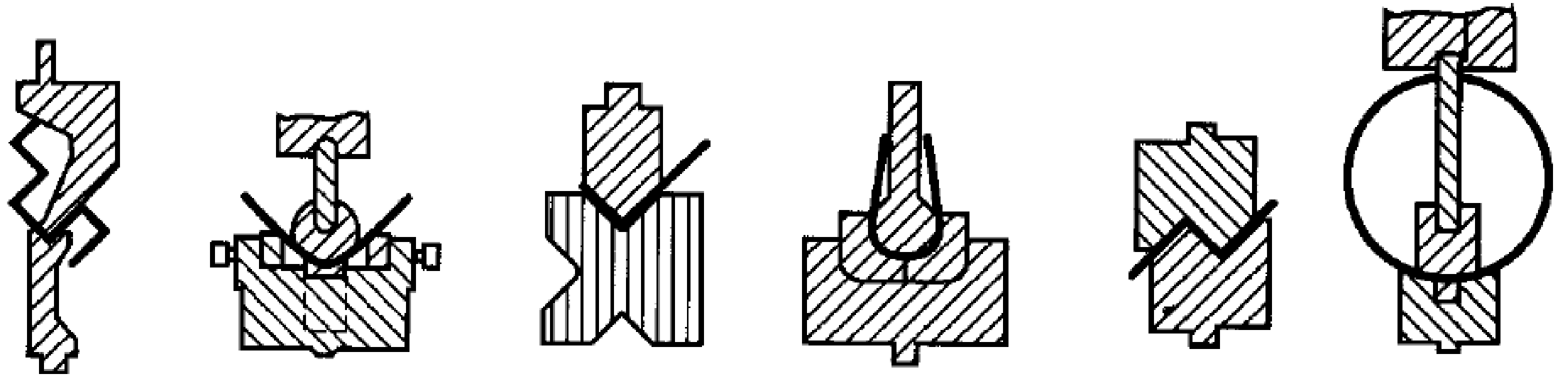


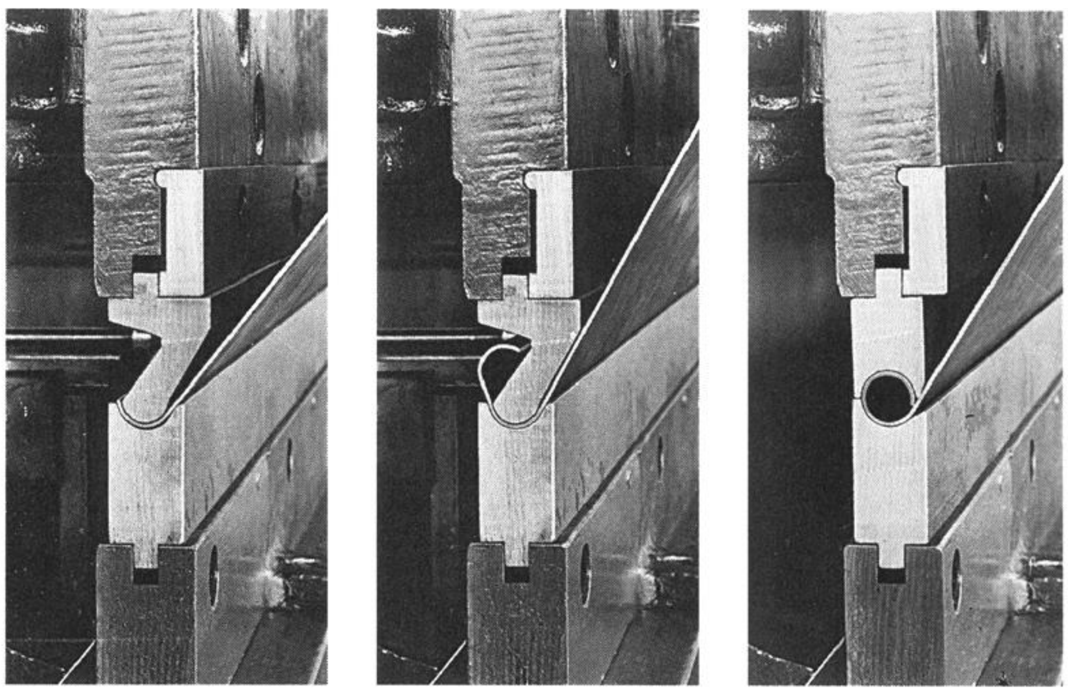
Air Bending:

