Chapter 6 Metal Extrusion and Drawing Processes and Equipment（*金属挤出与拉拔工艺及设备*）

- 6.1 Introduction
- 6.2 The Extrusion Process
- 6.3 Hot Extrusion
- 6.4 Cold Extrusion
- 6.5 Extrusion Defects
- 6.6 Extrusion Equipment
- 6.7 The Drawing Process
- 6.8 Drawing Practice
- 6.9 Drawing Defects and Residual Stresses
- 6.10 Drawing Equipment

Preface（*前言*）：

- **Extrusion and drawing involve, respectively, pushing or pulling a material through a die basically for the purpose of reducing or changing its cross-section area.**
- **This chapter examines the fundamentals of these processes and their applications.**
- **The chapter starts by discussing the basic types of extrusion processes, namely, direct, indirect, and hydrostatic extrusion, and explains how the extrusion force can be estimated from material and processing parameters.**
- **Hot and cold extrusion are then discussed; cold extrusion is often done in combination with forging to produce specific parts.**
- **Extrusion practices and die designs that avoid common defects are also presented.**
- **The drawing of rod, wire, and tubing is then examined in a similar manner, along with die design.**
- **The equipment characteristics for these processes are also described.**

Typical products made by extrusion and drawing: Long pieces having a wide variety of constant cross sections, rods, shafts, bars for machinery and automotive power-train applications, aluminium ladders, collapsible tubes, wire for numerous electrical and mechanical applications and musical instruments.

Alternative processes: Machining, powder metallurgy, shape rolling, roll forming, pultrusion and continuous casting,

6.1 Introduction

1. Extrusion

– a cylindrical billet is forced through a die (or die opening)

– extruded parts have constant cross-section（截面恒定/等截面）

ø die geometry remains unchanged throughout the operation

– may be carried out at room or elevated temperature

ø depending on the ductility of material

– is a batch （分批）or semicontinuous process（半连续生产）

ø because a chamber (container) is involved

ø each billet is extruded individually

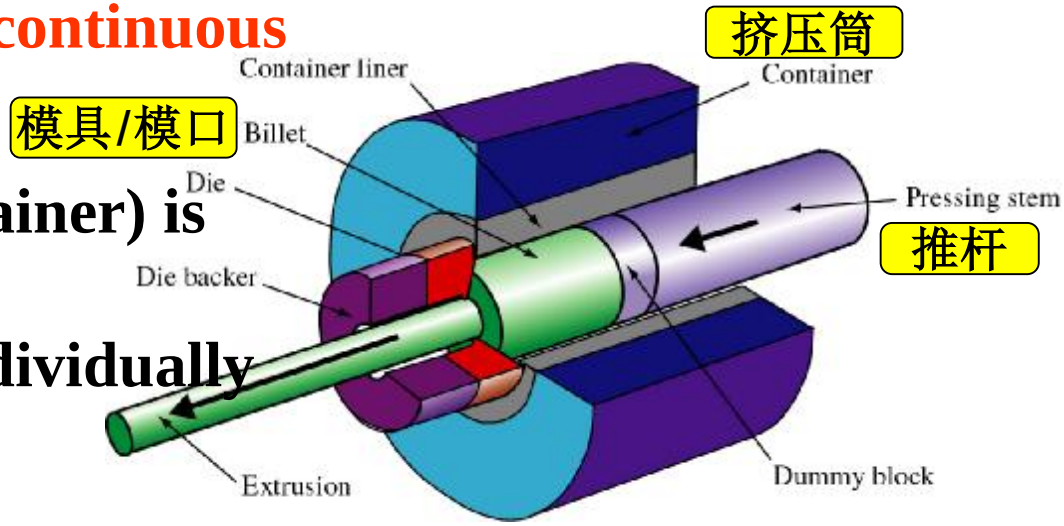
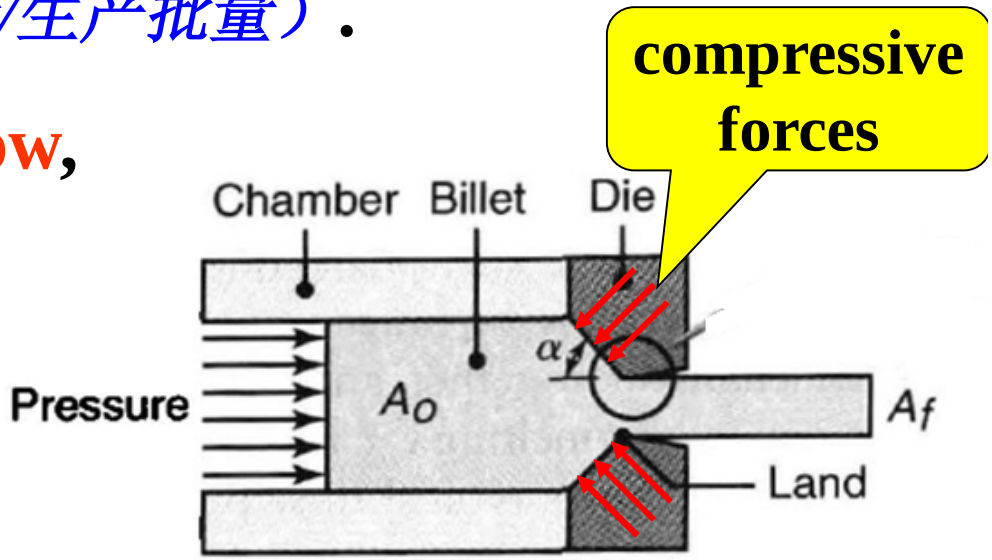


