Chapter 4 Metal-Rolling Processes and Equipment
（金属轧制工艺及设备）

- 4.1 Introduction
- 4.2 The Flat-Rolling Process
- 4.3 Flat Rolling Practice

重点学习掌握

- 4.4 Rolling Mills
- 4.5 Various Rolling Processes and Mills

部分学习掌握

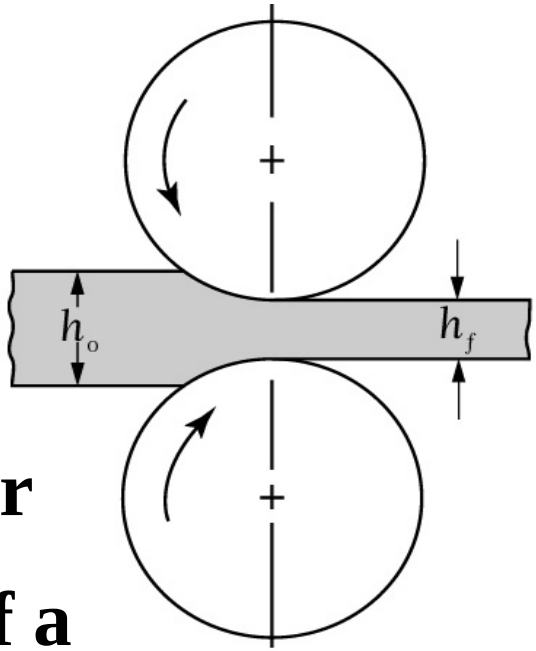
Preface（*前言*）：

- **This chapter on the forming and shaping of metallic and nonmetallic materials describes the rolling of metals, perhaps the most important metal-forming operation based on volume of metals rolled.**
- **The chapter begins with a description of the flat-rolling process, analyzing the force, torque, and power required in terms of relevant material and process parameters, as well as a review of defects and their causes in rolled products.**
- **Shape-rolling processes such as cross rolling, ring rolling, thread rolling, tube rolling, and tube piercing are also discussed.**
- **The chapter ends with a description of the characteristics of rolling mills and roll arrangements for specific products.**

Typical products made by various rolling processes: Plates for ships, bridges, structures, machines; sheet metal for car bodies, aircraft fuselages, appliances, containers; foil for packaging; I-beams, railroad rails, architectural shapes, large rings, seamless pipe and tubing; bolts, screws, and threaded components.

Alternative processes: Continuous casting, extrusion, drawing, machining of threaded components.

4.1 Introduction



- **Rolling（*轧制*）**
  - **the process of reducing the thickness (or changing the cross-section（*横截面*）) of a long workpiece by compressive forces（*压力*） applied through a set of rolls（*轧辊*）.**

ø **similar to the rolling of dough（*面团*） with a rolling pin（*擀面杖/擀面棍*）**

ø **accounts for about 90% of all metals produced by metalworking processes**

ø **first development in the late 1500s**

- **Modern steelmaking（*冶金*） practices and the production of various ferrous and non ferrous metals（*黑金属与有色金属*） and alloys（*合金*） now generally involve combing continuous casting with rolling（*连续铸轧*） processes.**
- **This greatly improves productivity（*生产效率*） and lowers products costs.**
- **Nonmetallic materials（*非金属材料*） also are rolled to reduce their thickness and enhance（*增强*） their properties.**
- **Typical application are in the rolling of plastics, powder metals（*粉末冶金材料*）, ceramic slurry（*陶瓷浆料*）, and hot glass.**

Classification of Rolling（轧制的分类）

- **By product：**
  - **flat rolling（平板轧制）** — § 4.2
  - **shape rolling （型材轧制）**
  - **tube rolling（轧管）**

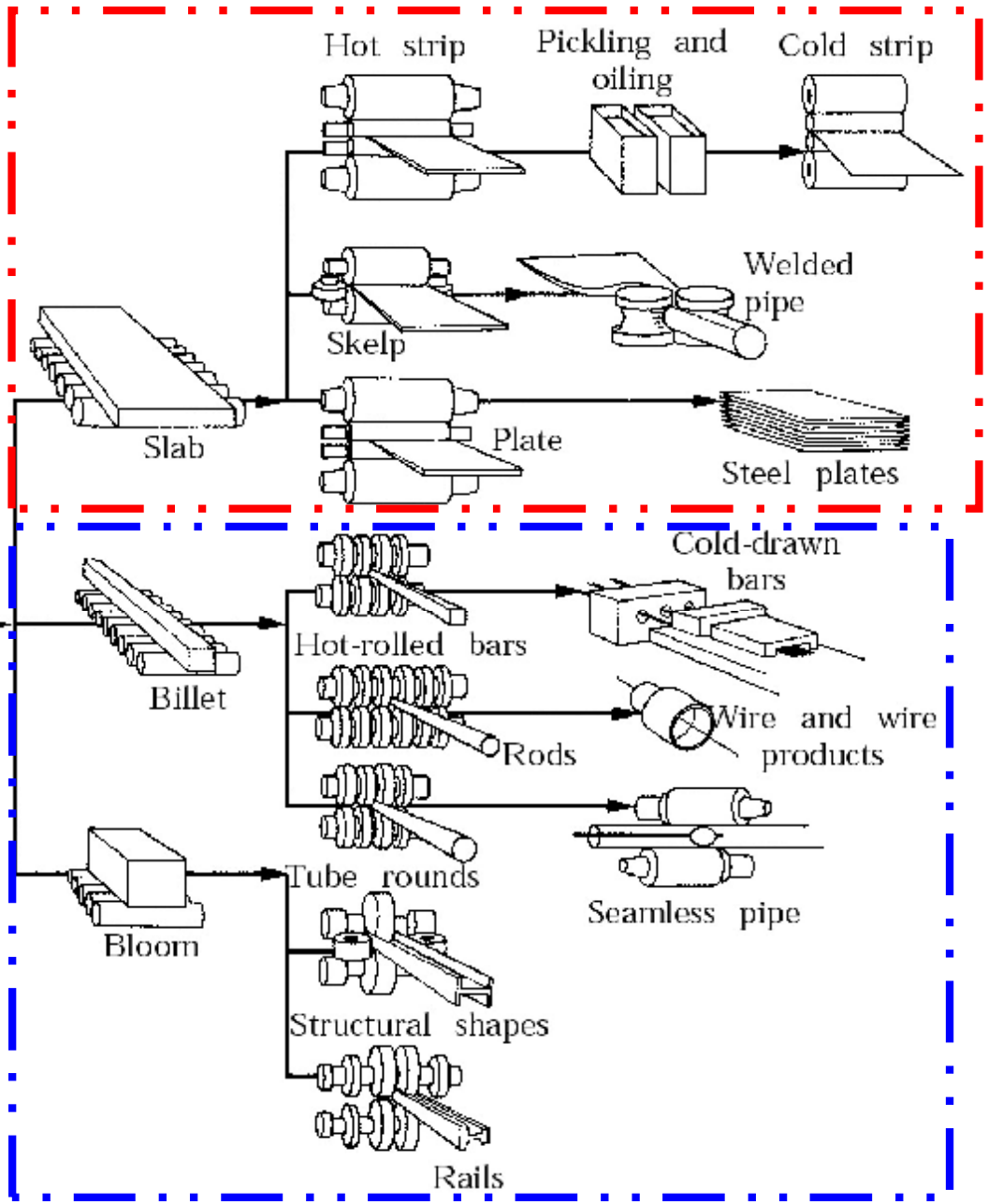
  § 4.5

- **By temperature：**
  - **hot rolling （热轧）**
  - **cold rolling （冷轧）**

  § 4.3

flat rolling ⟶

- **reduce the thickness**



shape rolling ⟶

- **change the cross-section**

Figure 4.1 Schematic outline of various flat- and shape-rolling processes. *Source*: American Iron and Steel Institute.

4.2 Flat Rolling（平板轧制）

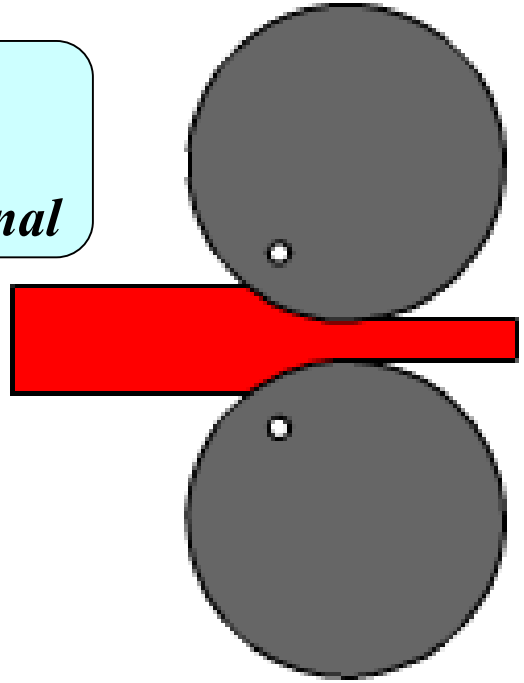
Outline

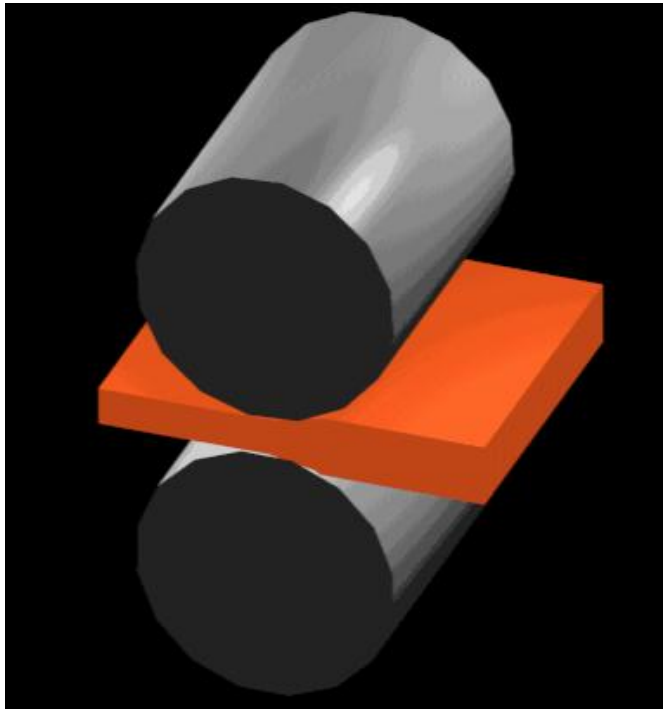
- **Important factors:**
  - process（工艺过程）
  - products:
    - plate and sheet（厚板与薄板）
- **Process variables:（工艺参数）**
  - neutral point（中性点）
  - frictional forces（摩擦力）
  - draft（压下量）
  - rolling force（轧制力）
- **Geometric considerations:**
  - roll bending （轧辊弯曲）
  - flattening of rolls（轧辊压扁）
  - thermal camber of rolls（轧辊热挠度）
  - spreading of strip（条料宽展）

Flat Rolling（平板轧制）

- A strip（带料/条料） of thickness h_o enters the roll gap（辊缝/辊隙） and is reduced to thickness h_f by a pair of rotating rolls, each roll being powered through its own shaft by electric motors（电动机）.

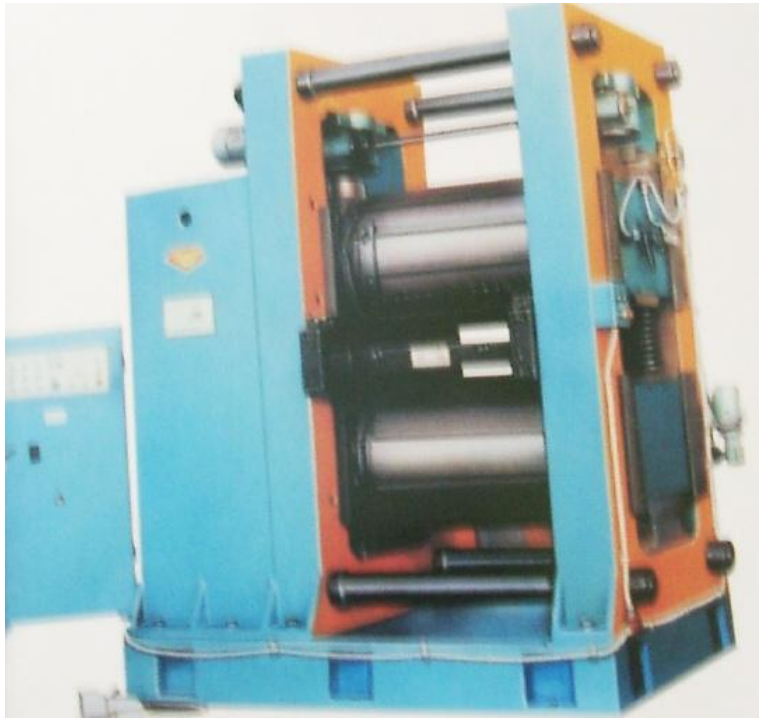
h_o/h_f:
o — original
f — finished/final





Rolling Mills and Rolls

（轧机与轧辊）



Products of Flat Rolling

厚板

ø **plate:** *thickness* ＞ 6 mm

ø **sheet:** *thickness* ⩽ 6 mm

- **strip**（*条料/带料*）
- **strip in coil** （*卷料/卷材*）

薄板

Application of Plate

- **machine structures**
- **ship hulls（*船体*）**
- **boilers（*锅炉*）** **: 300mm (12in.) thick**
- **bridges**
- **nuclear vessels（*核反应容器*）** **: 150mm (6 in.) thick**
- **battleships and tanks** **: 100～125mm thick**

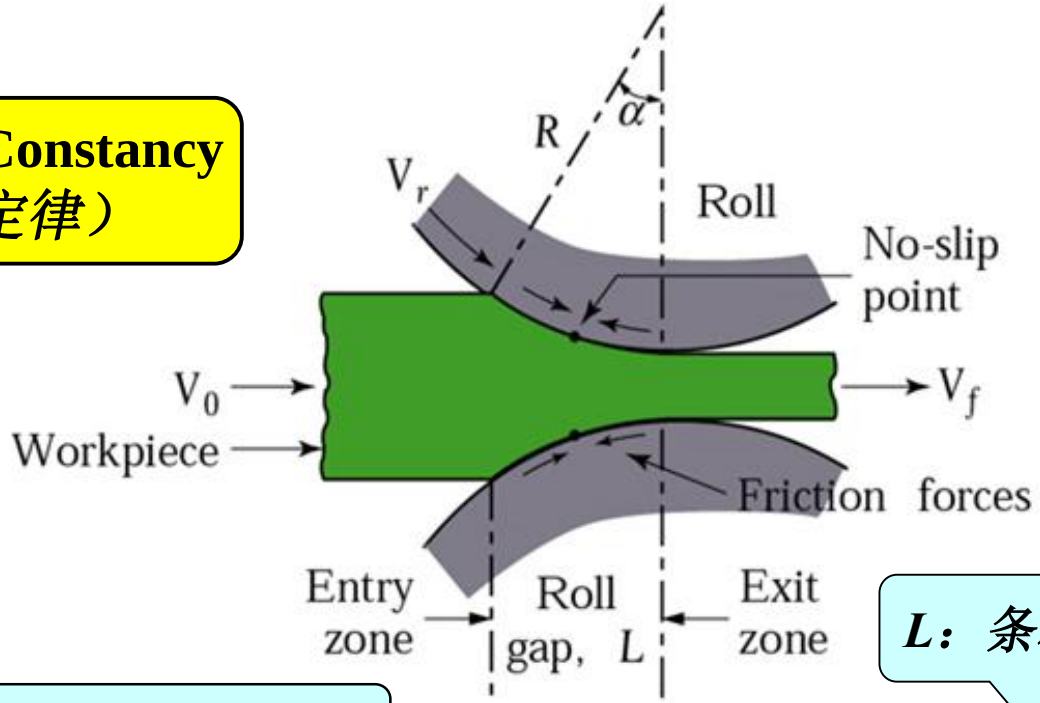
Application of Sheet

- automobile bodies （*车身*）
- aircraft fuselages（*机身*）: 1.8 ～ 1.9 mm thick
- appliances （*用具/器具*）

- kitchen and office equipment : 0.1 mm thick
- food and beverages container
- aluminum foil（*铝箔*）
  : 0.008 mm (8μm) thick

Flat Rolling Process

Law of Volume Constancy
（体积不变定律）



***L*：条料与轧辊的接触弧长**

plastic deformation zone

辊缝

Roll gap ≠ *L*

- **the thickness is reduced:** $\triangle h = h_o - h_f$ **draft（压下量）**
- **the length is increased:** $\triangle l = l_f - l_o$ **elongation（延伸量）**
- **the width is increased:** $\triangle w = w_f - w_o$ **spreading（宽展量/展宽量）**

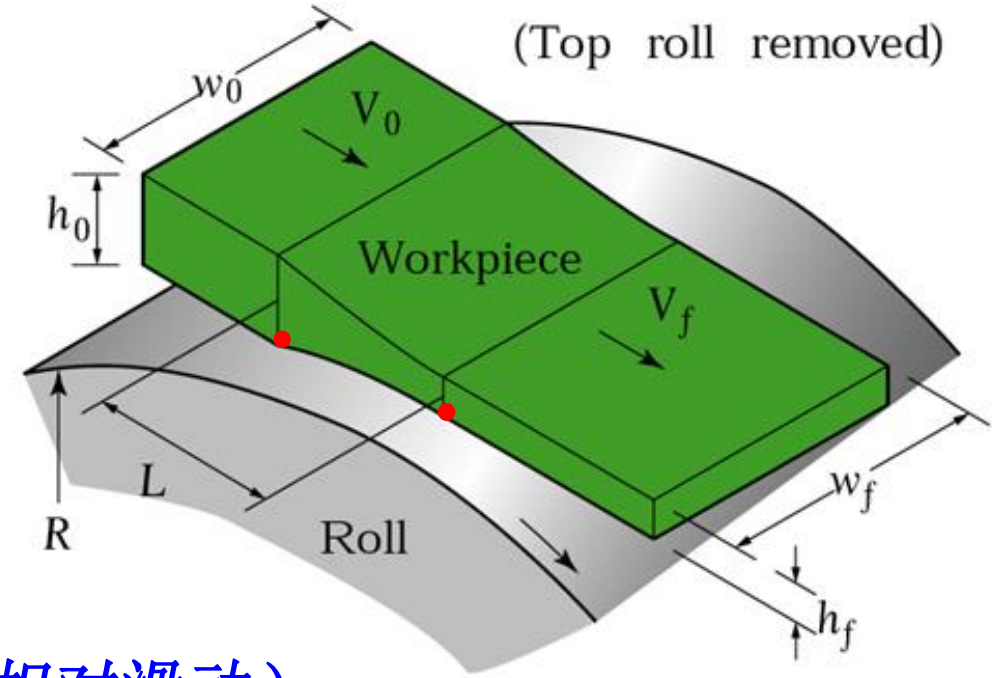
V_o : **the velocity of the strip at the entrance（入口）**

V_f : **the velocity of the strip at the exit（出口）**

V_r : **the surface speed of the rolls ,which is constant（不变的）**

$$V_0 < V_f$$

$$V_0 < V_r < V_f$$



- **There is relative sliding（相对滑动）between the roll and the strip along the arc of contact in the roll gap, *L*.**