Rotary Bending:

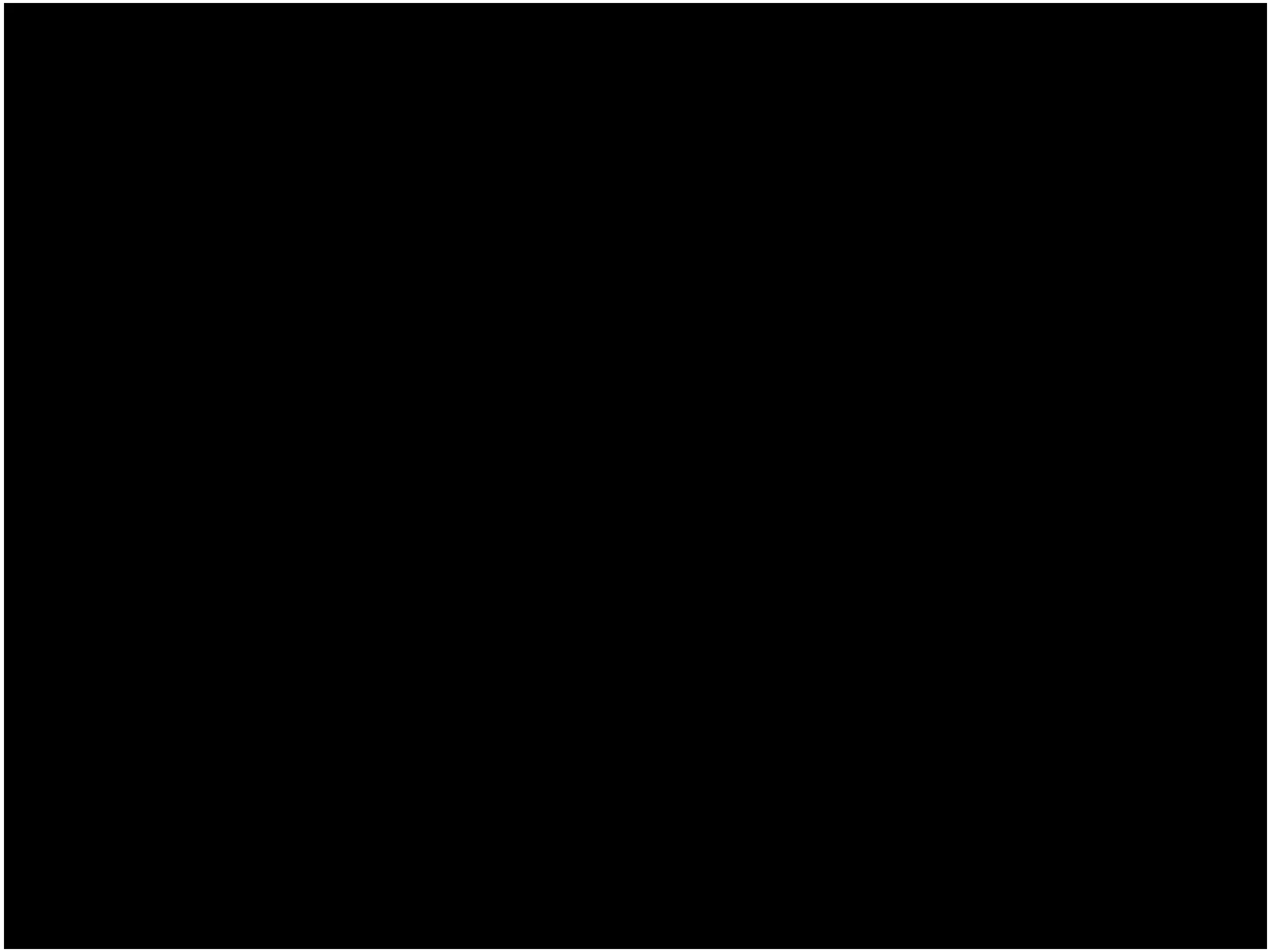


Angle Bending Dies



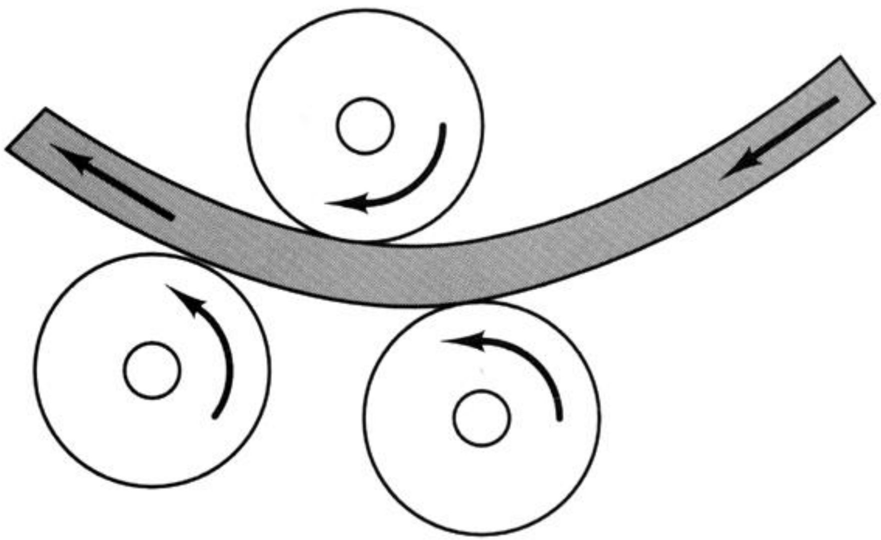


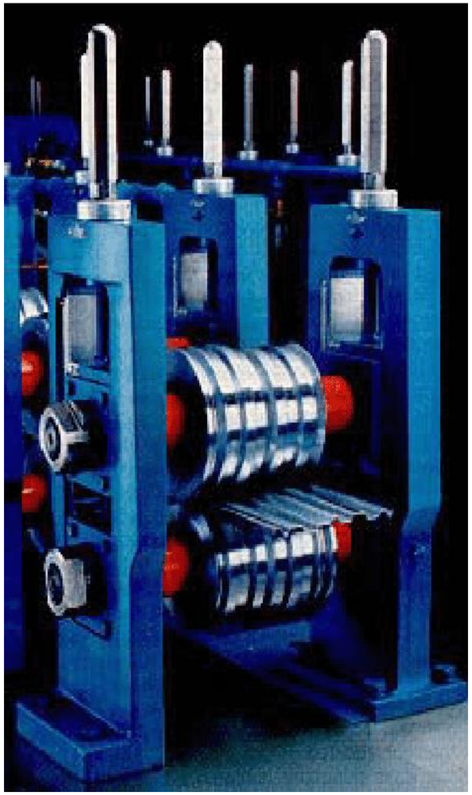
Angle Bending



Roll Bending

Plates, heavy sheets, and rolled shapes can be bent to a desired **curvature** in forming **rolls**.