Figure 6.1 Schematic illustration of the direct extrusion process.

Characteristics of Extrusion

to force out

- **Large deformation can take place without fracture, because the material is under high triaxial compression** *（三轴受压/三向压缩：轴向、径向、周向）*（ **due to the enhanced ductility of the metal）.**
- **Extrusion can be economical for large as well as short production runs** *（生产运行/生产批量）*.
- **Tools costs generally are low, particular for producing simple, solid sections.**



Characteristics of Extrusions（挤出件）

- Various **solid**（实心的） or **hollow**（中空的） cross-section
- Essentially **semifinished parts**（半成品）
- Can be **cut into** desired lengths, which then Become **discrete parts**.

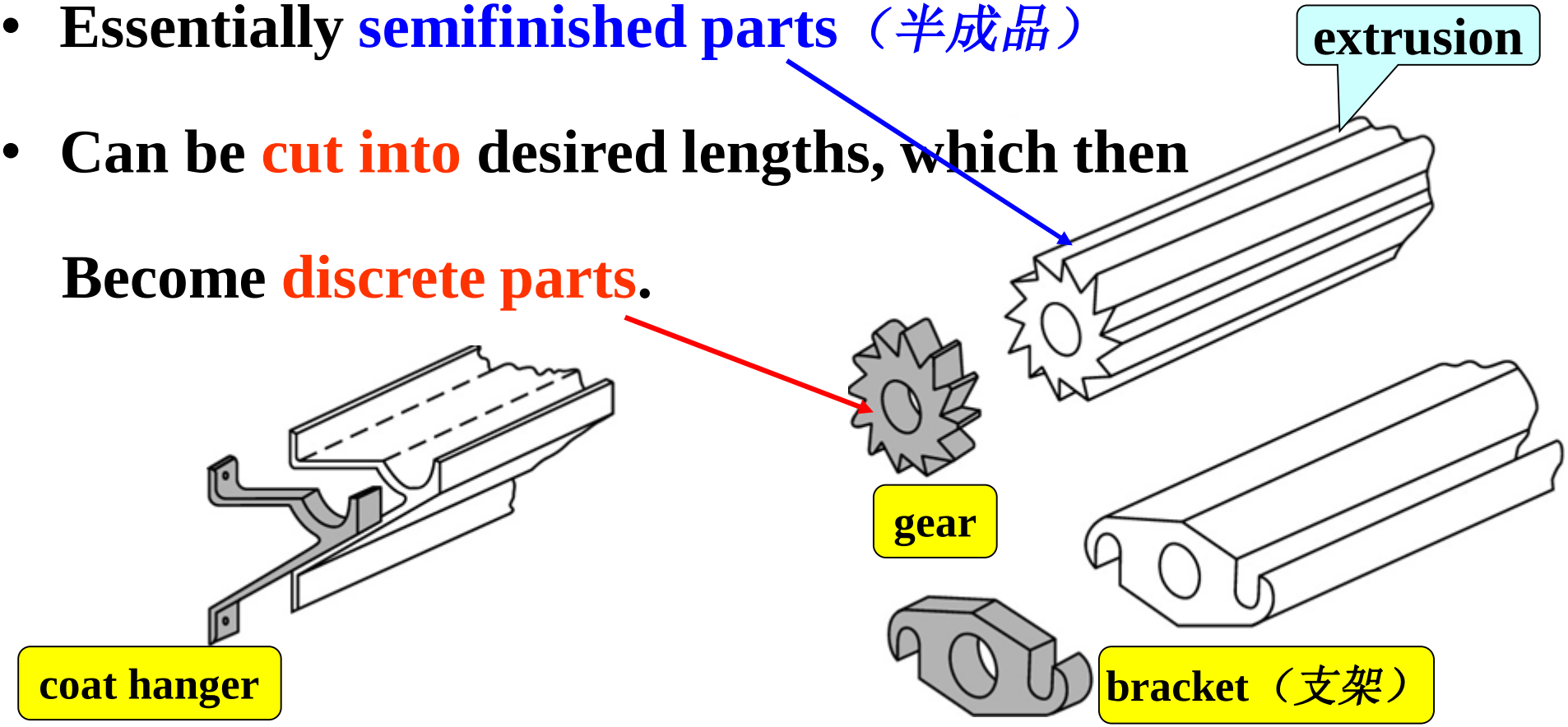
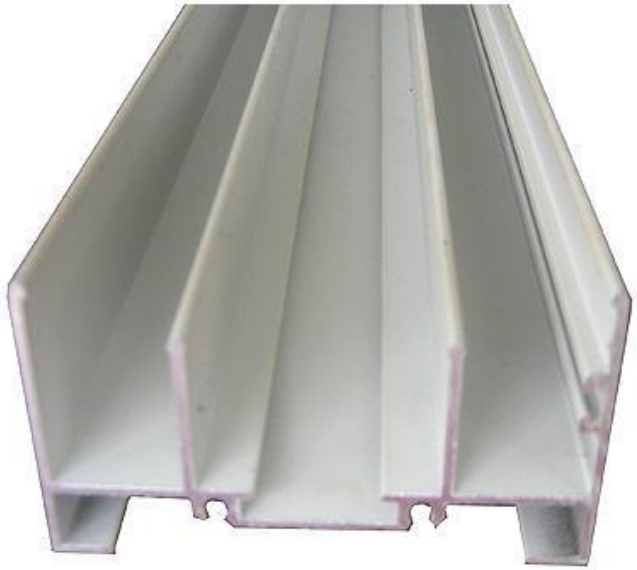


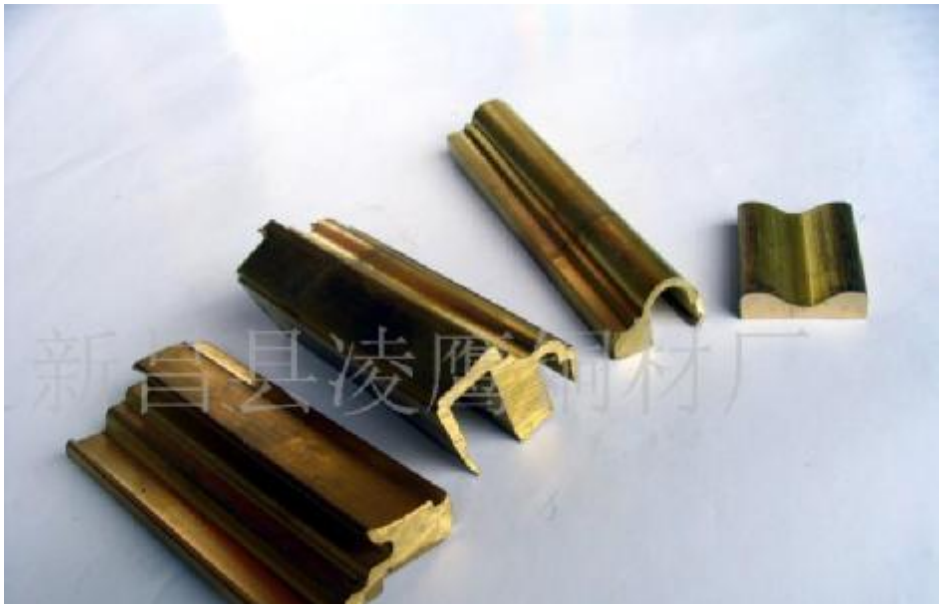
Figure 6.2 Extrusions, and examples of products made by sectioning off extrusions. *Source*: Kaiser aluminium.