Neutral Point or No-Slip Point

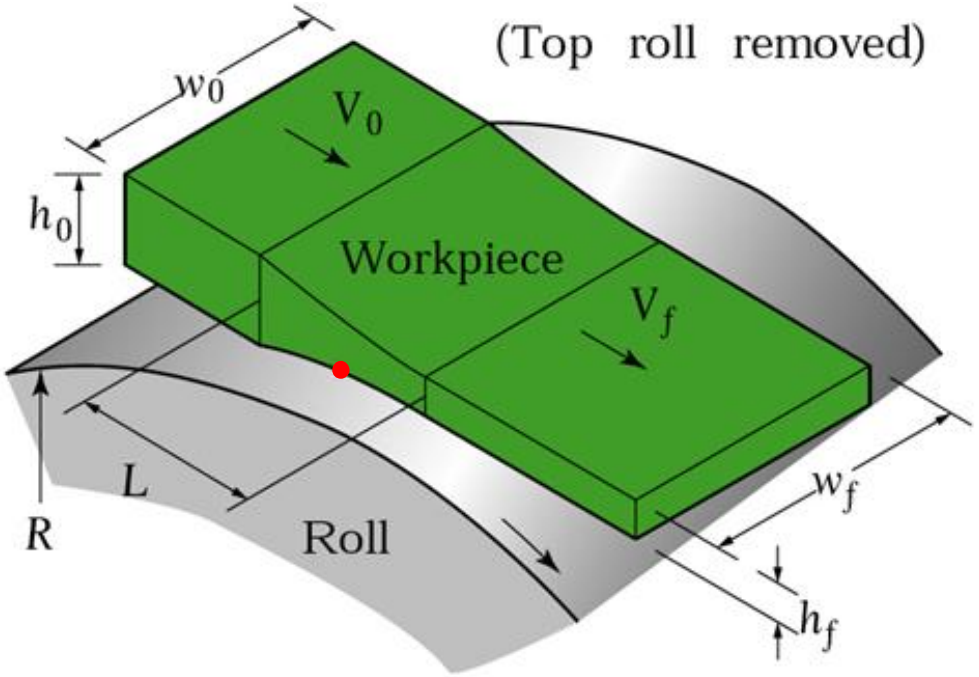
（中性点/无滑移点）

Definition: One point along the contact length, where

$$V_s = V_r$$

V_r : **the surface speed of the rolls, which is constant（不变的） while rolling**

V_s : **the velocity of the strip, which is variable（变化的） during the course of rolling**



Frictional Forces（摩擦力）

- **Since there is relative sliding between the roll and the strip along the arc of contact in the roll gap, the frictional forces, which oppose motion, act on the strip.**

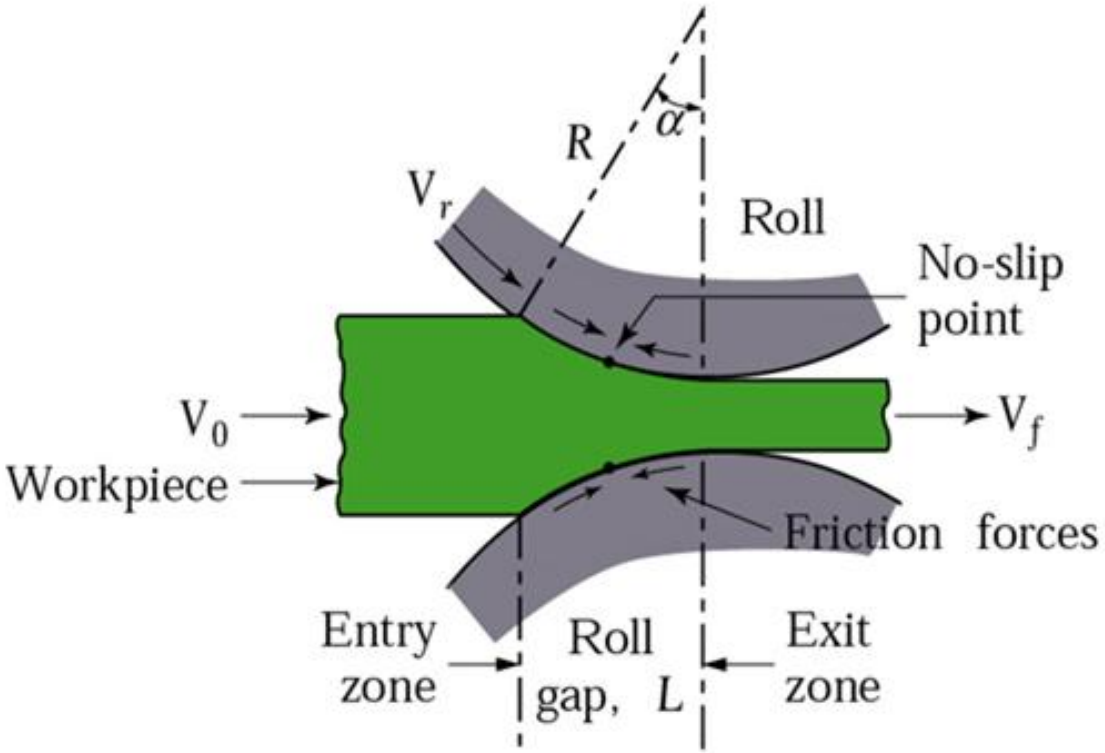
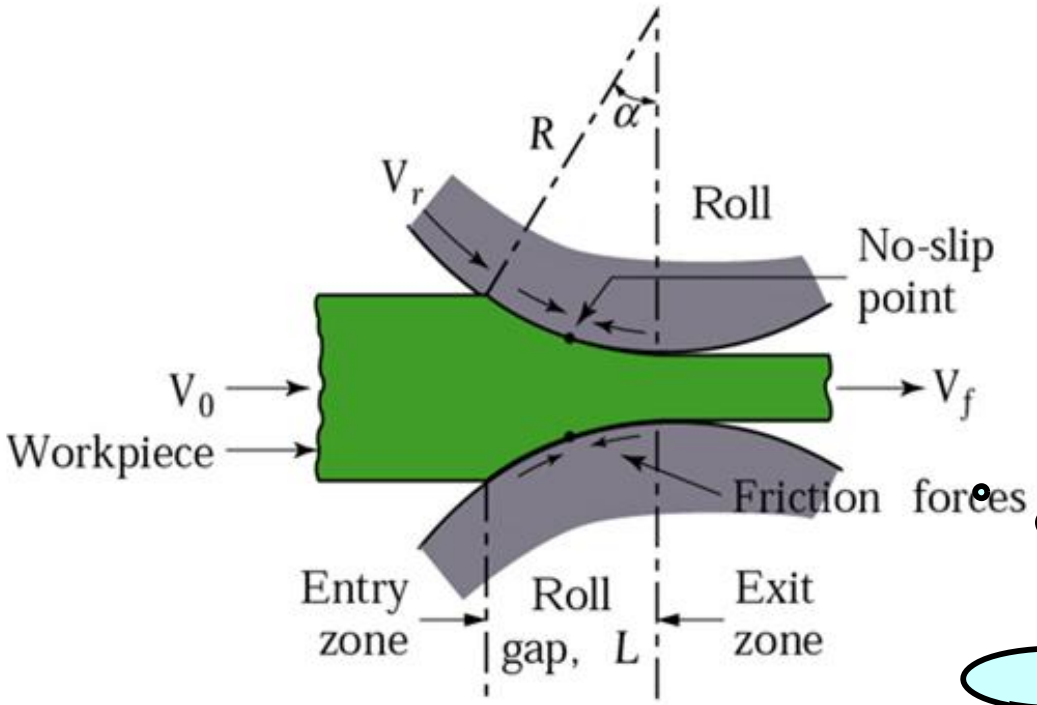


Fig4.2 (b) Friction forces acting on strip surfaces

Significance（*重要性/意义*） of Friction

- The rolls pull the material into the roll gap through a *net frictional force*（*净摩擦力*） on the material.
- **is necessary** for rolling materials.

“咬入”



along the rolling direction

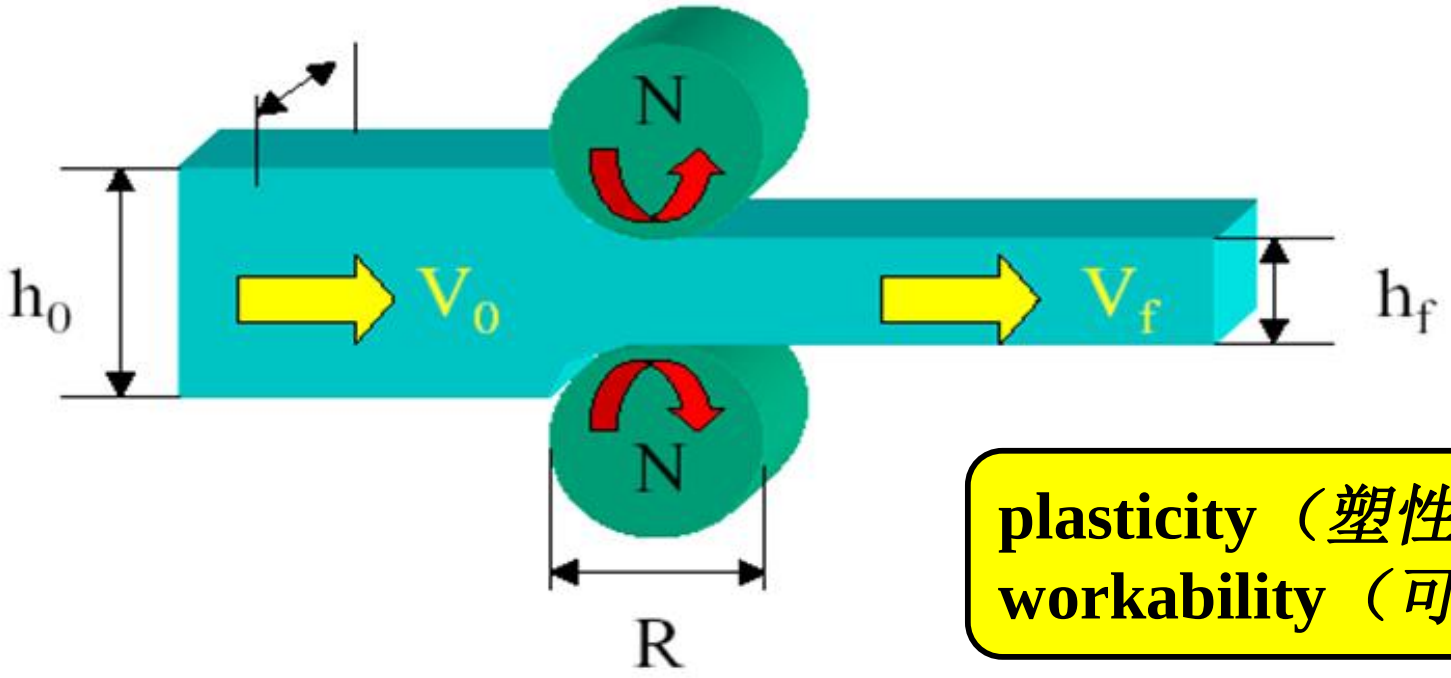
what’s the direction of net frictional force?

Disadvantages of Friction

- **Energy is dissipated（*浪费*） in overcoming friction; thus, increasing friction means increasing forces and power（*功率*） requirements.**
- **could damage（*损害*） the surface of the rolled product.**

- **A compromise（*折衷/妥协*） has to be made, one which induces low and controlled *coefficients of friction*（*摩擦系数*） by using effective lubricants（*润滑剂*）.**

Draft（压下量）

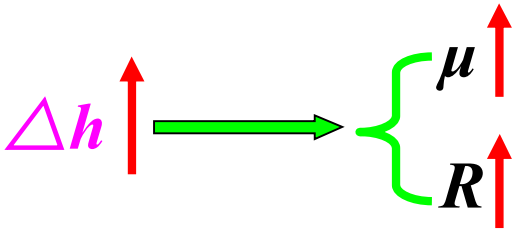


plasticity（塑性）
workability（可加工性）

- **reduction in thickness, $\triangle h$**

$$\triangle h = h_0 - h_f = \mu^2 R$$

μ: the coefficient of the friction
R: the roll radius



- **"The higher the friction and the larger the roll radius, the greater the maximum possible draft becomes."**

4.2.1 Roll Force, Torque, and Power Requirements

- **Roll Force（*轧制力*）**

$$F = LwY_{avg}$$

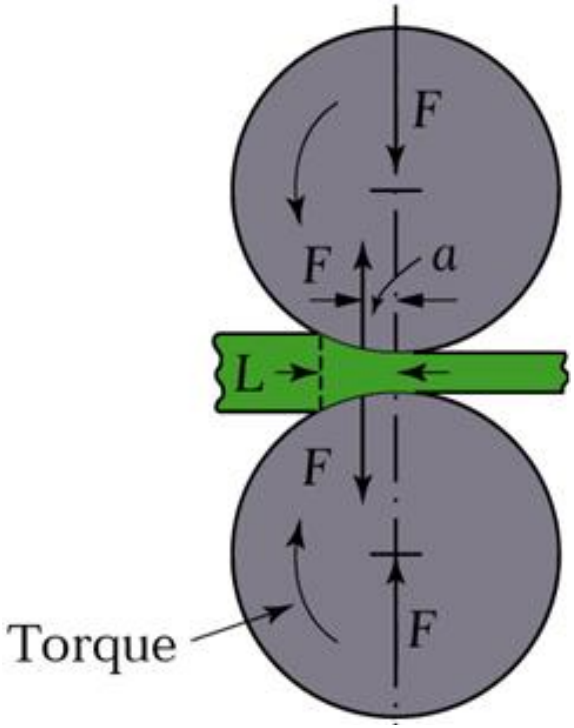
contact area
（*接触面积*）

***L*: the roll-strip length of contact arc**
***w*: the width of the strip**
Y_{avg}: the average true stress（*平均真实应力*）

- **Torque（*轧制力矩/扭矩*）**

$$T = Fa$$

$$= F \cdot L / 2$$



- **Power（*功率*） per roll**

$$P = Tw$$

***T:* torque（*轧制力矩/扭矩*）**
ω *:* angle speed（*角速度*）

$$= (F \cdot L / 2)(2p\, n)$$

***n:* revolutions（*转数*） per second of the roll**

$$= p\, FLN / 60 \text{ W}$$

$$= p\, FLN / 60000\ k\text{W}$$

***N:* rpm (revolutions per minute) of the roll，*n*=*N*/60**
W: watt（*瓦特*）,功率单位

$$= p\, FLN / 33000\ hp$$

***k*W：kilowatt（*千瓦*）,功率单位**
hp：horsepower（*马力*）,功率单位

Four-high Rolling-mill
（四辊轧机）

Too high roll forces can cause the rolls（轧辊）:

- **deflection（弯曲/挠度）**
- **flattening（压扁）**

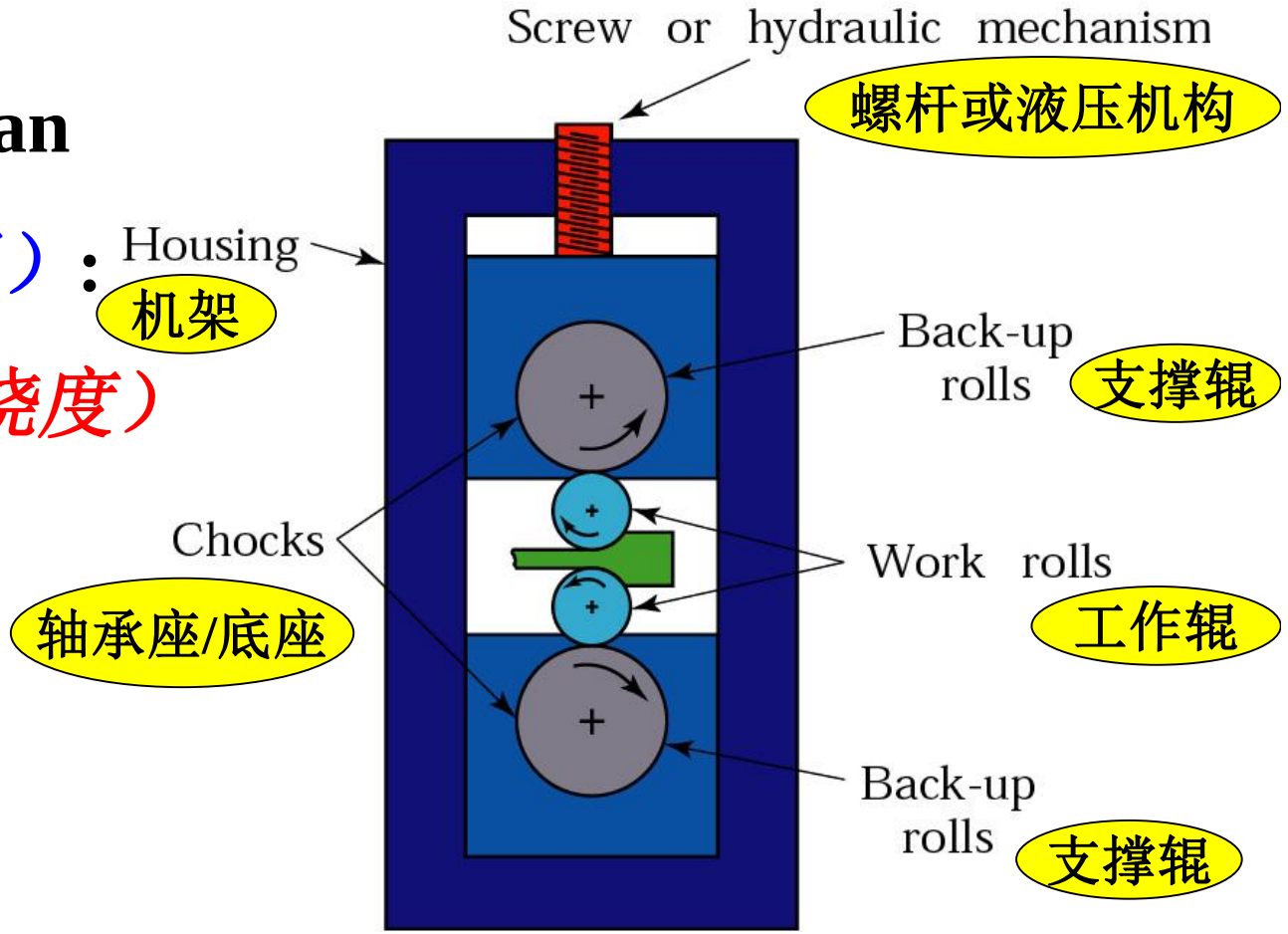
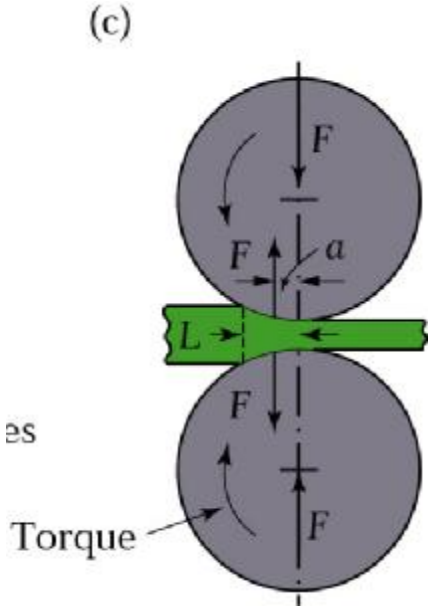


Figure 4.3 Schematic illustration of a four-high rolling-mill stand（轧机机座）, showing its various features. The stiffnesses（刚度） of the housing, the rolls, and the roll bearings are all important in controlling and maintaining the thickness of the rolled strip.

Reducing Roll Forces

$$F = LwY_{avg}$$

$$L \approx \sqrt{R\Delta h} \longrightarrow \Delta h = m^2 R$$



a. Reducing **friction, μ**;

b. Using **smaller-diameter** rolls, ***R***, to reduce the contact area;

c. Taking **smaller reductions** per pass, Δh, to reduce the contact area;

d. Rolling at **elevated temperatures（高温）** to **lower the strength（强度）** to the material;

e. Applying **front and/or back tension（前拉力与/或后拉力）** to the strip.