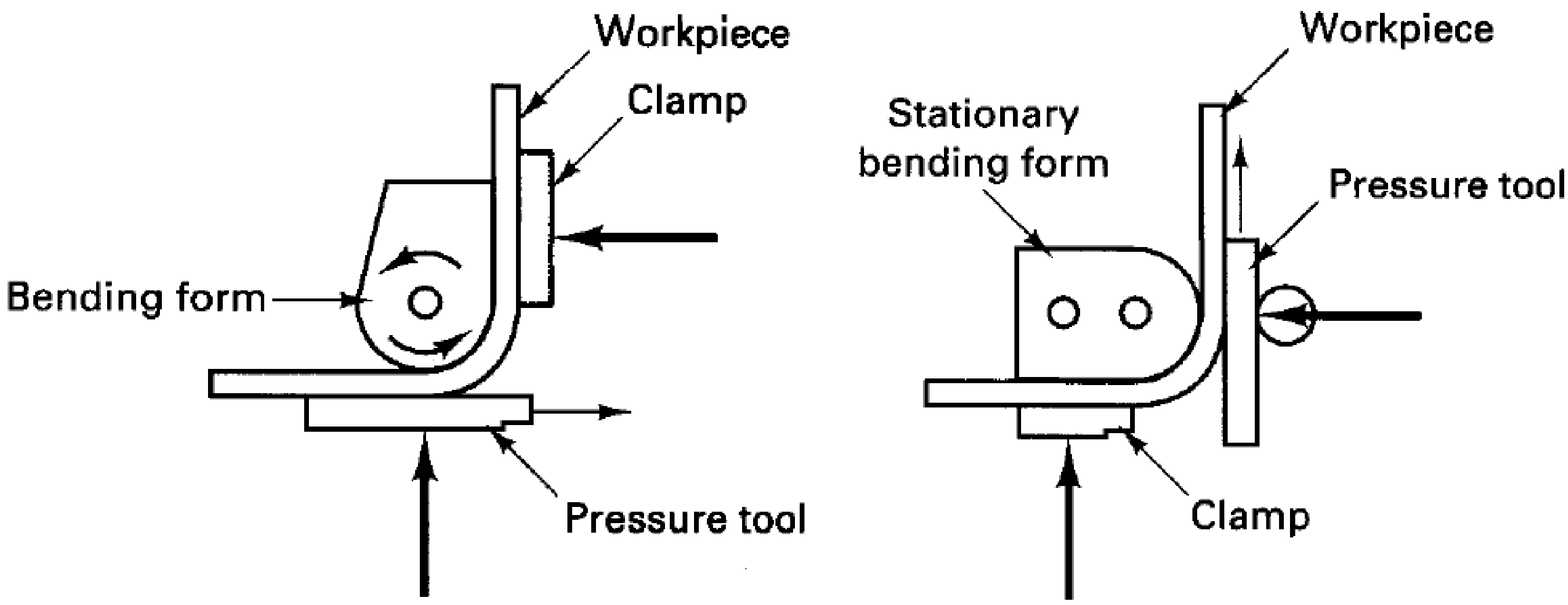




Roll Bending

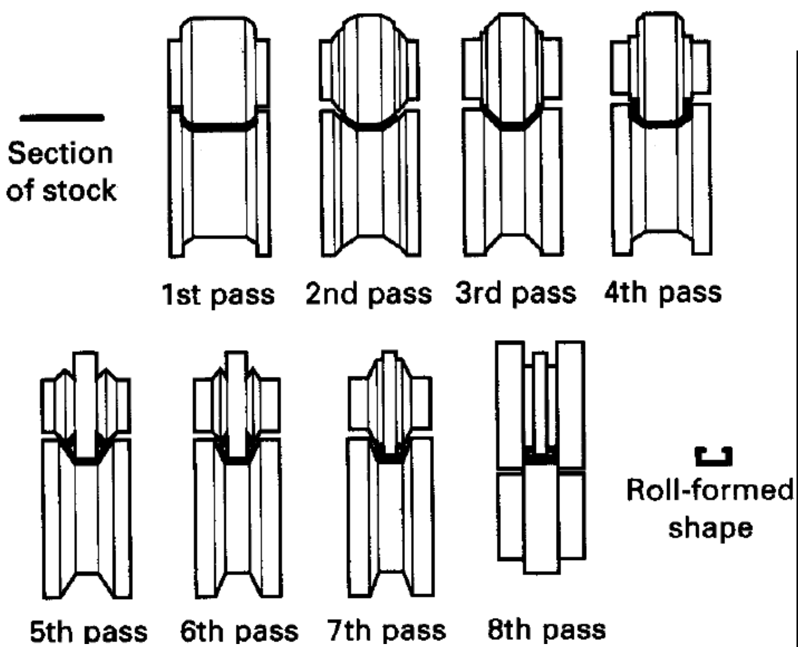
Draw Bending

- In draw bending, the workpiece is clamped against a bending form and the entire assembly rotates to draw the workpiece across a pressure tool.