Typical Extruded Products

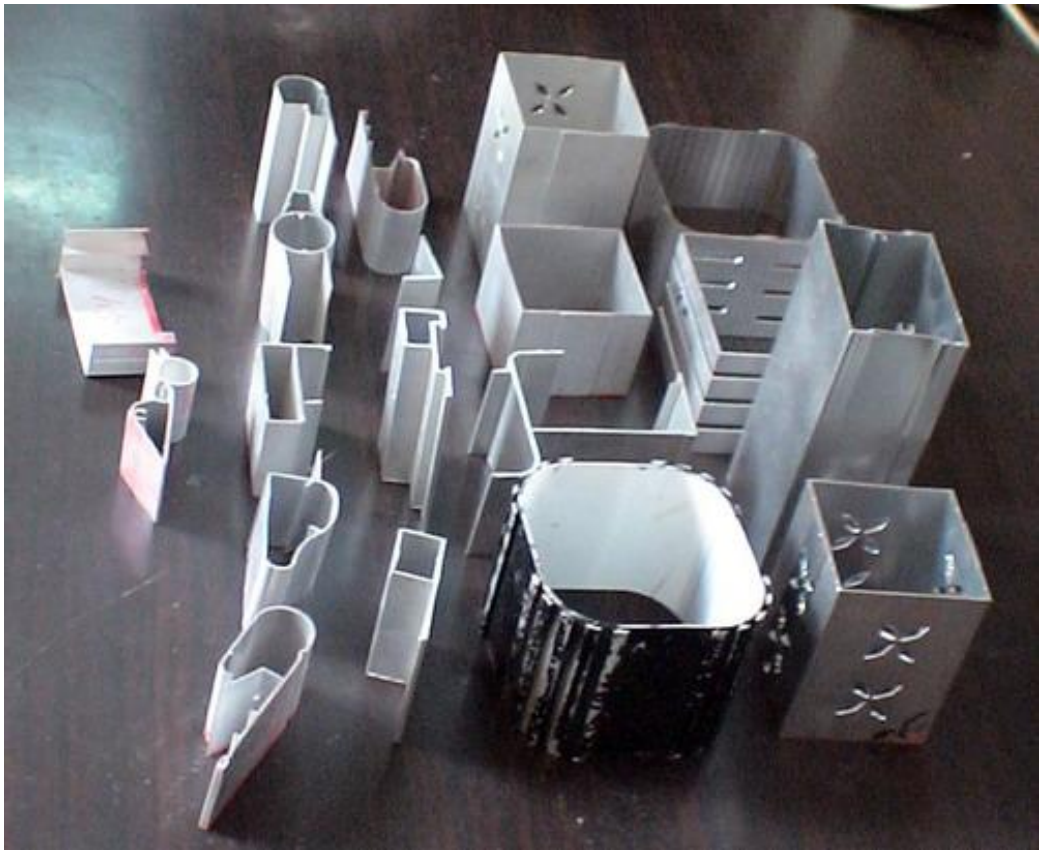
- **railings（*滑轨*）for sliding doors**
- **tubing（*管件*）having various cross-section**
- **structural and architectural shapes（*结构或建筑型材*）**
- **door and window frames（*门框及窗框*）**