- **To apply longitudinal tensions（纵向拉力） to the strip**
  - **As a result, the compressive stresses（压应力） required to deform the material plastically become smaller**
  - **particularly important in rolling high-strength metal**

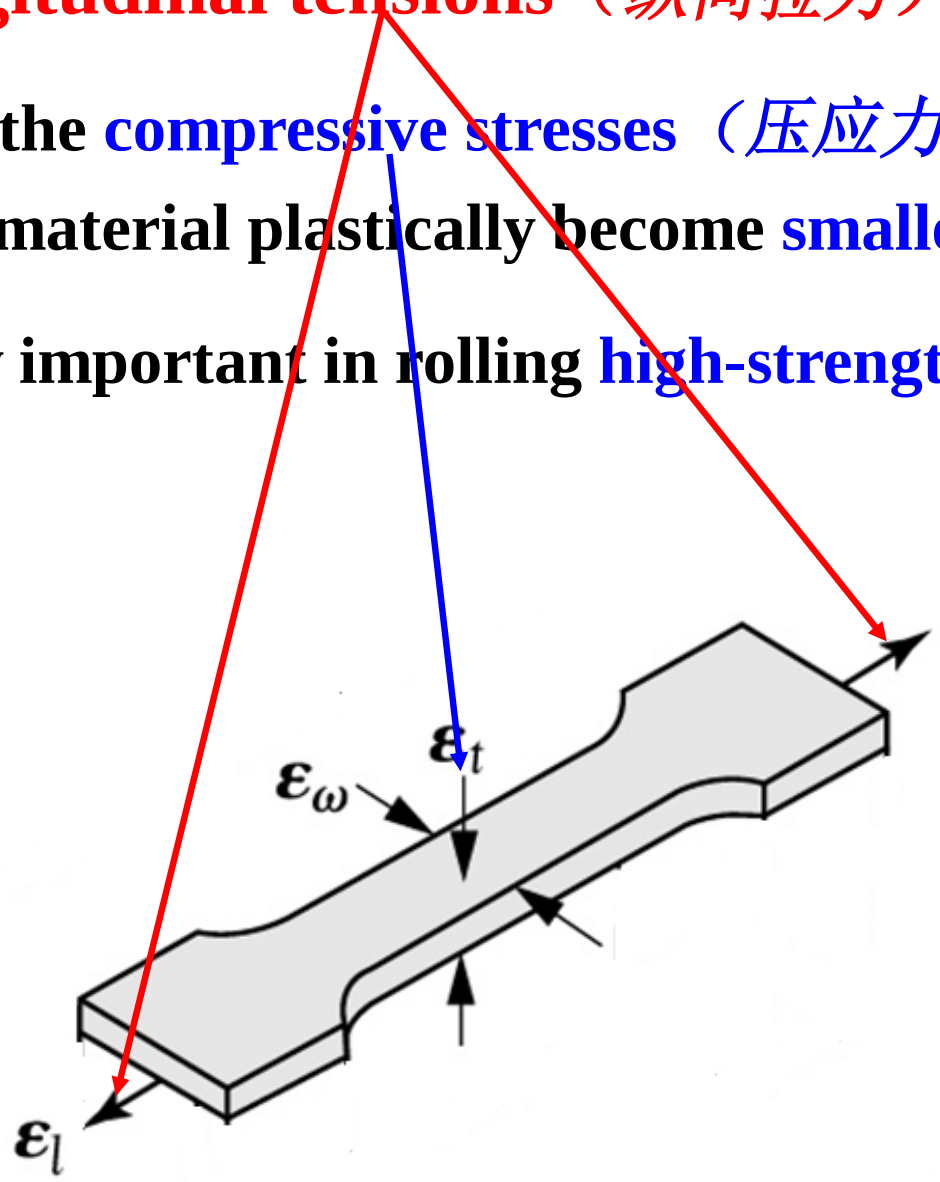
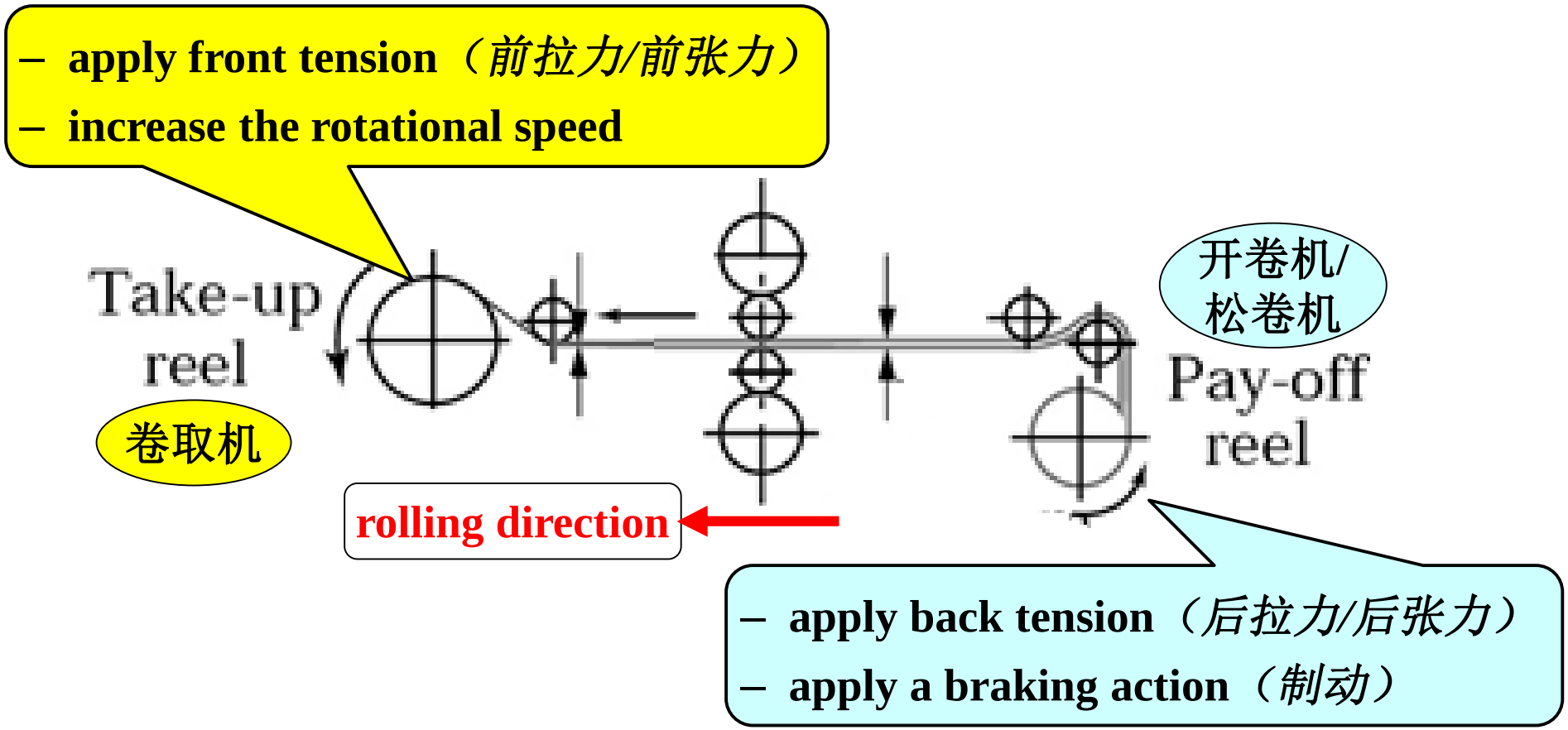


Figure Stains on a tensile-test specimen.（拉伸试验试样应变状态）



- **Steckel rolling（*斯特克尔轧制法*）:**
  - **be carried out by front tension only**
  - **with no power supplied to the rolls**

4.2.2 Geometric Considerations

a. **Roll bending** （*轧辊弯曲*）

b. **Flattening of rolls**（*轧辊压扁*）

c. **Thermal camber of rolls**（*轧辊热挠度*）

changes in the shape of rolls

d. **Spreading of strip**（*条料宽展*） → **change in the shape of plate and sheet**

Roll Bending （轧辊弯曲）

Reason:

- roll forces tend to bend the rolls elastically（弹性地）

Result:

- the rolled strip tends to be thicker at its center than at its edges.

Solutions:

1) the higher elastic modulus（弹性模量） of the roll material, the smaller the roll deflection（轧辊挠度）

2) roll camber（轧辊凸度）: grinding（磨削） the rolls so that their diameter at the center is slightly larger than at their edges.

3) application of moments（力矩/弯矩） at their bearings

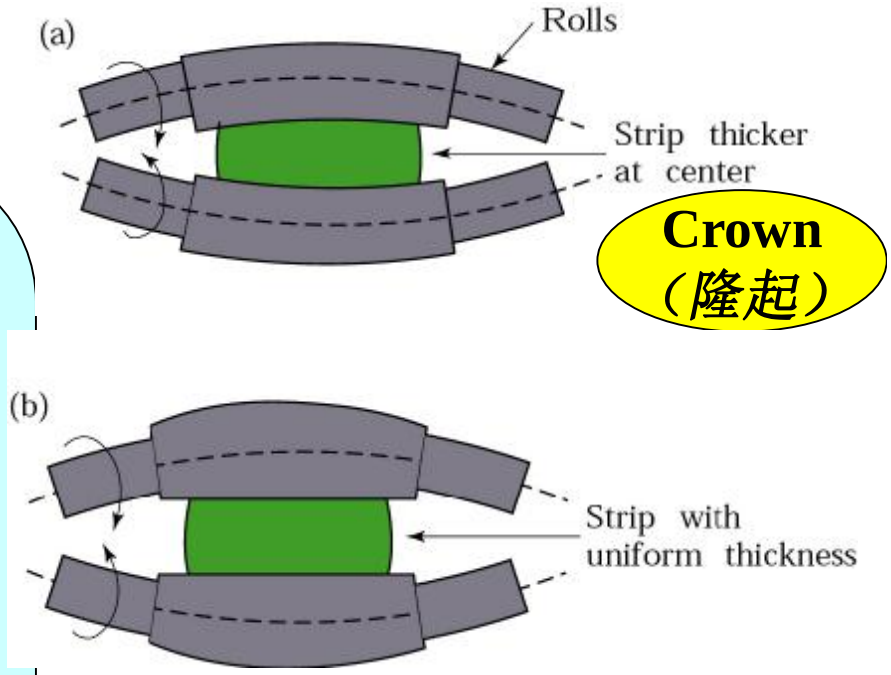


Figure 4.4 (a) Bending of straight cylindrical rolls, caused by the roll force. (b) Bending of rolls ground with camber（凸度）, producing a strip with uniform thickness.

- **Application of moments（*弯矩*） at their bearings**

  – 通过加在辊体两端的反力矩来平衡轧辊两端工作压力产生的弯矩，减小轧辊的变形

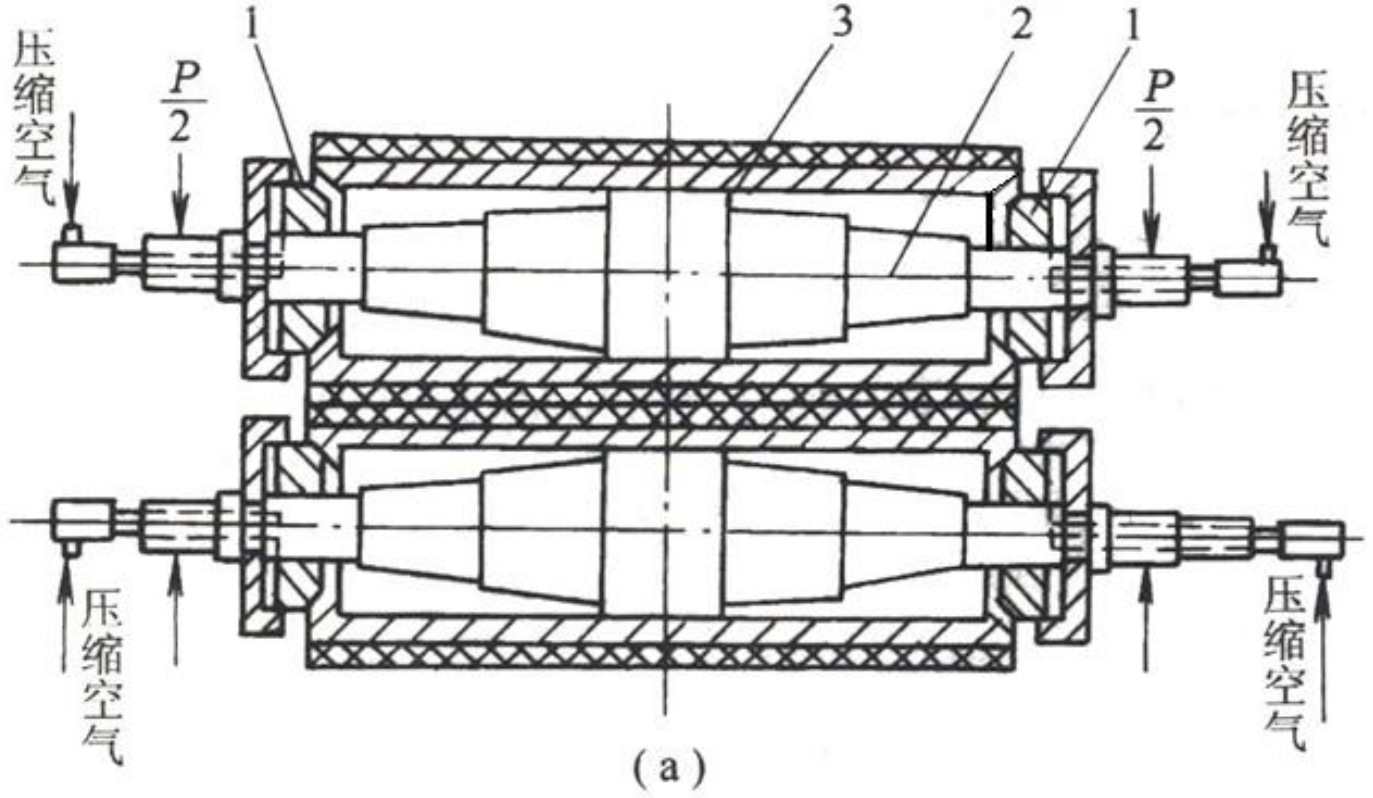


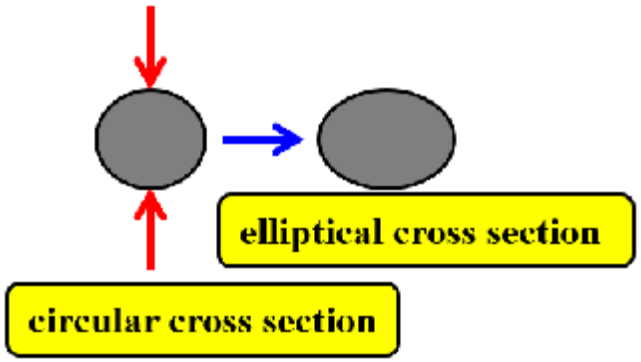
图 3－27　P.F.轧辊示意图

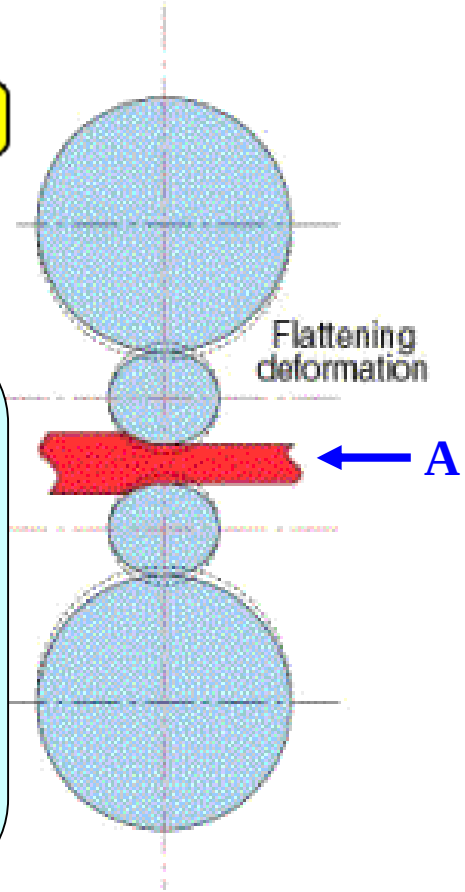
1—活动锥套　2—辊轴　3—辊体

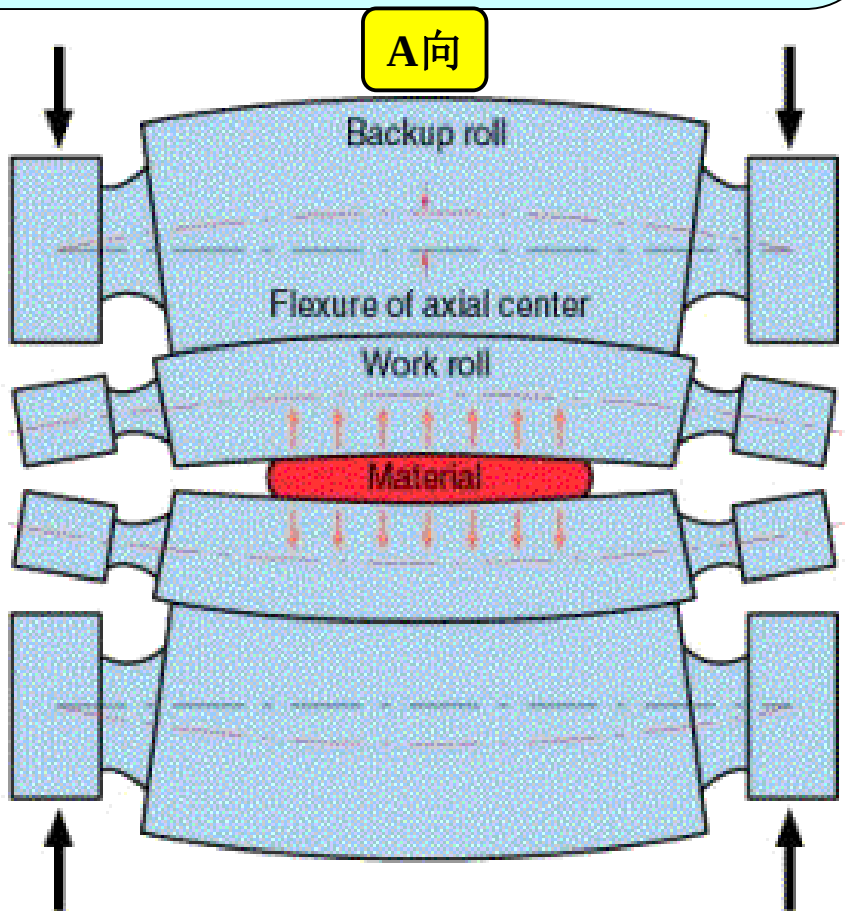
Flattening of Rolls （轧辊压扁）

Reason:
- elastic deformation caused by roll forces

Result:
- It produces a larger roll radius and a larger contact area for the same draft. The roll force, in turn, increases with increased flattening.





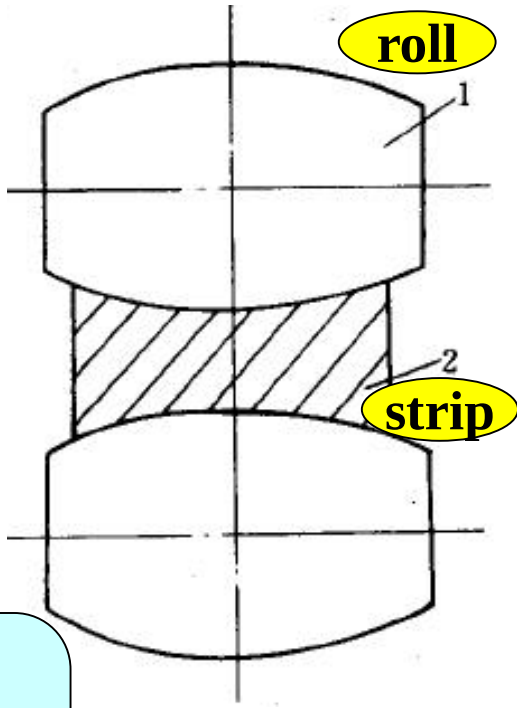


Solutions:
1) enhance the strength of roll materials
2) enhance the radius of the roll

Thermal Camber （热挠度）

Reason:

- the rolls becomes slightly **barrel-shaped**（鼓形/桶形） because of the **heat** generated by plastic deformation during rolling.



Result:

- can produce strips that are **thinner at the center** than at the edges.

Solution:

- the total (or final) camber can be controlled by varying the location of the **coolant**（冷却液/冷却剂） on the rolls during hot rolling.

Spreading of a Strip （条料宽展）

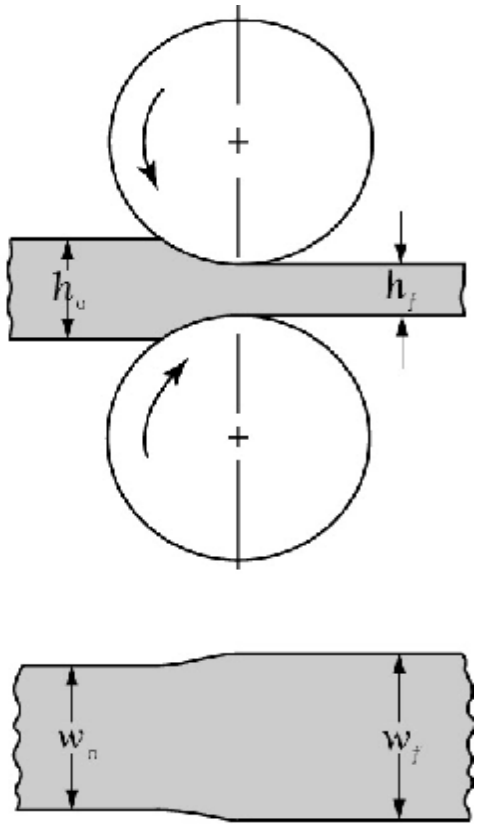
Spreading:

– increase in width

Phenomenon:

– for strip with high w_0/h_0 ratios（宽厚比/宽高比）, the width of the material remains effectively constant after rolling.