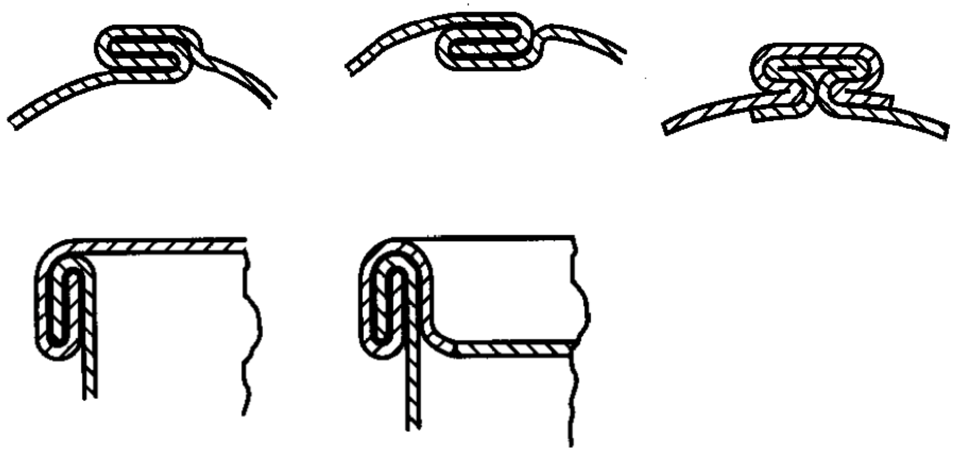
Cold Roll-Forming

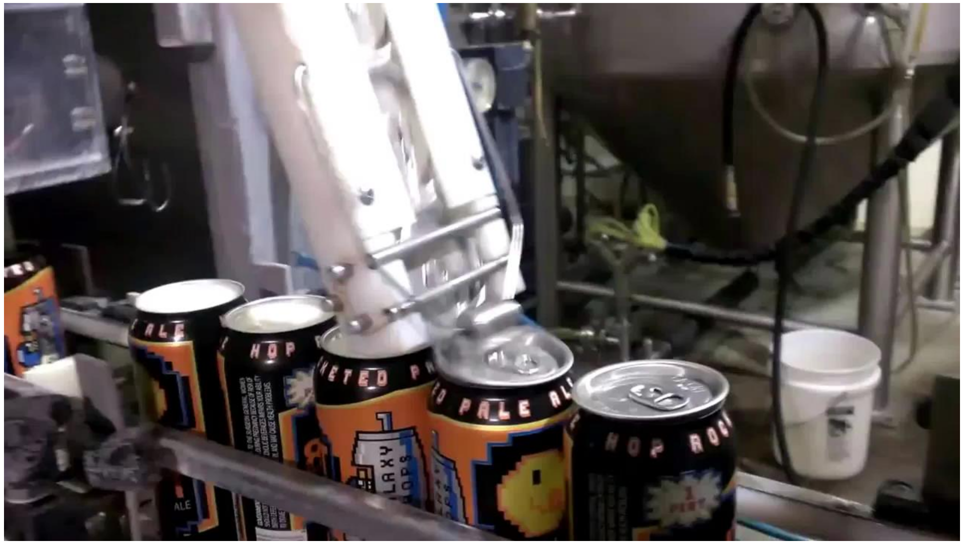
- Cold roll-forming involves the progressive bending of metal strip as it passes through a series of forming rolls.



Seaming (Ekleme, Dikiş)

used to **join ends** of sheet metal to form **containers** such as cans, pails, and drums.





Videos to Watch

https://www.amazon.com/clouddrive/share/Ct5cCm9Htp6ZtxxwyFOPF0QMAE0NGDTq7oupw6fvPuY

https://www.youtube.com/watch?v=yMgSGgiUO4A