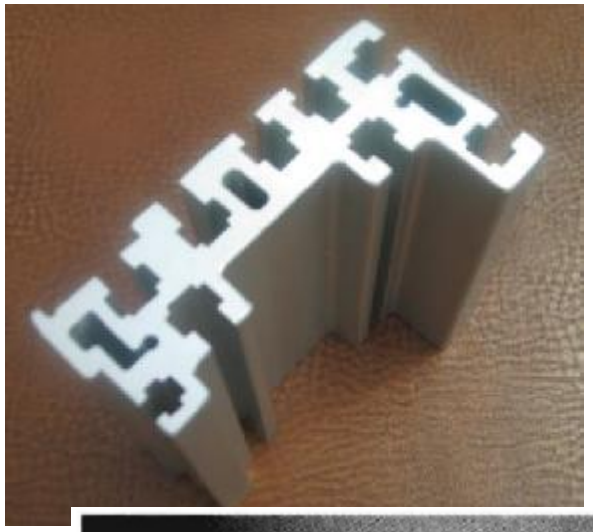
Typical Extruded Products

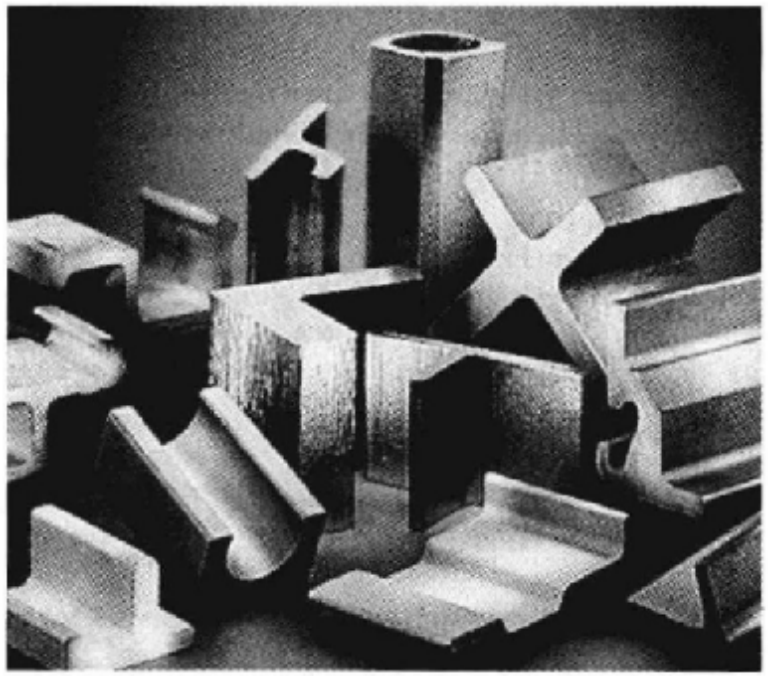




Typical Extruded Products







extruded profiles（*挤出型材*）
with various cross-section

Extruded Materials

- **Commonly used material**
  - **aluminium**
  - **copper（*Cu*）**
  - **steel**
  - **magnesium（*Mg*）**
  - **lead（*Pb*）**
- **Other metals and alloys**
  - **with various levels of difficulty**
- **Plastics**

Chapter 18

2. Drawing

- the cross-section of solid rod（杆件）, wire（线材）, or tubing（管件） is reduced or changed in shape by pulling it through a die.
- drawn parts also have constant cross-section
- usually be carried out at room temperature. 冷拔
- may be a continuous process（连续生产）