– for strip with smaller w_0/h_0 ratios, the width increases considerably in the roll gap.

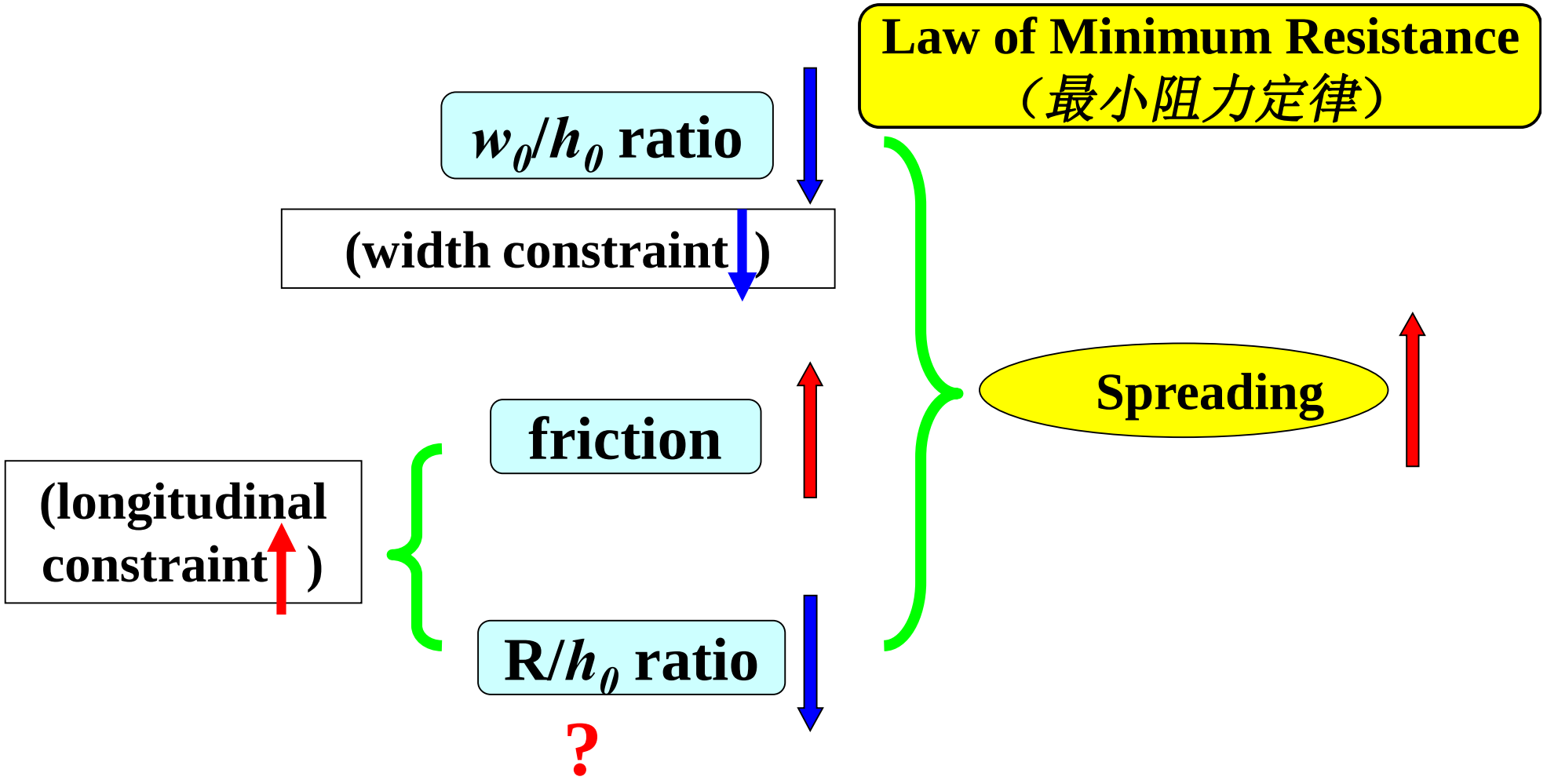


Solutions:

-- by the use of vertical rolls（立式轧辊） in contact with the edges of the rolled product (edging rolling) （立轧/轧边）

Figure 4.5 Increase in the width (spreading) of a strip in flat rolling (see also Fig. 4.2a). Similarly, spreading can be observed when dough is rolled with a rolling pin.

Influence Factors of Spreading



- Textbook: (P124)
- “spreading increases with decreasing width-to-thickness ratio of the entering strip, increasing friction, and decreasing ratio of the roll radius to the strip thickness.”

Correction

R/h_0 ratio

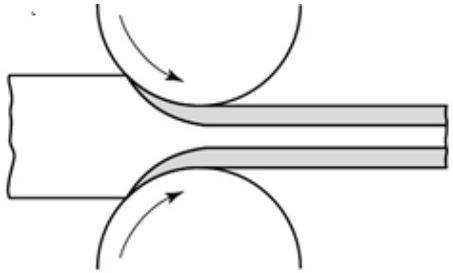
R (for equal h_0)

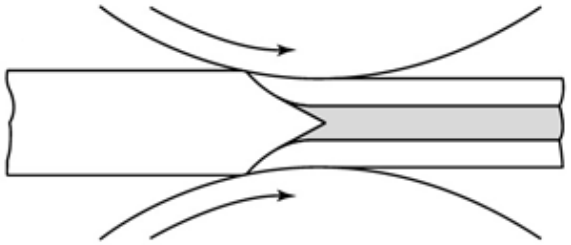
L (arc length of contact)

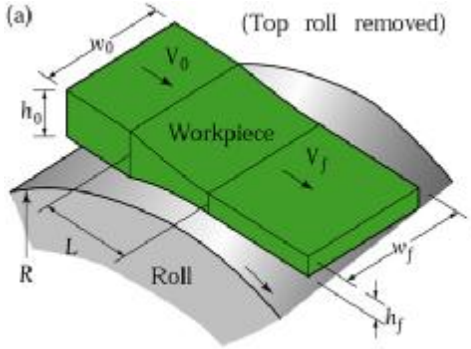
longitudinal constraint

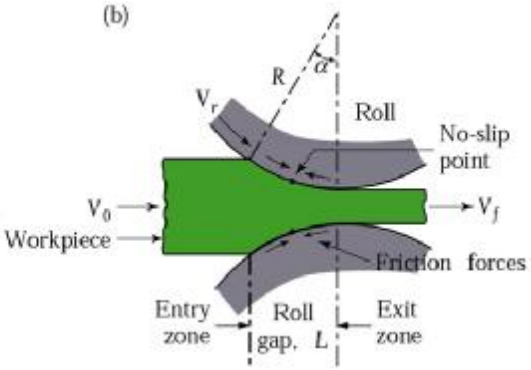
tend to flow longitudinally

less to increases in width → spreading









- spreading **decreases with decreasing** ratio of the roll radius to the strip thickness.

spreading

压下增加宽展增加的原因

a、因为压下量增加时，变形区长度增加，变形区形状参数　增大，因而使纵向塑性流动阻力增加，纵向压缩主应力数值加大。根据最小阻力定律，金属沿横向运动的趋势增大，因而使宽展加大。

b、压下增加，高方向压下来的金属体积也增加，所以使Δ B 也增加。

2）轧辊直径的影响

其它条件不变时，宽展Δ B 随轧辊直径 D 的增加而增加。

因为当 D 增加时变形区长度加大，使纵向的阻力增加，根据最小阻力定律，金属更容易向宽度方向流动.

特别注意

轧辊为圆柱体这一特点，产生有利于延伸变形的水平分力，它使纵向摩擦阻力减少，有利于纵向变形，即增大延伸。

所以，即使变形区长度与轧件宽度相等时，延伸与宽展的量也并不相等，而由于工具形状的影响，延伸总是大于宽展。

3）轧件宽度的影响

假如变形区长度 l 一定，当轧件宽度 B 逐渐增加时，由 l ＞B 到　l ＝B 如下图所示，宽展区是逐渐增加的，因而宽展也逐渐增加

当由 l ＝B　到 l ＜B 时，宽展区变

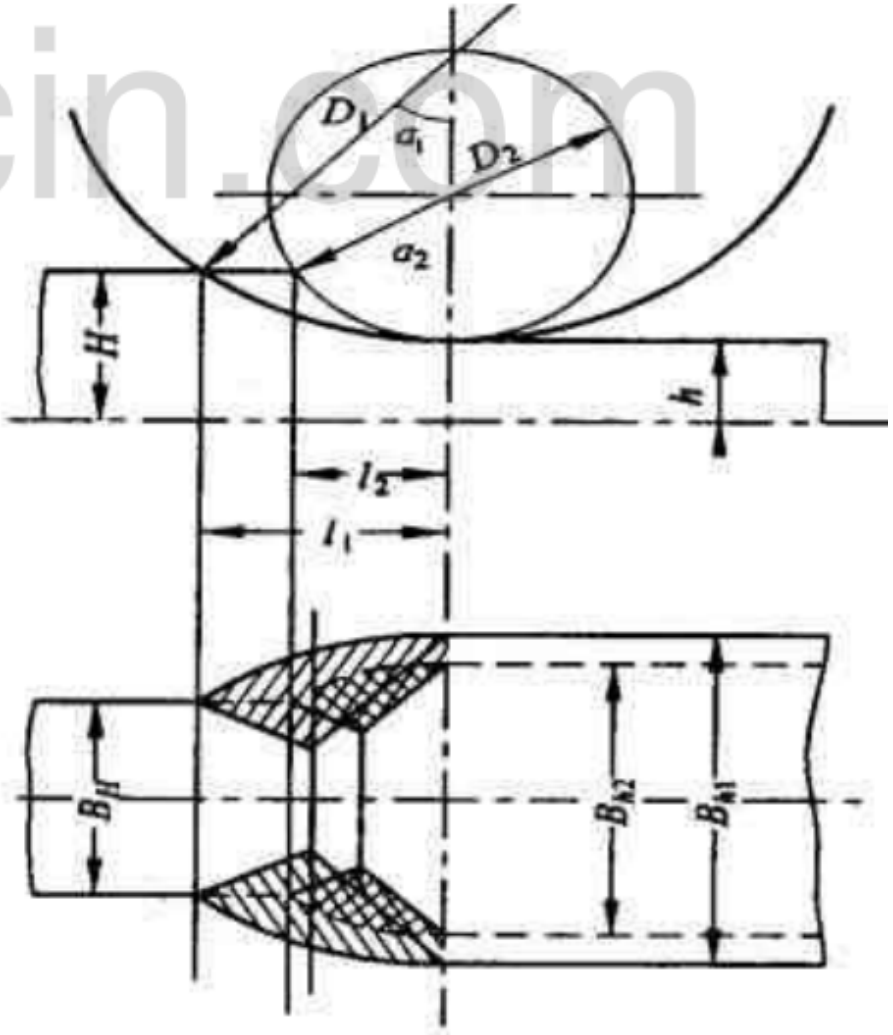


图 **4-5**　轧辊直径对宽展的影响

4.3 Flat-rolling Practice（平板轧制实际应用）

Outline

- **Types of flat rolling:**
  - **hot rolling（热轧）**
    - basic concept
    - advantages
    - temperature
    - products
    - defect（缺陷）
  - **cold rolling（冷轧）**
    - basic concept
    - advantages
  - **pack rolling（迭板轧制）**
  - **temper rolling （表面精轧）**
  - **levelling rolls（校直轧）**

- **Defects （缺陷）in rolled plates and sheets**
  - **surface defects**
  - **wavy edges**
  - **cracks**
  - **alligatoring**

1. Hot Rolling （热轧/初轧）

– done above the recrystallization（再结晶）temperature

ø the initial（最初的）breaking down （破裂/打碎） of an ingot or of a continuously cast slab is done by hot rolling

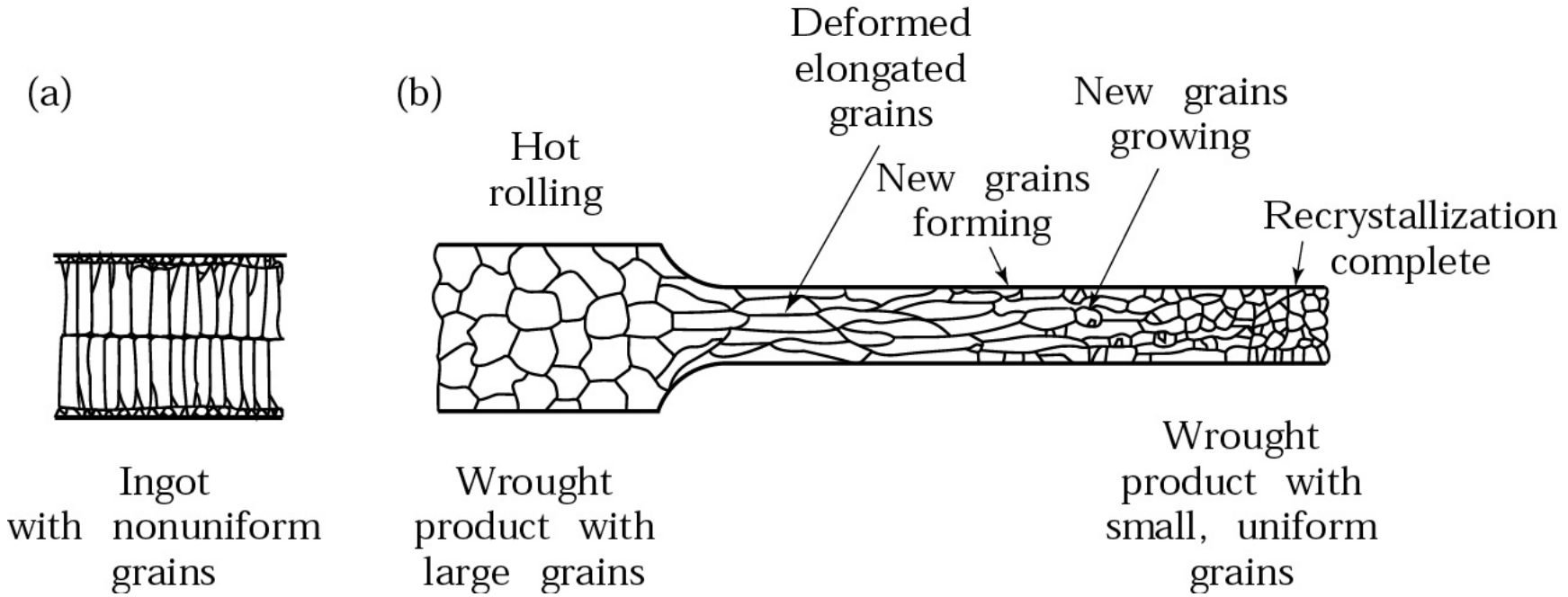
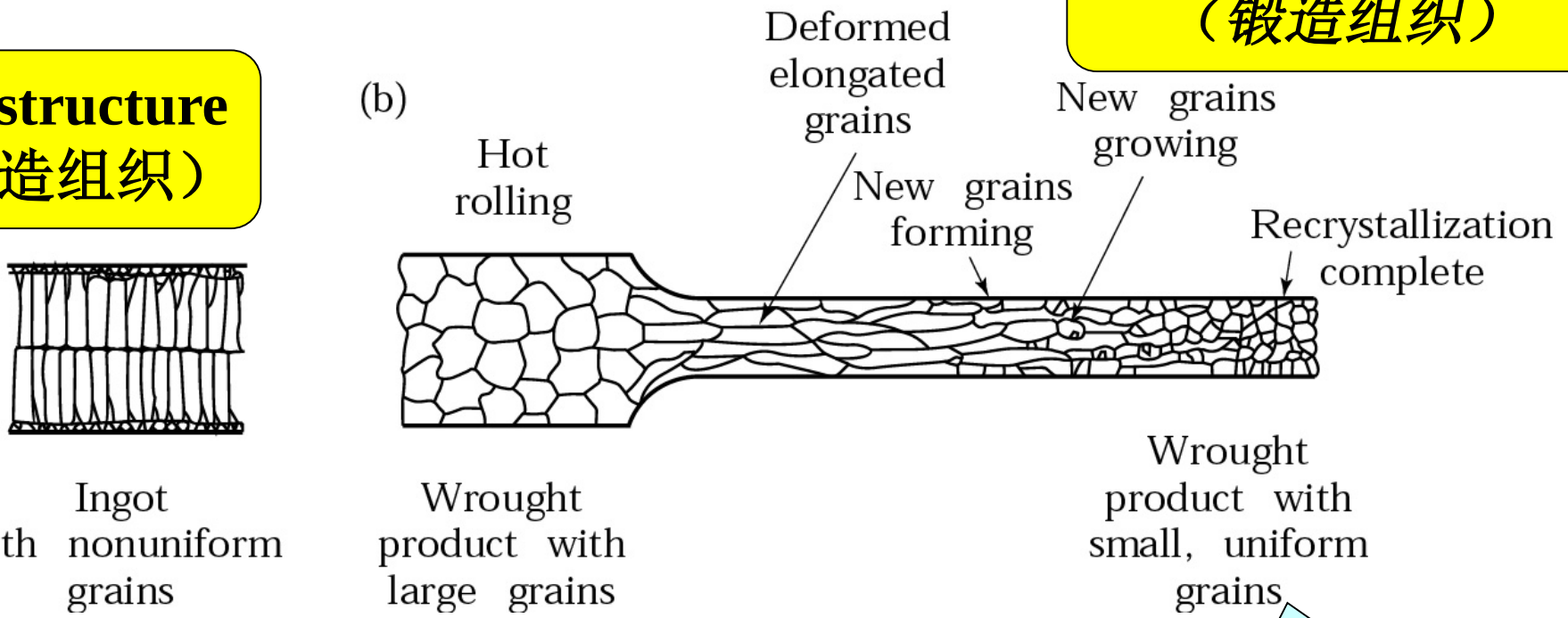


Figure 4.6 Changes in the grain structure of cast or of large-grain wrought metals during hot rolling.

cast structure → **wrought structure**

cast structure
（铸造组织）

wrought structure
（锻造组织）



dendritic（*树枝状的*）
coarse（*粗大的*）
nonuniform grains（*晶粒不均匀*）
brittle（*脆的/脆性的*）
porous（*多孔的*）

equal/uniform grain(*等轴晶/晶粒均匀*)
finer(*细化的*) **grain size**
enhanced ductility(*韧性/塑性/延展性*)
non-porosity(*无孔*)

Advantages of Hot Rolling

- **reduce grain size**
- **improve ductility（*塑性/延展性/柔韧性*）**

breaking down of an cast ingot or slab

– **breaking up（*破裂/打碎*）brittle grain boundaries（*晶界*）**

– **closing up（*压合/压实*）internal defects（*内部缺陷*）, especially porosity （*多孔性*）**

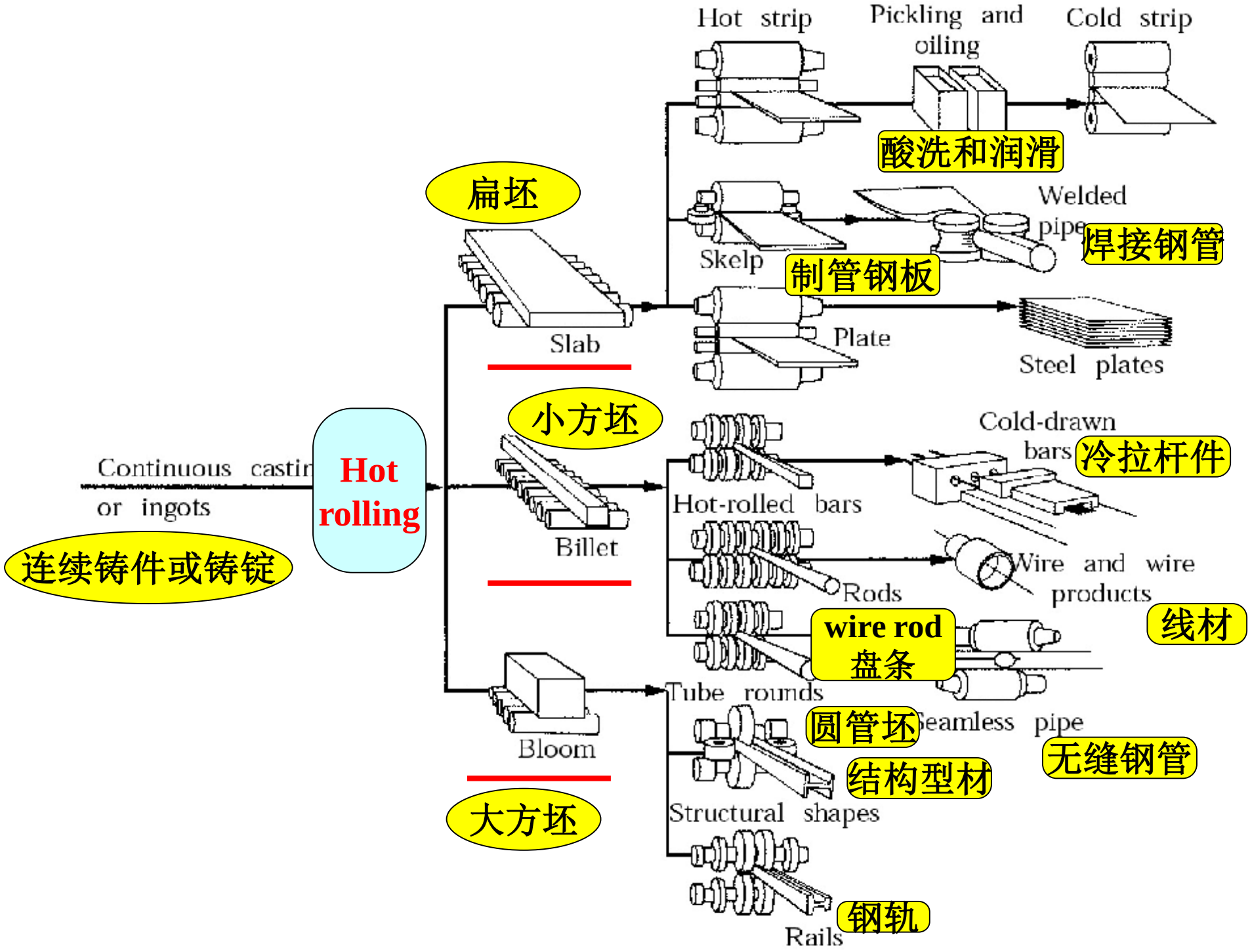
Temperature of Hot Rolling

- **Varies with different metals:**

  - **aluminum (Al) alloys（*铝合金*）: about 450℃ (850℉)**
  - **alloy steels（*合金钢*）: 1250℃ (2300℉)**
  - **refractory alloys（*高温合金/难熔合金*）:1650 ℃ (3000℉)**

Products of the First Hot-rolling Operation（初轧）

- **slab**
  - Ø rectangular in cross-section（矩形截面）
  - Ø rolled into plates and sheets later
- **bloom**
  - Ø has a square（正方形）cross-section
  - Ø at least 150mm on the side
  - Ø processed further by shape rolling into structure shapes, such as I-beams（工字梁） and railroad rails
- **billet**
  - Ø square
  - Ø with a cross-section area smaller than blooms
  - Ø rolled into various shapes, such as round rods（圆棒） and bars（杆材）, by the use of shaped rolls


Hot strip
Pickling and oiling
Cold strip
酸洗和润滑
扁坯
Welded pipe
焊接钢管
Skelp
制管钢板
Slab
Plate
Steel plates
小方坯
Cold-drawn bars
冷拉杆件
Continuous castin
or ingots
Hot rolling
Hot-rolled bars
Billet
Rods
Wire and wire products
线材
连续铸件或铸锭
wire rod
盘条
Tube rounds
圆管坯
Seamless pipe
无缝钢管
Bloom
结构型材
Structural shapes
大方坯
钢轨
Rails

Defect（*缺陷*） in Hot Rolling

- **Scale（*氧化皮/氧化垢*）**

  - mainly consists of the oxides （*氧化物*）

Conditioning （*清理/处理*） Methods

- **using a torch （*气炬*）(scarfing *火焰表面清理*）**
- **pickling with acids （acid etching，*酸洗/酸蚀*）**
- **by such mechanical means as blasting with water（*喷水*）**
- **grinding（*研磨*）**

2. Cold Rolling （冷轧）

– carried out at room temperature （室温）

Advantages of Cold Rolling

- better surface finish（表面光洁度）↑ → roughness（表面粗糙度/Ra） ↓

  — because of lack of scale

- better dimensional tolerances（尺寸公差）↓ → accuracy（尺寸精度） ↑

  — without thermal expansion

- enhanced mechanical properties ↑ → strength and toughness（强度与刚度） ↑

  — due to strain hardening（应变硬化）

3. Pack Rolling （迭板轧制）

– two or more layers of metal are rolled together, which improves **productivity**（生产率）.

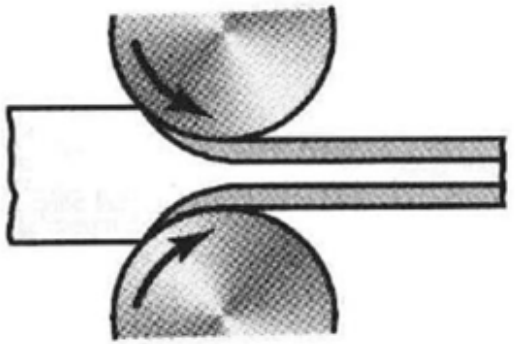
Example: Aluminum Foils（铝箔）

- pack rolled in **two layers**
- foil-to-foil side: matte（无光泽的）and satiny（光滑的） finish
- foil-to-roll side: shiny and bright

  Ø reason: contact under high contact stresses with the polished（抛光的） rolls

4. Temper Rolling or Skin Pass （硬化冷轧或表面光轧）

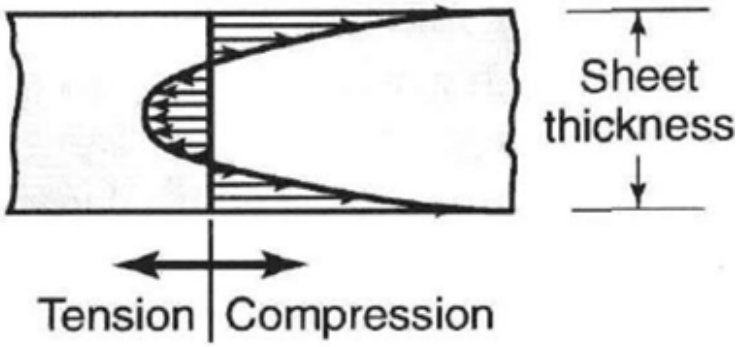
- the sheet metal is subjected to a final light rolling pass （轧制工步/轧制道次） of 0.5% to 1.5% reduction shortly before stretching（拉伸）
- produce compressive residual stress（残余压应力） on the surface



Application:

§ 7.3

- To correct the situation of yield-point elongation（屈服点延伸） for mild steel （低碳钢/软钢） when stretched during sheet-forming operations



5. Leveling Rolls（矫直轧/校平）

— to improve flatness（平面度/平整度）, the rolled strip is passed through a series of leveling rolls（矫直辊）

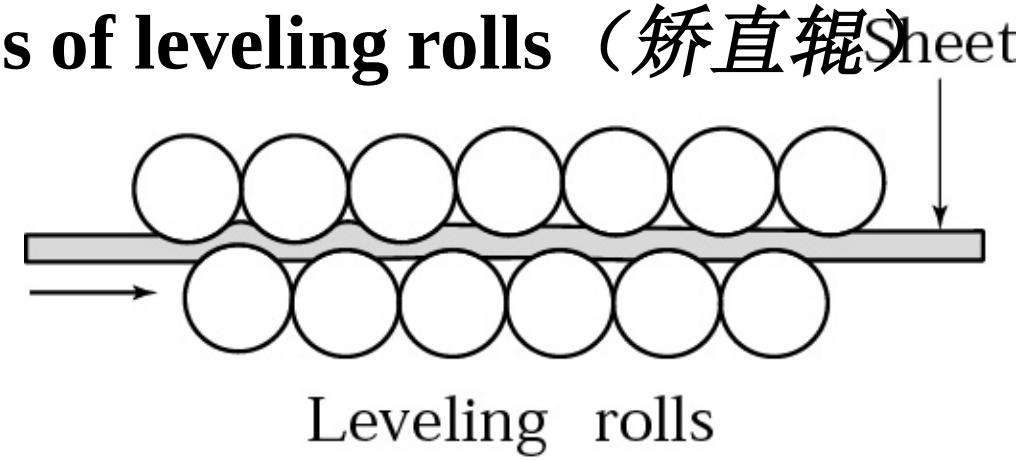


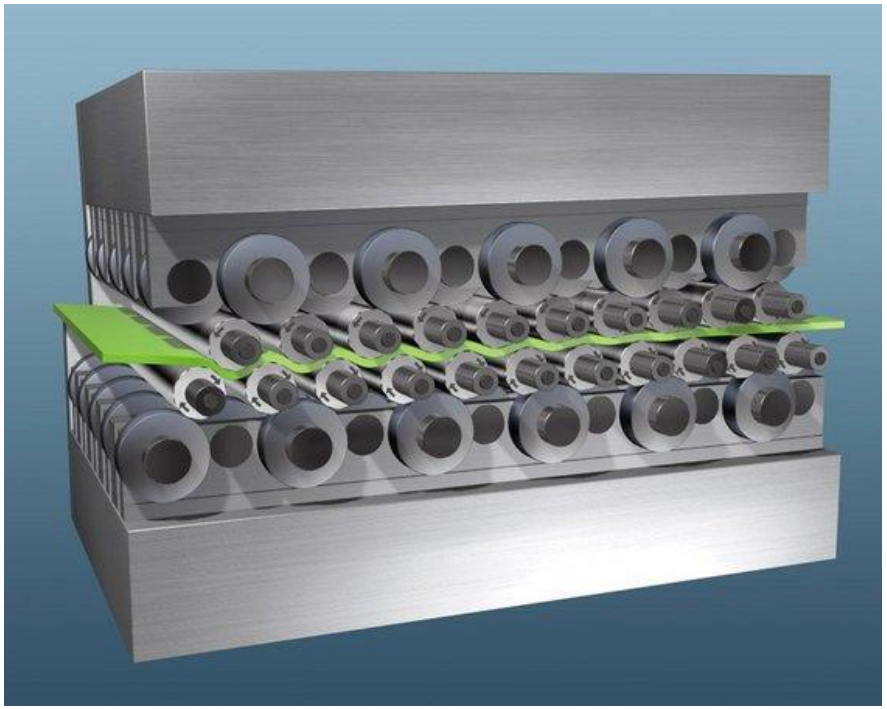
Figure 4.7 A method of roller levelling to flatten rolled sheets.

Method:

- **Several different roller arrangements are used.**
- **Each roll is driven separately, by an individual electric motor.**
- **The strip is flexed（弯曲） in opposite directions as it passes through the sets of rolls.**

Leveling Rolls

- 在辊式矫直中，金属板经过不断地交错变形弯曲。
- 从机器进料处到出料处，矫直辊是交错排列的。在两个矫直辊之间总有一个矫直辊在。在第一个矫直辊的地方交错弯曲最强，往出口处方向不断减弱。变形曲线接近一个不断减弱的正弦函数。
- 弹塑性的交错弯曲以及不断减弱的矫正变形促成了金属板的平整，最重要的就是消除了内应力



4.3.1 Defects（*缺陷*） in Rolled Plate and Sheets

- **Defects may be present on the surfaces of rolled plates and sheets, or there may be internal structural defects.**
- **Defects are undesirable because:**

Ø **compromise（*使不达标*） surface appearance（*表观质量*）**

Ø **adversely（*有害地/不利地*） affect：**

– **strength**

– **formability（*可成形性*）**

– **other manufacturing characteristics**

Surface Defects

Types：

- **scale**
- **rust（*锈*）**
- **scratches（*刮痕/划痕*）**
- **gouges（*擦伤*）**
- **pits（*凹点/凹陷*）**
- **cracks（裂纹）**

Reasons：

- **inclusions（*夹杂物*） and impurities（*杂质*） in the original cast material**
- **various other conditions related to material preparation and to the rolling operation.**

Typical Defects in Flat Rolling

a. **wavy edges（*波状边*）**

b. **zipper cracks（*拉链状开裂*） in the center**

c. **edge cracks（*边缘开裂*）**

d. **alligatoring （*分层/鳄唇开裂*）**

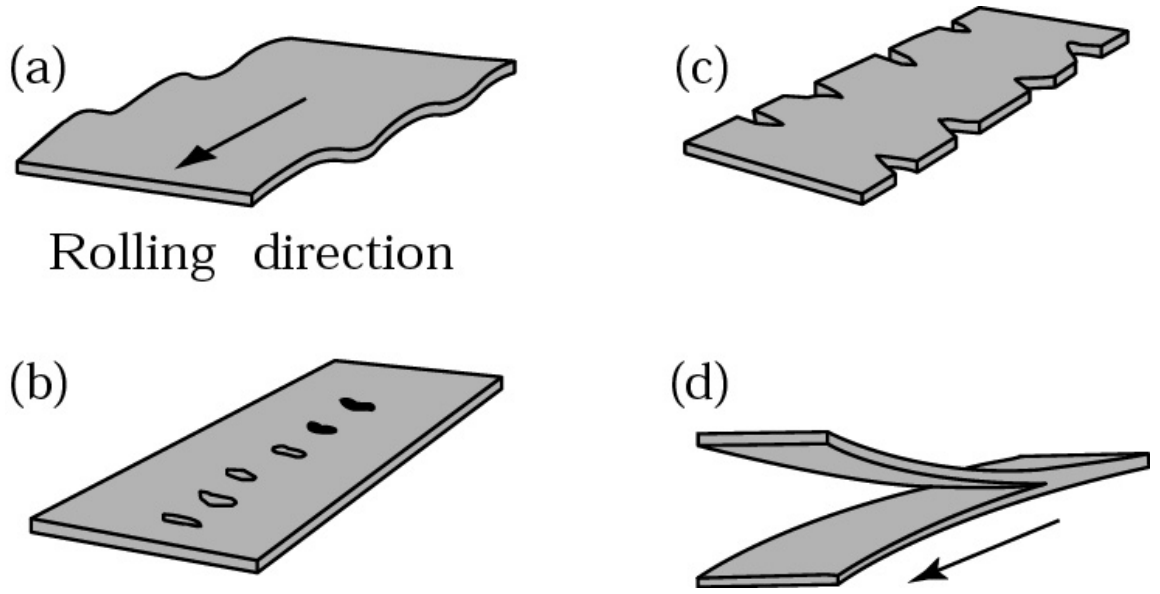
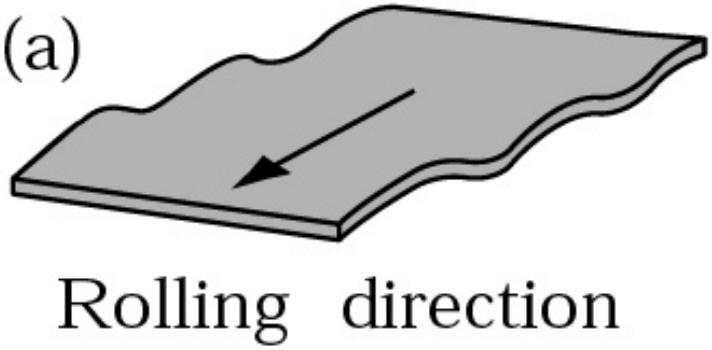
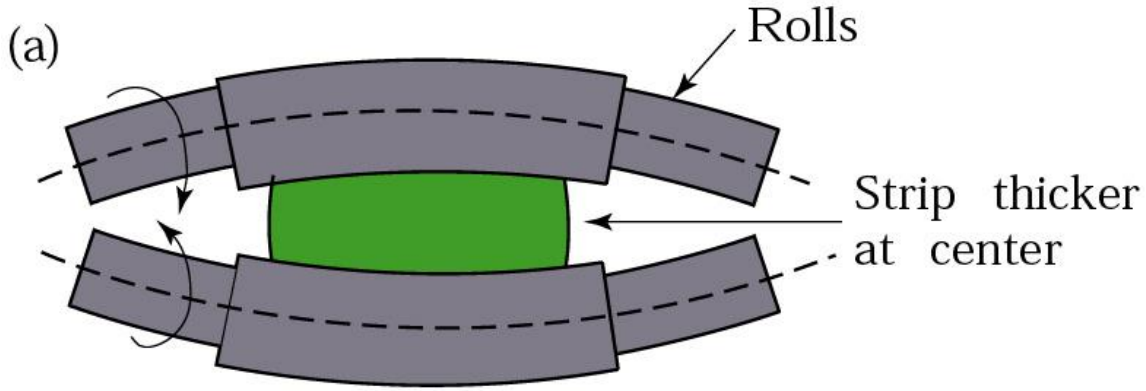


Figure 4.8 Schematic illustration of typical defects in flat rolling

a. wavy edges（波状边）



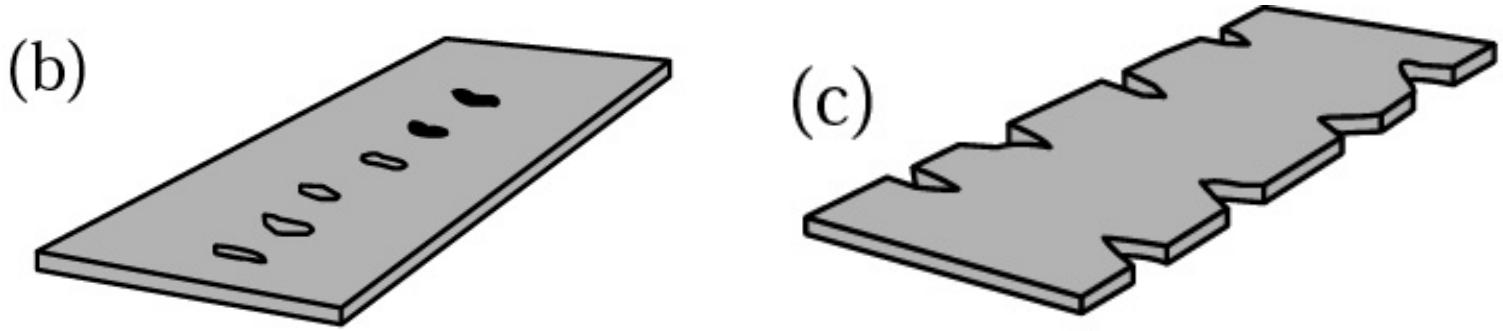
- because of **roll bending**
- the strip is **thinner** along its **edges** than its center
- the edges **elongate**（延伸） **more** than the center;
- the edges **buckle**（歪扭/翘曲), because they are restrained（受限/受约束） by the central region from expanding freely in the longitudinal (rolling) direction.



b. zipper（拉链状） cracks（裂纹） in the center

c. edge cracks

– due to poor material ductility at the rolling temperature



- Before the further sheet-metal-forming operations, edge defects in rolled sheets are often removed by:

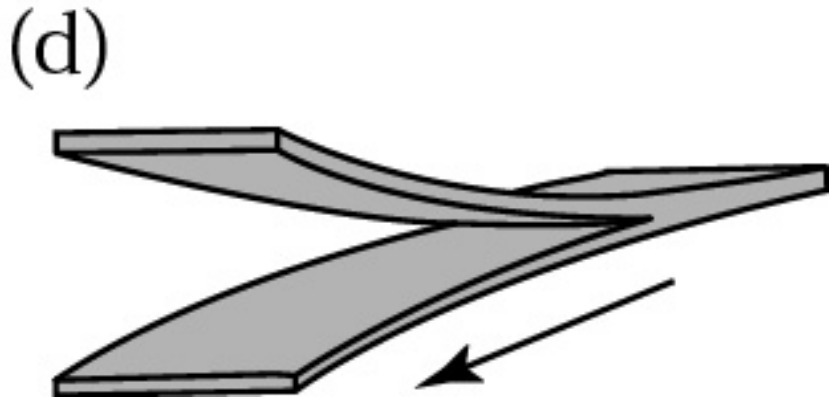
Chapter 7

Ø shearing (冲裁）

Ø slitting（切边）

d. alligatoring （*分层/鳄唇开裂*）

- a complex phenomenon
- typically caused by:
  - Ø nonuniform bulk-deformation （*不均匀体积变形*）during rolling
  - Ø the presence of defects in the original cast material



4.4 Rolling Mill（轧机）

Outline

- **Types of rolling mills and the characteristics:**
  - **two-high rolling mills**（二辊轧机）
  - **three-high rolling mills** （三辊轧机）
  - **four-high rolling mills** （四辊轧机）
  - **cluster mills**（多辊轧机）

- **Diverse roll arrangement（*不同的轧辊排列*） are used for several types of rolling mills and equipment**
- **Although equipment for hot and cold rolling is essentially the same, differences exist in:**
  - **roll materials**
  - **process parameters**
  - **lubricants**
  - **cooling systems**

- **The design, construction, and operation of rolling mills require major investments（投资）**
- **Highly automated mills produce close-tolerance（公差小）, high-quality plates and sheet at high production rates and low cost per unit weight, particularly when integrated with continuous casting.**
- **Equipment Capacity（能力）:**
  - **width of rolled products: may range up to 5m**
  - **thickness: as thin as 0.0025 mm**
  - **rolling speeds: may range up to 40m/s**

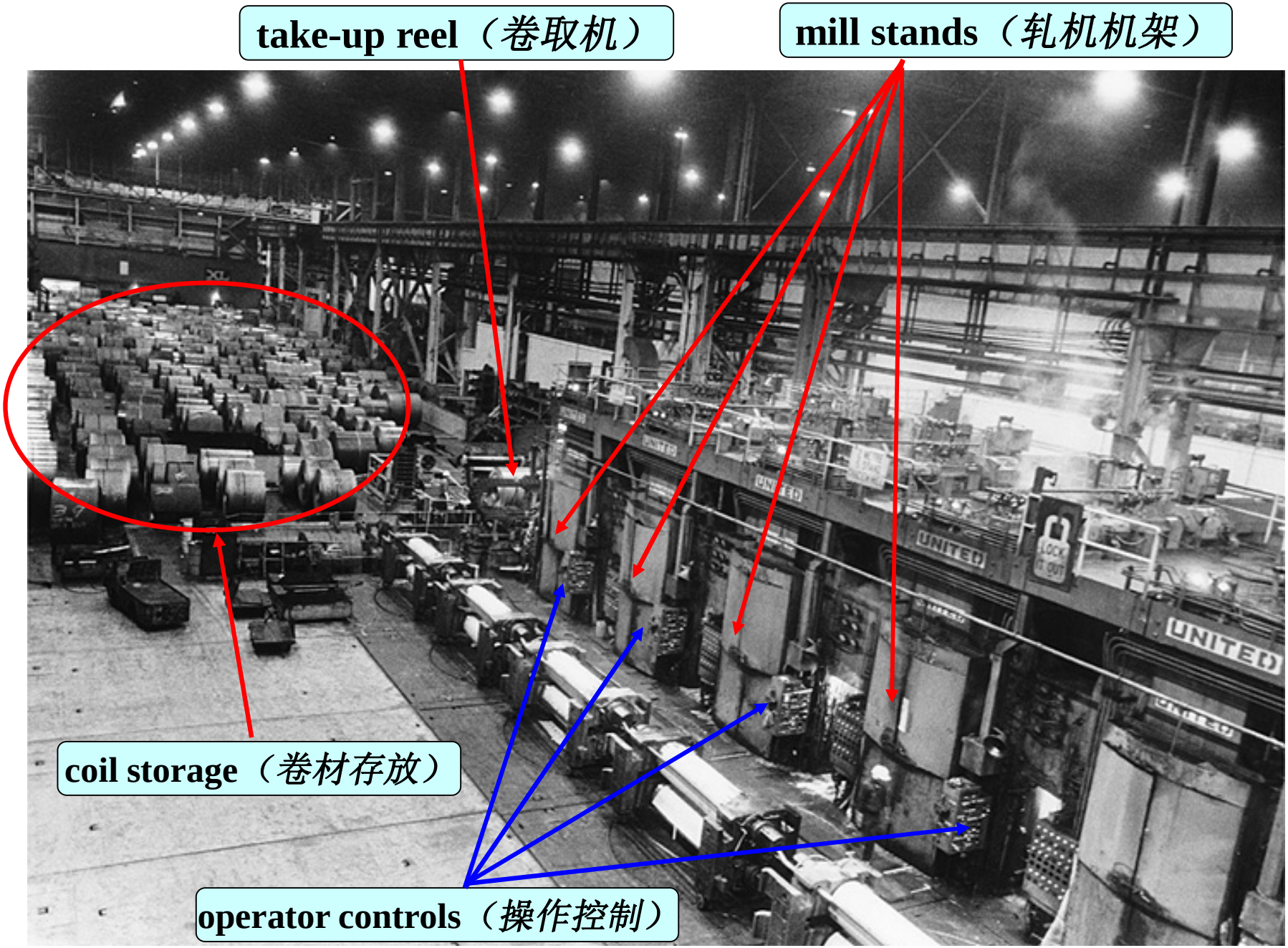


Figure 4.10 View of a rolling mill. *Source*: Courtesy of Ispat Inland.

Types of Rolling Mills

1. Two-high rolling mill（二辊轧机）

- used for hot rolling in initial breakdown passes on cast ingots or in continuous casting
- also named roughing mill or cogging mill, or blooming mill （粗轧机/初轧机/开坯轧机）
- roll diameters： 0.6m ～ 1.4m

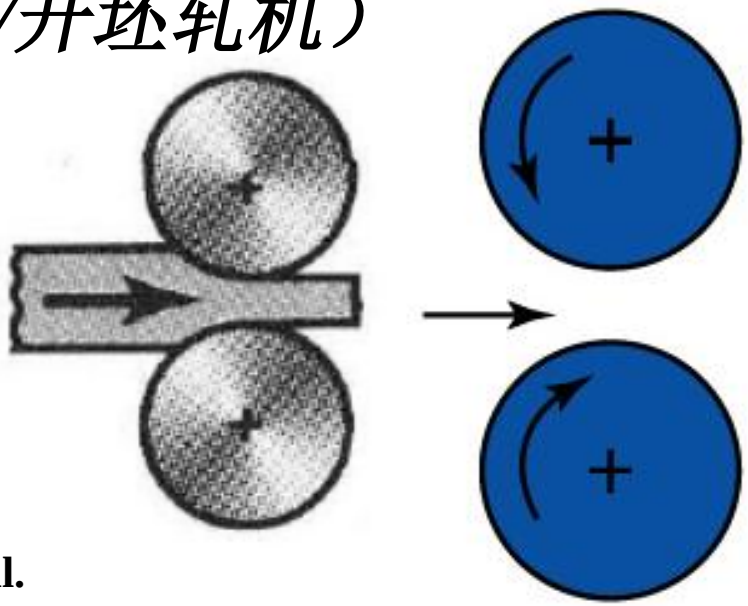


Figure 4.3 Schematic illustration of various roll arrangements: (b) two-high mill.

2. Three-high rolling mills （三辊轧机）

- also called **reversing mills**（可逆式轧机）
- the direction of material movement is **reversed** after each pass
- the plate being rolled is **repeatedly** raised to the upper roll gap, **rolled**, and then lowered to the lower roll gap by **elevator mechanisms**（升降机构） and various **manipulators**（操纵器）

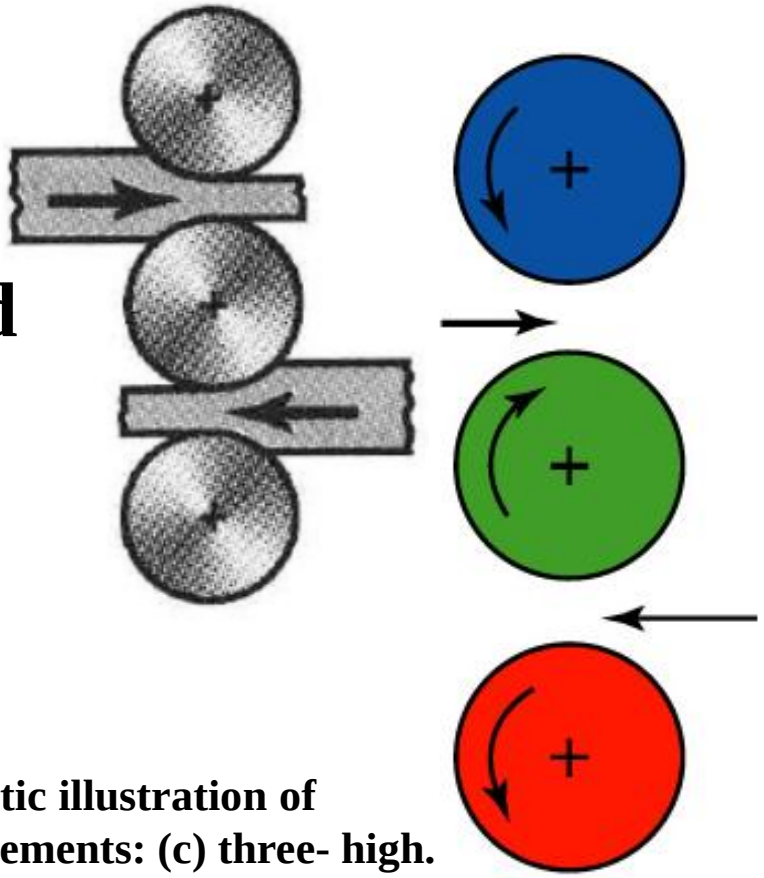
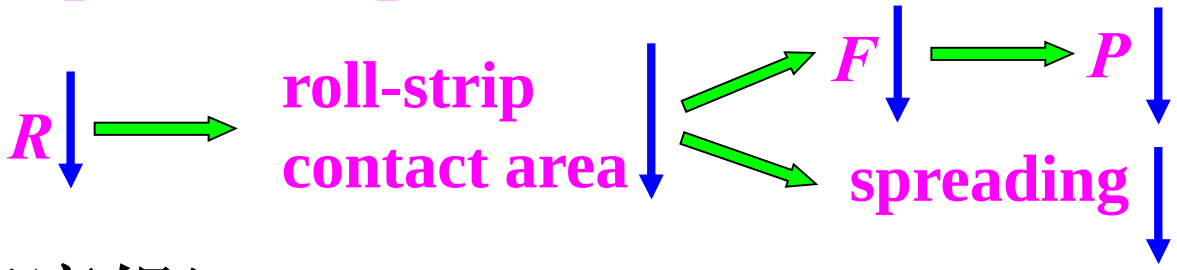


Figure 4.3 Schematic illustration of various roll arrangements: (c) three- high.

3. Four-high rolling mills and cluster mills

（四辊轧机与多辊轧机）

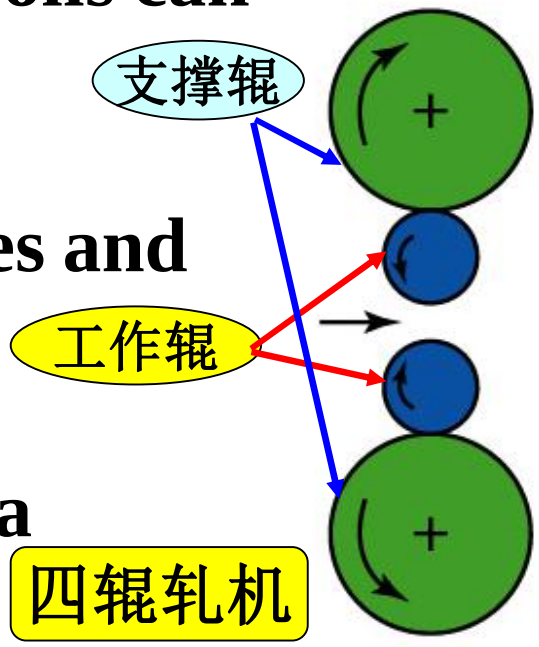
– based on the principle that small-diameter rolls lower roll forces and power requirements and reduce spreading



– when worn（磨损） or broken, small rolls can be replaced at less cost

– small rolls deflect more under roll forces and have to be supported by other rolls

– common rolled widths are 0.66m, with a maximum of 1.5m.



森吉米尔式多辊轧机/二十辊冷轧机

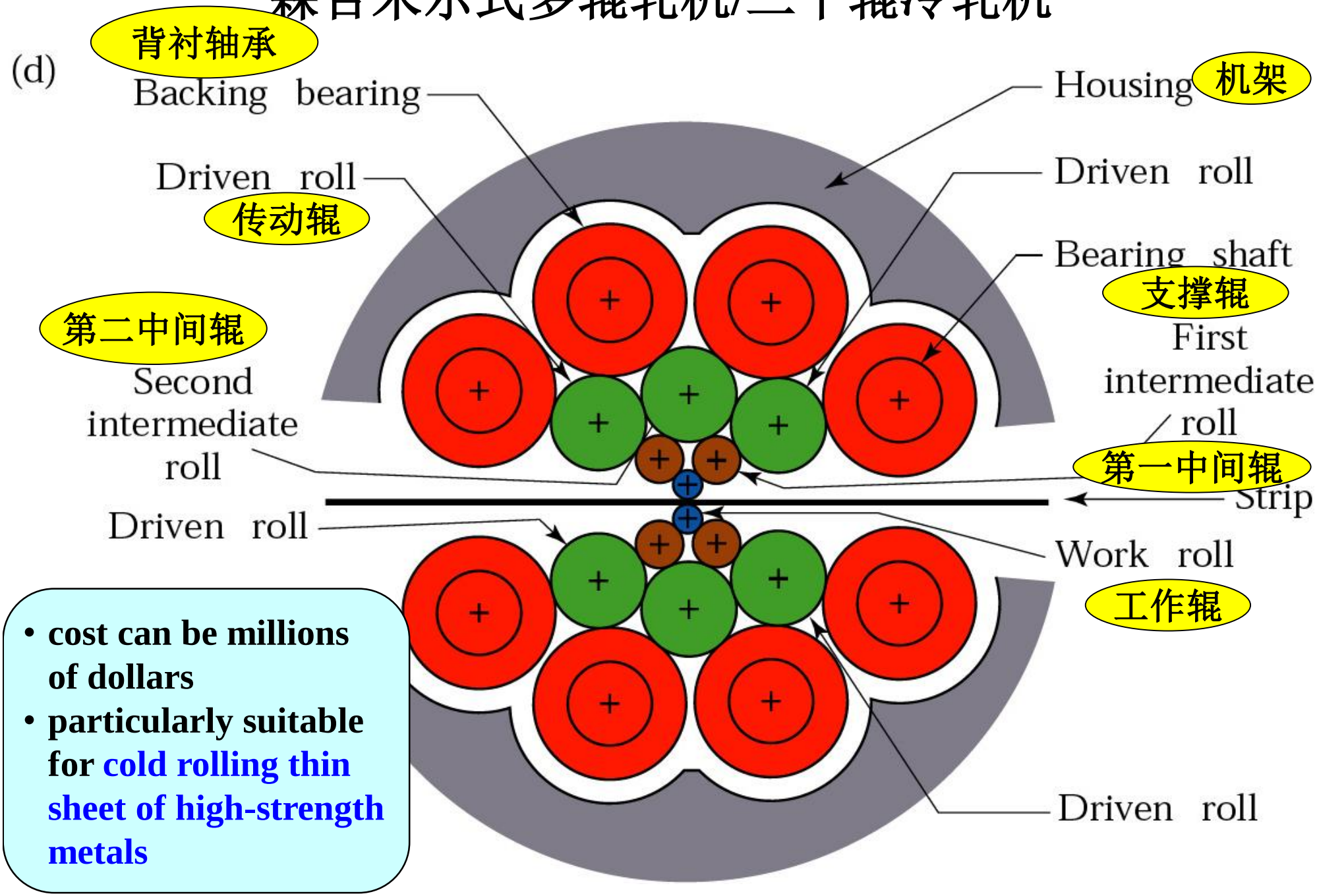
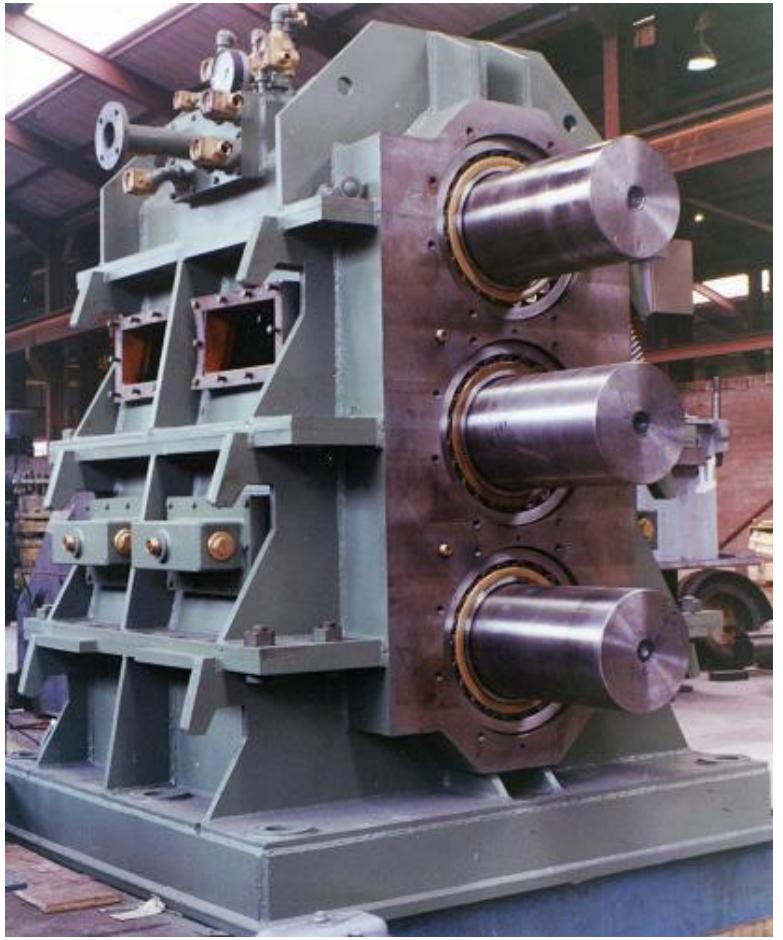


Figure 4.3 Schematic illustration of various roll arrangements： (d) cluster (Sendzimir) mill.

Rolling Equipment

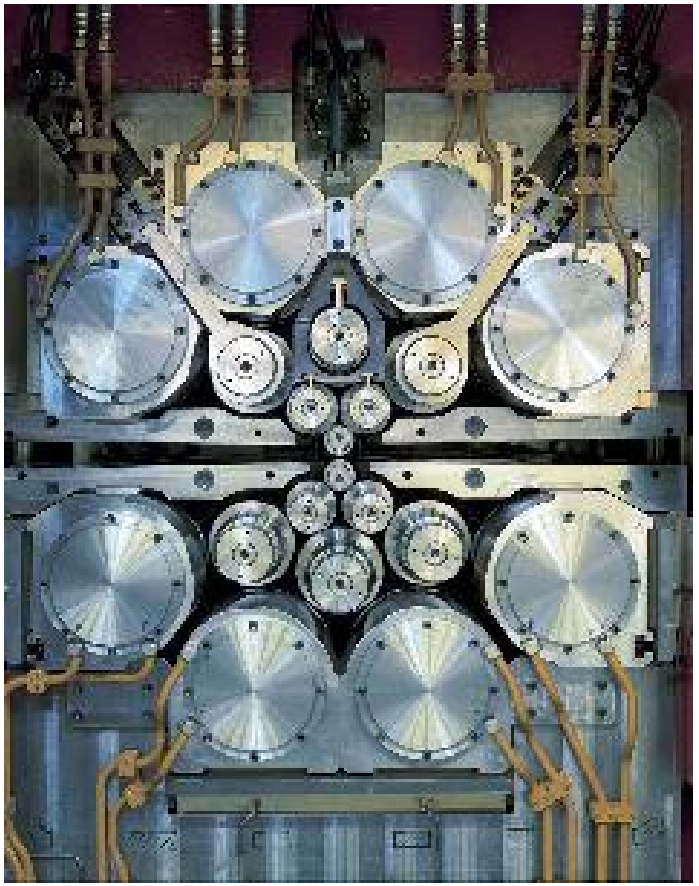
two-high rolling mill
（二辊轧机）



three-high rolling mill
（三辊轧机）

Rolling Equipment

four-high rolling mill
（四辊轧机）



cluster mill
（多辊轧机）

4.5 Various Rolling Processes and Mills

Outline

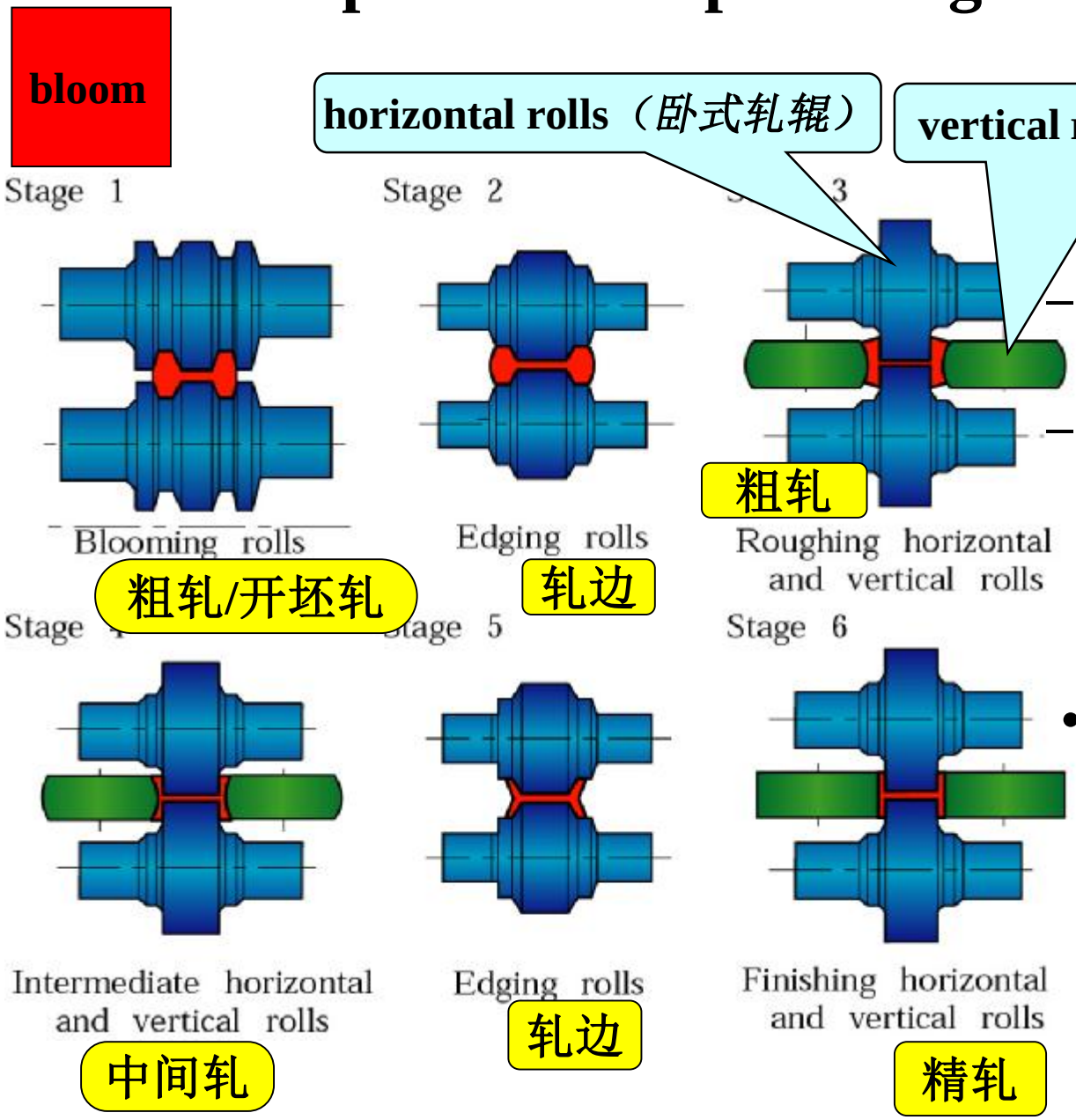
- **Types of other rolling processes:**
  - **shape rolling**（*型材轧制*）
  - **roll forging**（*辊锻/轧锻/滚锻*）
  - **skew rolling**（*斜轧/楔横轧*）
  - **ring rolling**（*圆环轧制*）
  - **thread rolling**（*螺纹轧制*）
  - **rotary tube piercing**（*斜轧穿管*）
  - **tube rolling**（*管材轧制/轧管*）

1. Shape rolling（*profile rolling/型材轧制*）

- **changing the cross section of the stock（*毛坯/原材料*）**
- **using a set of specially designed rolls**

- **Straight and long structural shapes can be produced:**
  - **solid bars（*实心杆件*）**
  - **channels（*槽钢*）**
  - **I-beams （*工字梁*）**
  - **railroad rails（*铁轨*）**

Steps in the shape rolling of an I-beam part



– specially designed rolls per pass (roll-pass design)

– various other structural sections, such as channels and rails, are also rolled by this kind of process

- （成形/变形）工步/工序:
  - forming operations
  - steps
  - passes
  - process sequences
  - stages

Review

Forming（成形）

plastic forming/deformation
（塑性成形/变形;塑性加工）

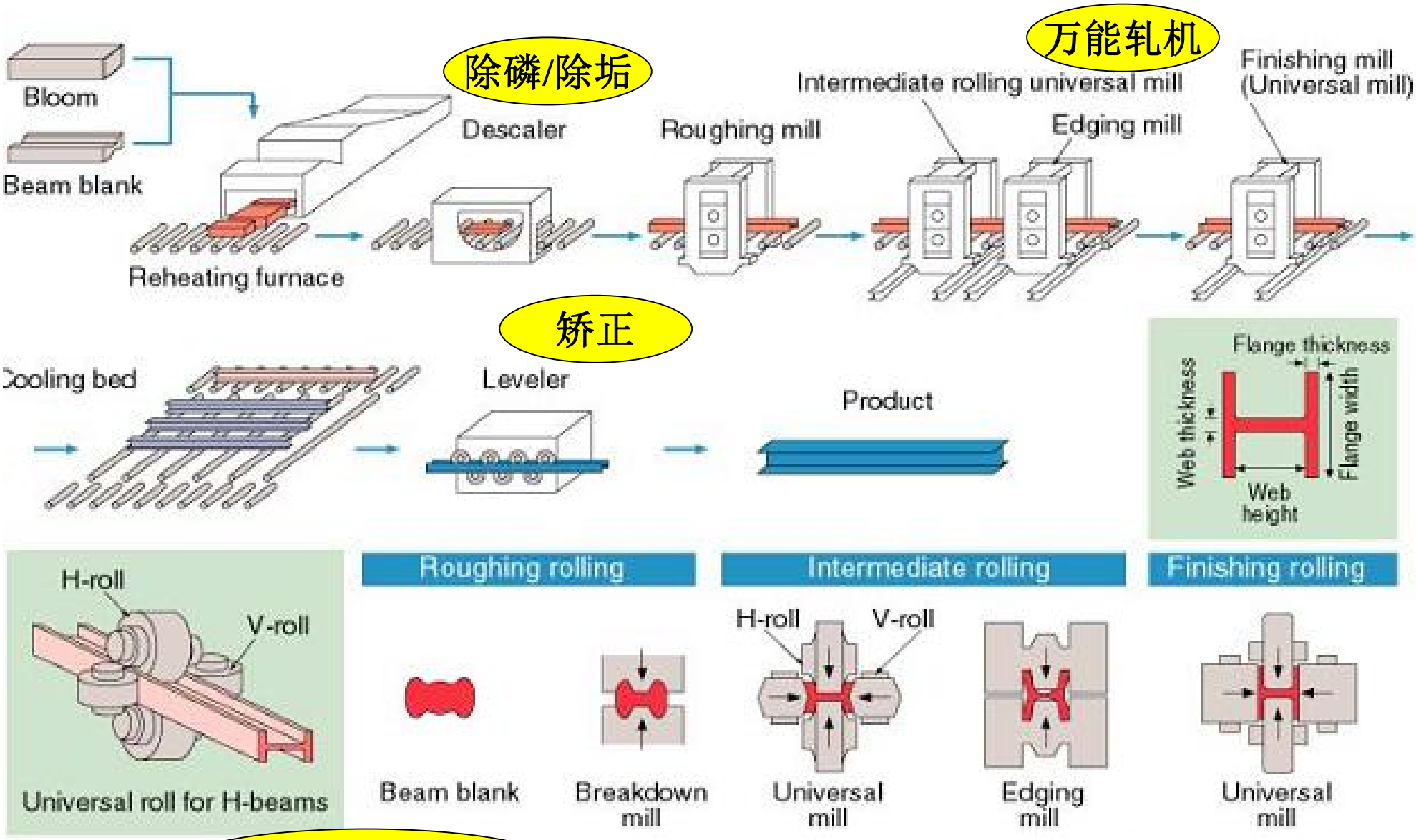
- **Changing the shape of an existing solid body（实体）**

all called

workpiece, stock, or blank
（毛坯/坯料/工件）

in the shape of a plate（板材）, a sheet（板料）, a bar（杆件）, a rod（棒材）, wire（线材）, or tubing（管件/管材）

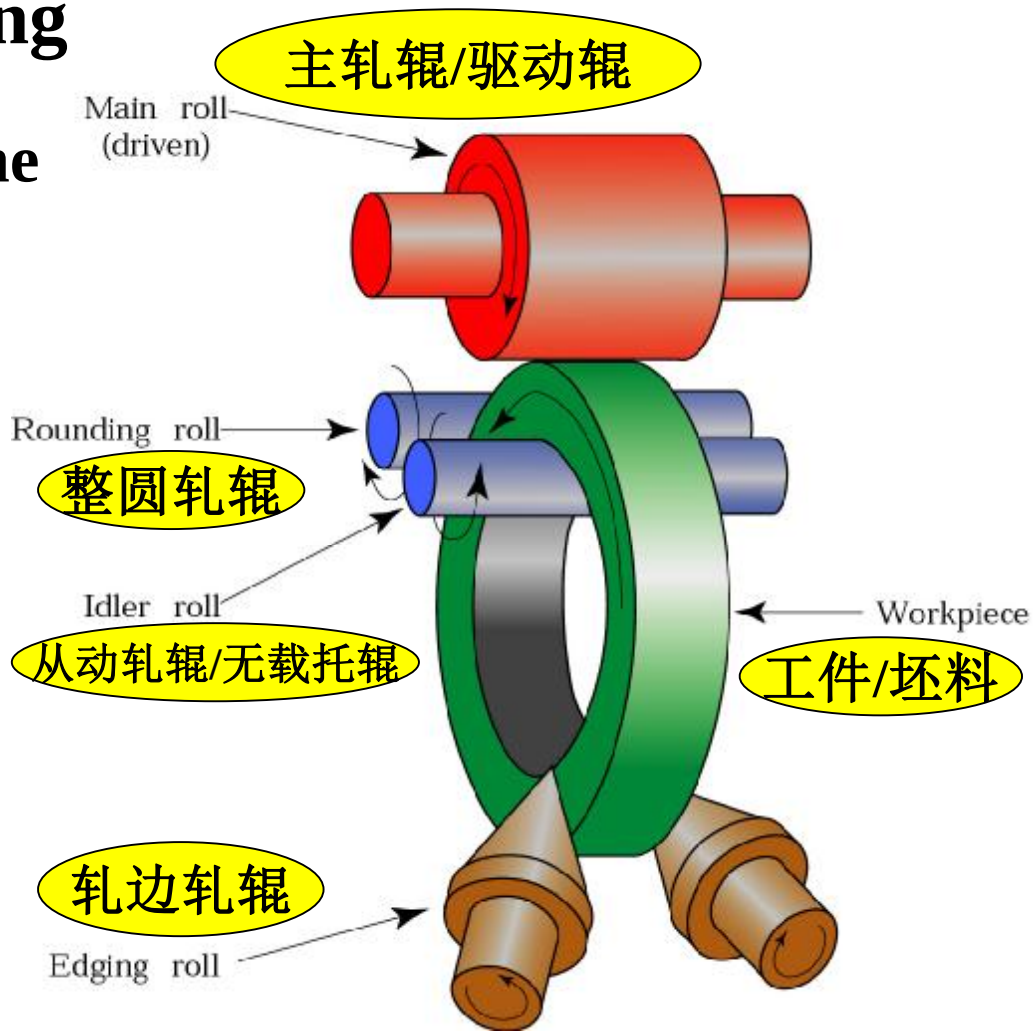
Stages in Shape Rolling of an I-beam part



- **Roll-pass design requires considerable experience**
  - **to avoid external and internal defects**
  - **to hold dimensional tolerance**
  - **to reduce roll wear（*轧辊磨损*）**

2. Ring Rolling（圆环轧制）

- **A thick ring is expanded（扩展） into a large-diameter thinner ring**
  - **the ring is placed between the two rolls**
  - **one of which is driven**
  - **the thickness is reduced by bringing the rolls together**
  - **in the ring's diameter is increased due to volume constancy（体积不变）**



various shapes can be ring rolled using shaped rolls

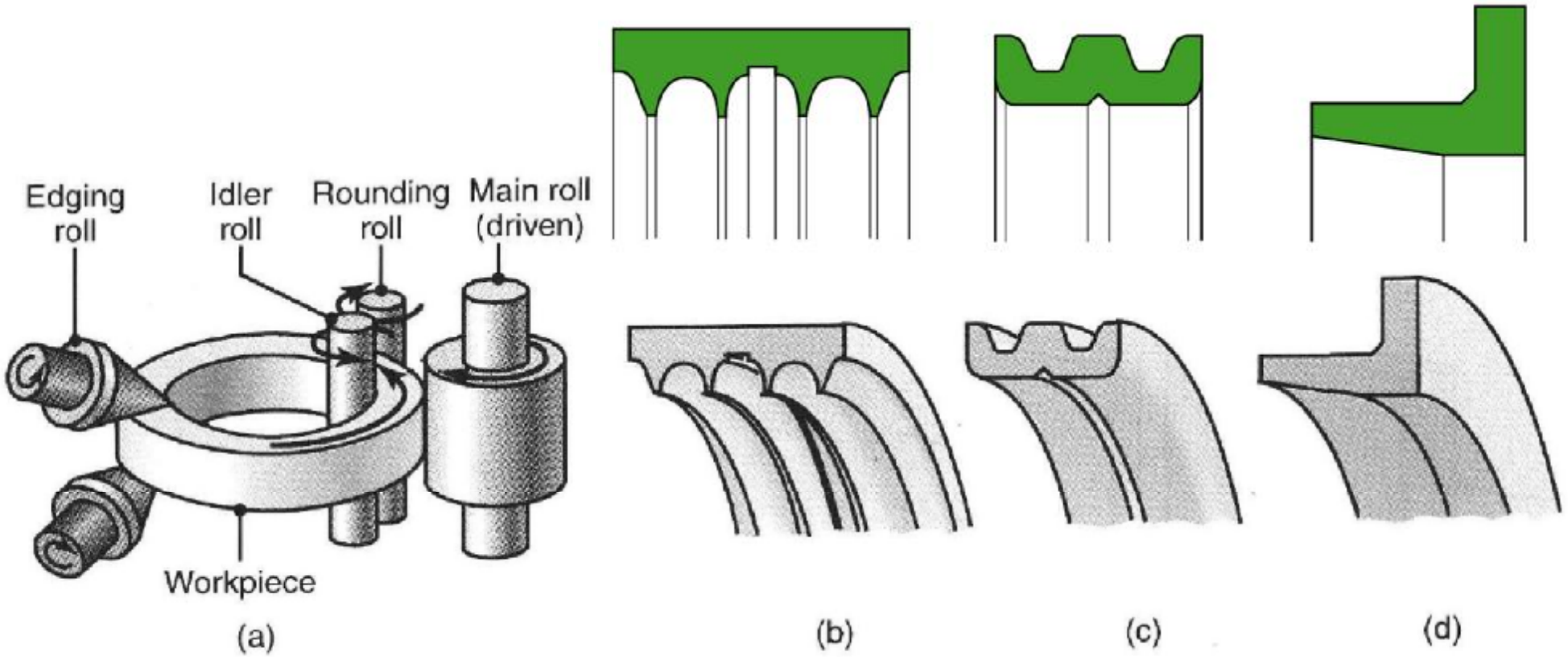


FIGURE 4.15 (a) Schematic illustration of a ring-rolling operation. Thickness reduction results in an increase in the part diameter. (b) through (d) Examples of cross sections that can be formed by ring rolling.

Typical Application

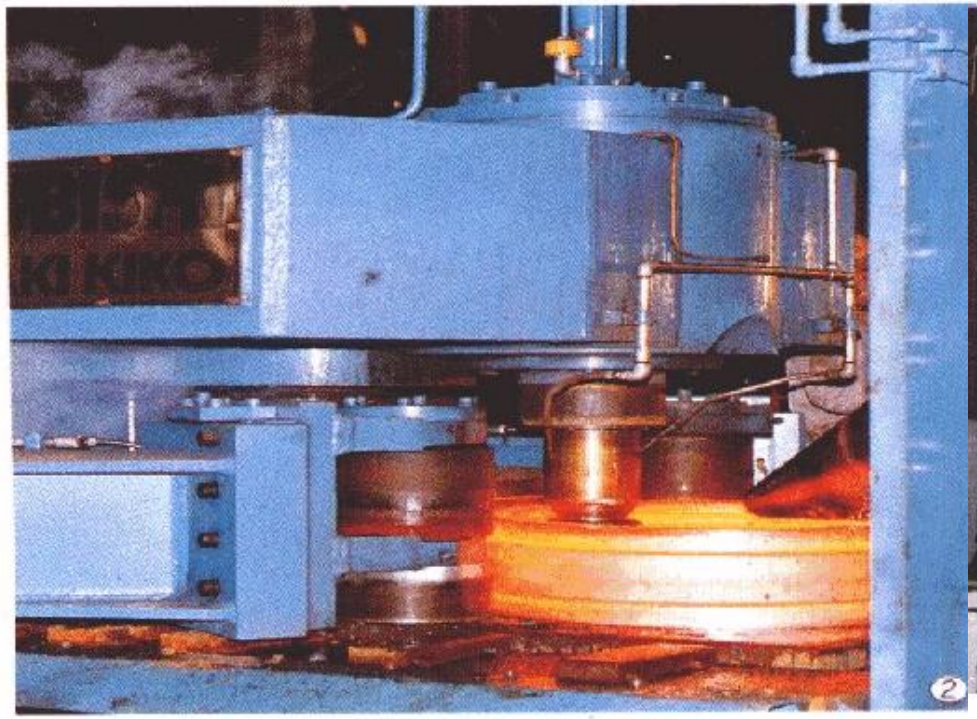
- large rings for rockets（*火箭*） and turbines（*涡轮*）
- gearwheel rims（*边缘带齿的轮子*）
- ball-bearing and roller-bearing races（*滚珠轴承与滚柱轴承环*）
- flanges（*法兰盘*）
- reinforcing rings（*增强环/补强环*） for pipes

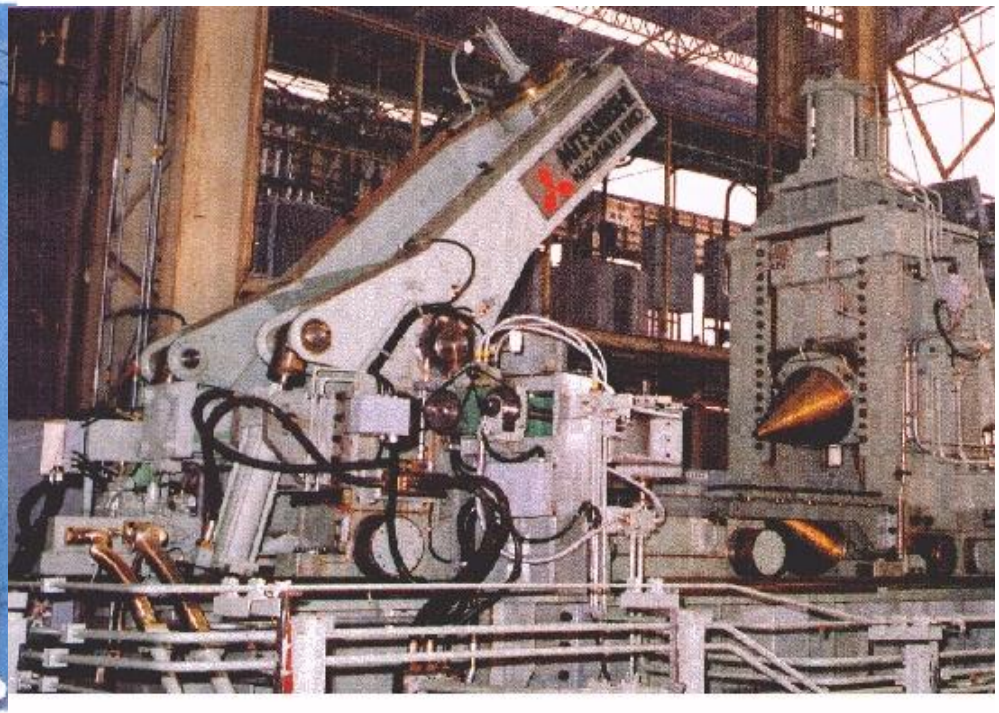
- **Can be carried out at room or at elevated temperature（*高温*）**
- **depending on the size, strength, and ductility of the workpiece material.**

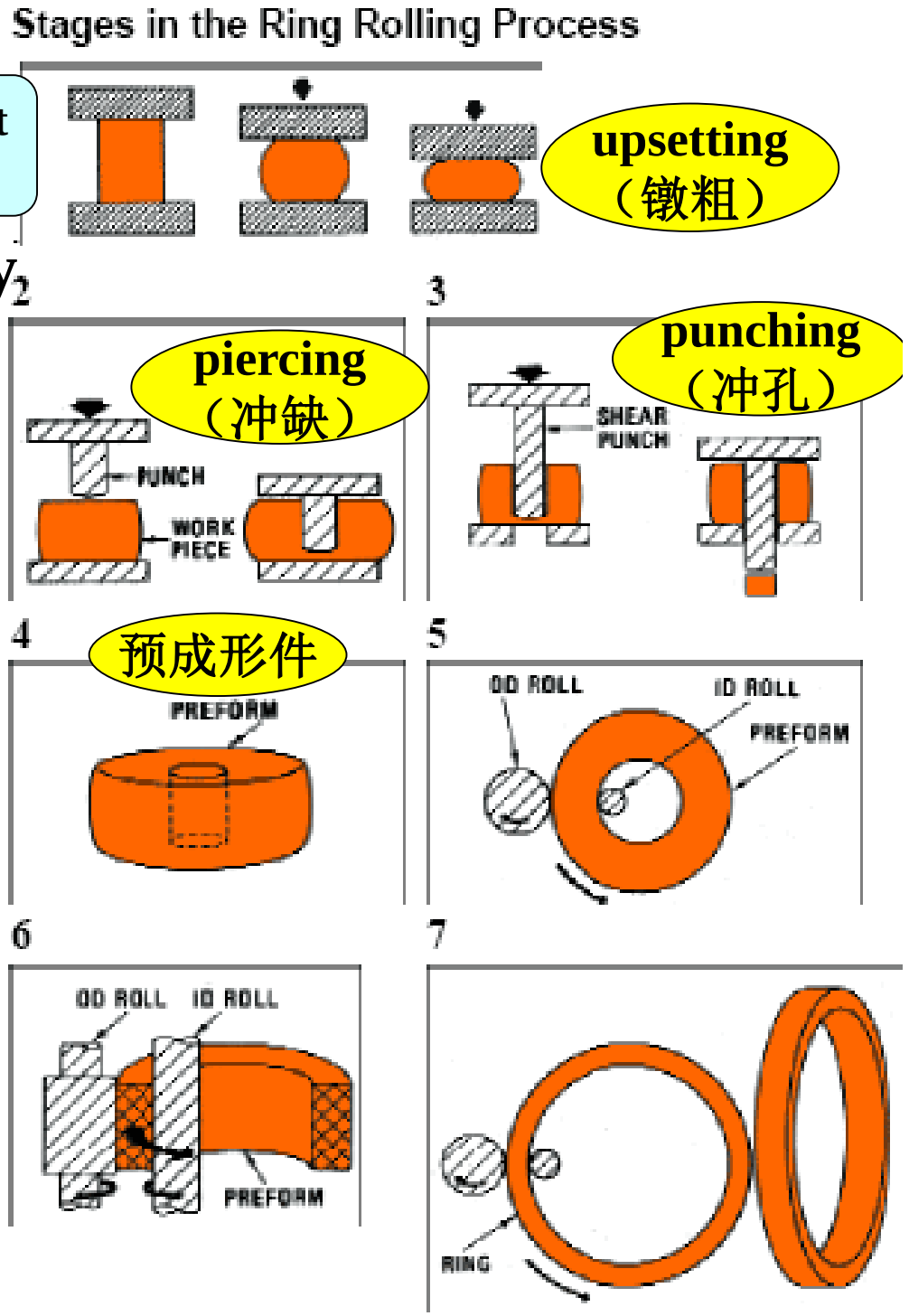
hot ring rolling
（*热轧圆环*）

cold rolling bearing ring
（*冷轧轴承环/轴承套圈*）

Ring Rolling Mill（*轧环机*）







- The ring-shaped blank may be produced by:
  - cutting from plate or bar, then piercing（*冲缺/冲孔*）
  - cutting from a thick-walled pipe（*厚壁管件*）

Advantages of Ring-rolling

① **short production times**（*省时*）

② **material saving**（*省料*）

③ **close dimensional tolerances**（*尺寸公差*）

④ **favorable grain flow**（*有利的晶粒流动/良好的成型组织*）**in the product.**

3. Thread Rolling （螺纹轧制）

- **Cold-forming process**
- **Straight or tapered threads**（直螺纹或锥形螺纹） **are formed on round rods or wires by passing them though dies**（模具）
  - **using a pair of reciprocating flat dies**（往复运动的平板模
  - **using two roller dies**（滚动模）

搓丝

滚丝

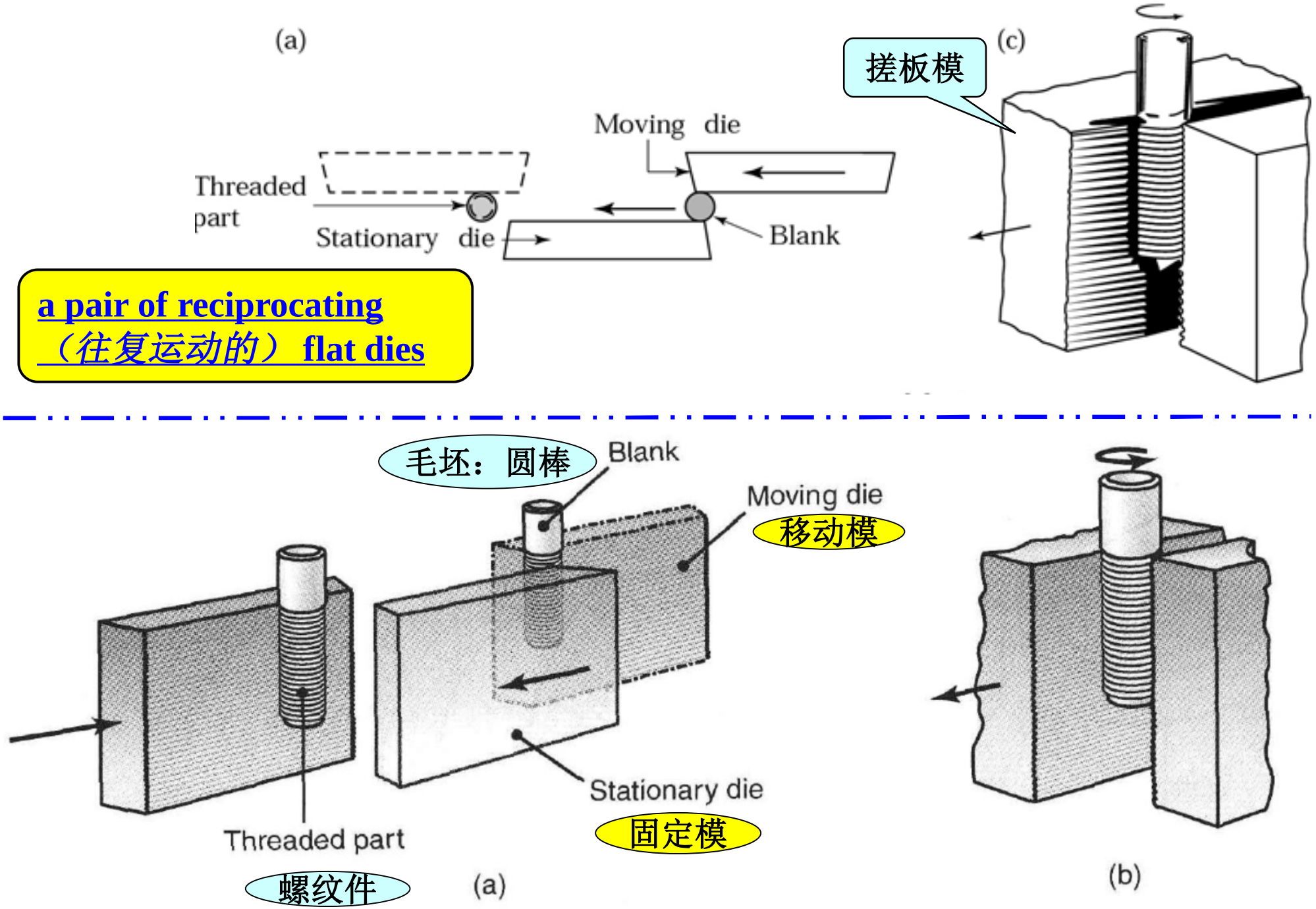


Figure 4.16 Thread-rolling processes: (a) and (b) reciprocating flat dies

two-roller dies

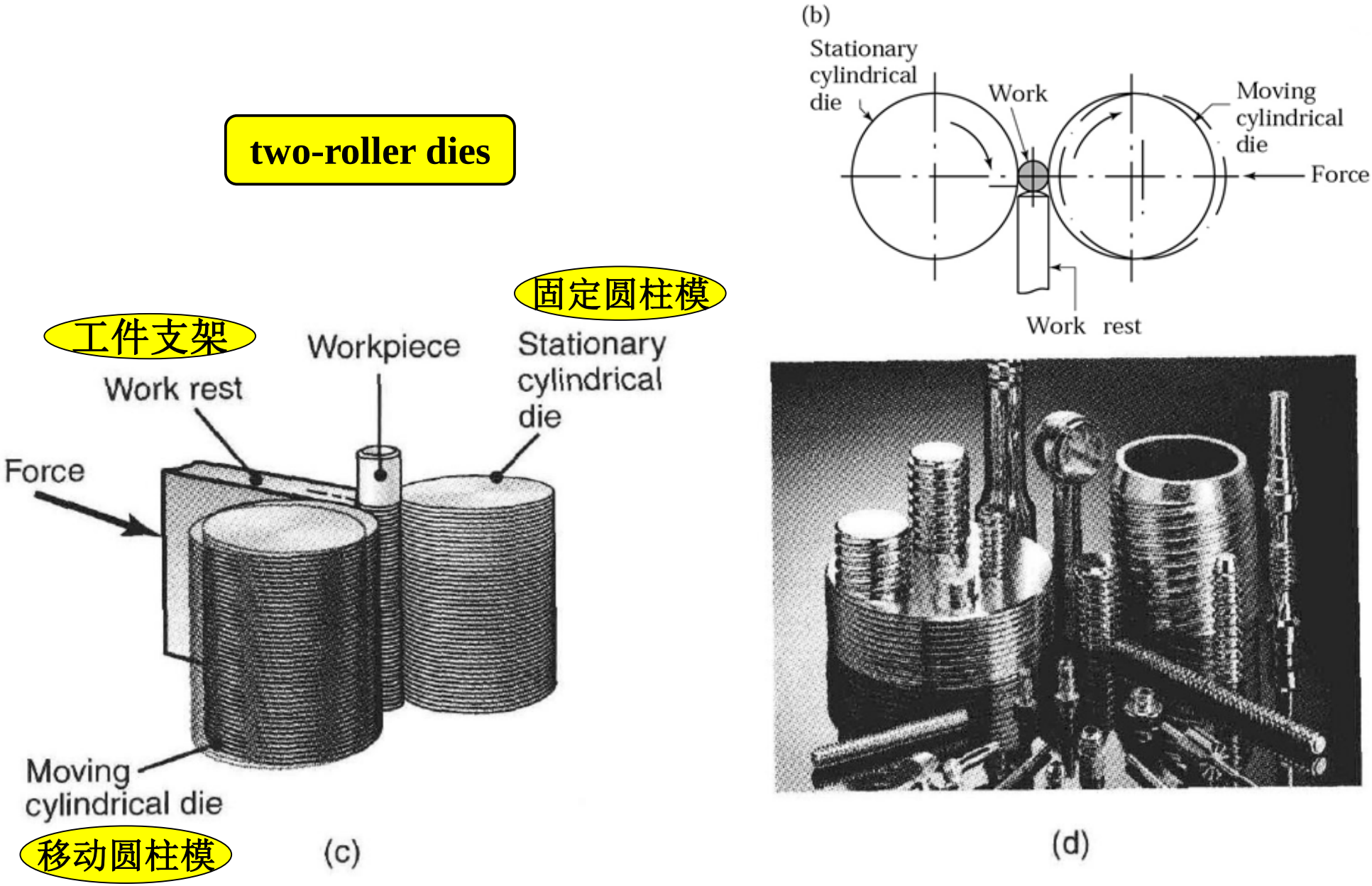


FIGURE 4.16 Thread-rolling processes: (a) and (b) reciprocating flat dies; (c) two-roller dies; (d) A collection of thread-rolled parts made economically at high production rates. *Source*: Courtesy of Tesker Manufacturing Corp.

- Threads are rolled in the soft condition due to ductility requirements
  - then be heat treated
  - subjected to final machining or grinding if necessary
  - widely used for standard thread forms（螺纹标准件）
- Threads are machined and/or ground in the hard condition
  - usually used for uncommon or special-purpose threads

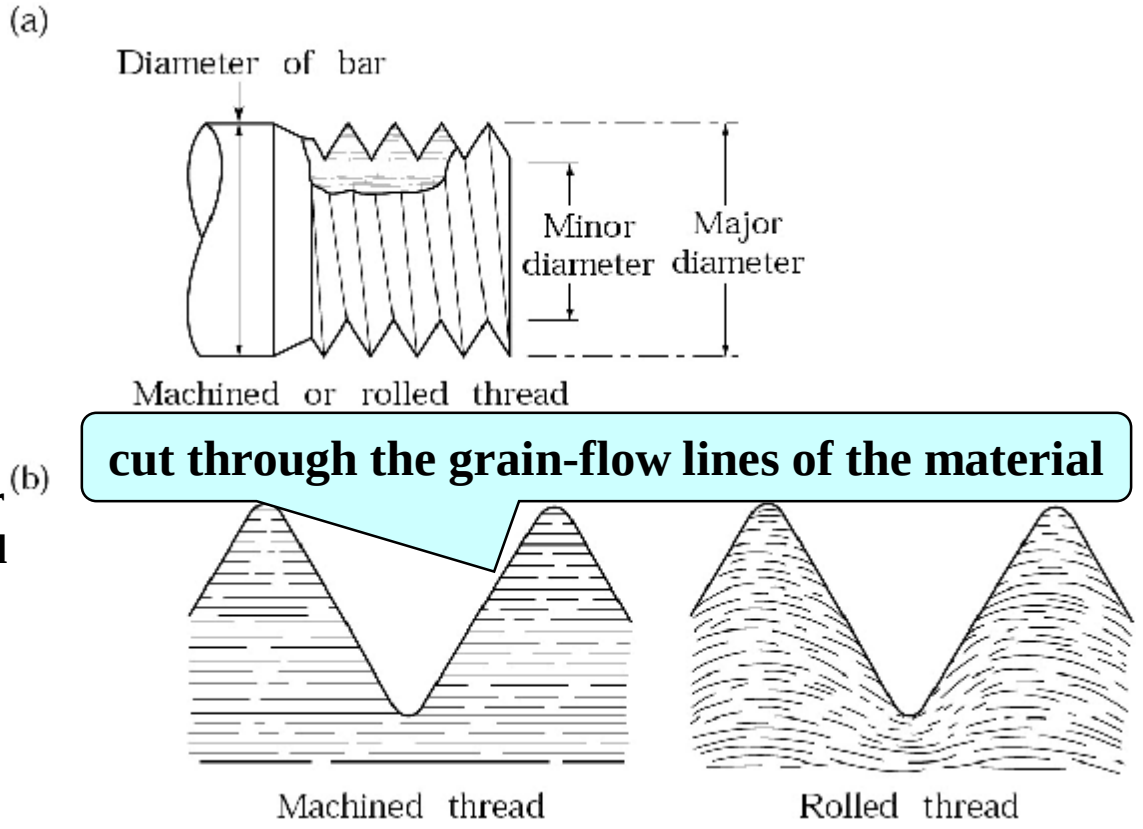


Figure 4.17 (a) Features of a machined or rolled thread. (b) Grain flow in machined and rolled threads. Unlike machining, which cuts through the grains of the metal, the rolling of threads causes improved strength, because of cold working and favorable grain flow.

Advantages of Thread-rolling

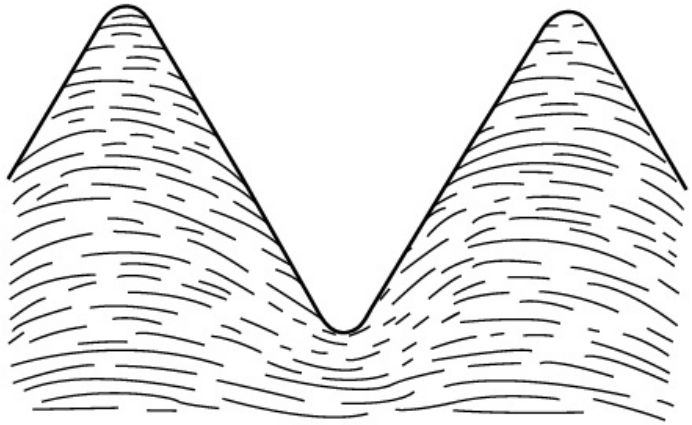
① without any loss of material (scrap（废料）).

② surface finish is very smooth.

③ induces compressive residual stresses （残余压应力） on the workpiece surfaces, thus improving fatigue life(疲劳寿命）.

④ high rates of production

⑤ cold working（冷作硬化） and favorable grain-flow pattern improve the strength



Rolled thread

KEY TERMS

rolling 轧制

rolls 轧辊，辊子

compressive forces 压力

flat rolling 平板轧制

plate 厚板

sheet 薄板

aluminum-alloy 铝合金

coarse-grained 晶粒粗大

brittle 脆性的

porous structure 多孔结构

ingot 铸件

wrought structure 锻造结构

aluminum foil 铝箔

matte 不光滑

shiny 有光泽的

satiny 光滑

shape-Rolling 成形轧制

stock 原料，坯料

ring-rolling 圆环轧制

thread-rolling 螺纹轧制

cold-forming 冷成形

threads 螺纹

gear 齿轮

grain 晶粒

flat Rolling 平板轧制

strip 带料，条料

roll gap 轧制间隙，轧辊间隙

shaft 轴

velocity 速度

frictional force 摩擦力

coefficients of friction 摩擦系数

lubrication 润滑

draft 压下量

hot rolling 热轧

cold rolling 冷轧

pack rolling 迭板轧制

recrystallization temperature 再结晶温度

room temperature 室温

ductility 柔韧性

alloy steels 合金钢

refractory alloys 难熔合金

bloom （大）方坯

slab 扁坯

billet 小方坯，毛坯

I-beams 工字梁

cross-section 截面

pickling with acids (acid etching) 酸洗，酸蚀

grinding 研磨

room temperature 室温

surface finish 表面光洁度

dimensional tolerances 尺寸公差

mechanical properties 机械性能

strain hardening 应变硬化，加工硬化

productivity 生产率

Review Questions

1. **What is rolling?**
2. **How to classify rolling process?**
3. **What is the flat rolling?**
4. **What is the difference between a plate and a sheet?**
5. **Give some examples of the application of the plates and sheets.**
6. **Explain the relationship of the velocity between the strip and rolls.**
7. **Explain the advantages and disadvantages of the friction during the rolling.**

8. **Define (a) roll gap, (b) neutral point, (c) draft**
9. **Describe the difference between a bloom, a slab , and a billet.**
10. **List the defects commonly observed after flat rolling**
11. **What is the hot rolling and cold rolling? What are the differences between them?**
12. **What are the differences between cast structure and wrought structure?**

13. **What is scale? And how to remove?**

14. **What is the shape rolling? Make a list of some parts that can be made by shape rolling.**

15. **Describe the types of products that can be made by thread rolling.**

16. **What are the advantages of the shape rolling process ?**