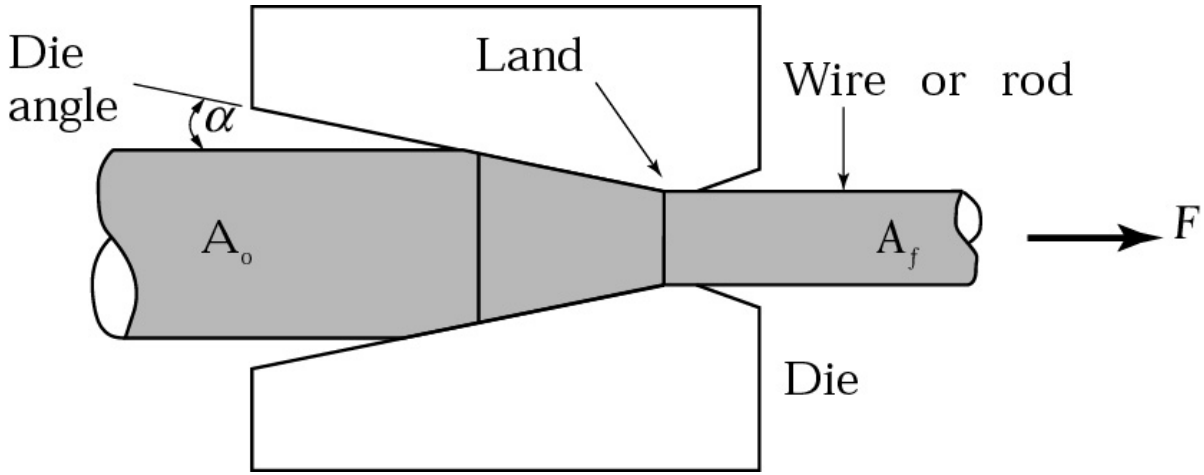


Figure 6.18 Process variables in wire drawing

Typical Drawn Products

- **Rods （*棒材*）**
  - **used for shafts, spindles（*芯轴*）, and small pistons（*活塞*）**
  - **as raw material for fasteners（*紧固件*） such as rivets, bolts, and screws**
- **Various profiles（*型材*）**
- **Wire （*线材*）**
  - **smaller in cross-section than rod, down to 0.01 mm in diameter, or even smaller**
  - **in industry, wire is generally defined as a rod that has been drawn through a die at least once**
  - **cover a wide range of applications, such as electrical and electronic wiring cables（*电线/电缆*）, tension-loaded（*受拉载荷*） structural members, welding electrodes（*焊条*）, springs（*弹簧*）, paper clips, spokes（*轮辐*） for bicycle wheels, and stringed musical instruments（*弦乐器*）.**

Typical Drawn Products

rod and wire (stainless steel)

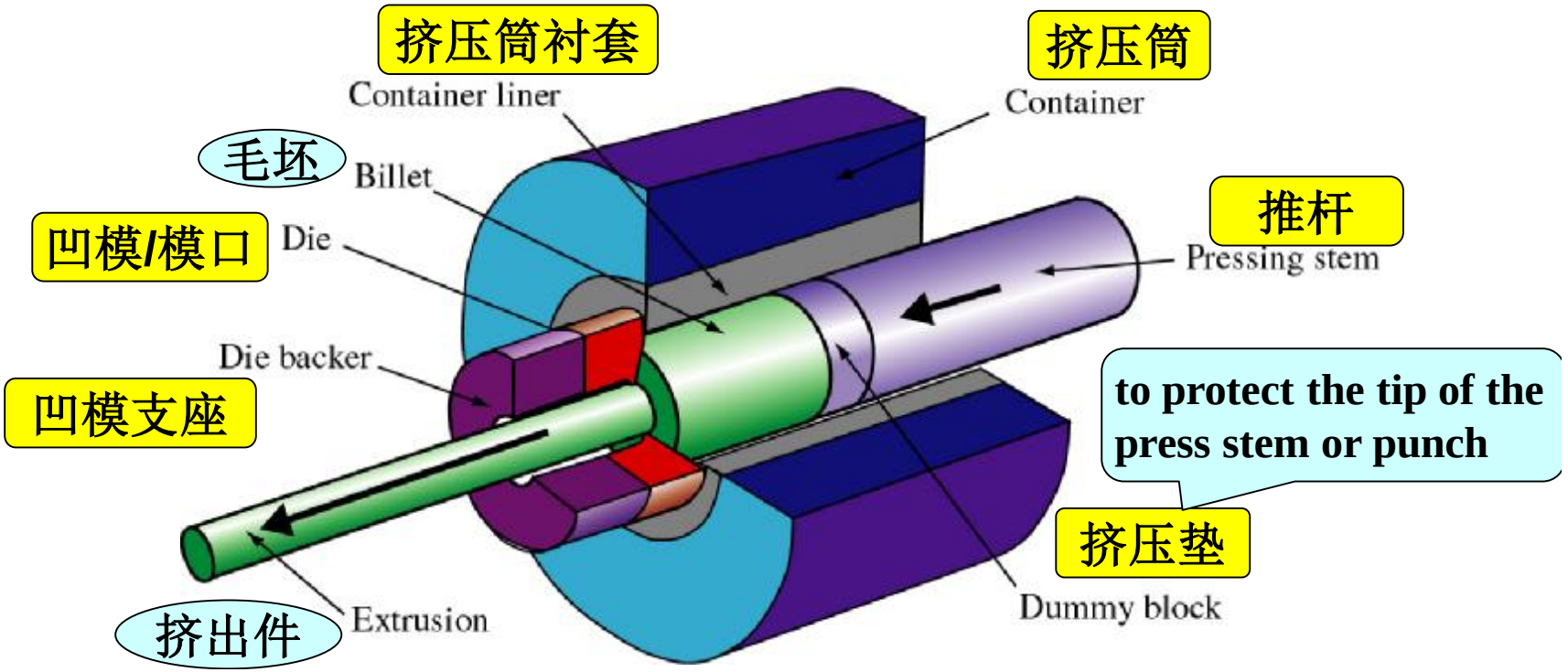
6.2 The Extrusion Process

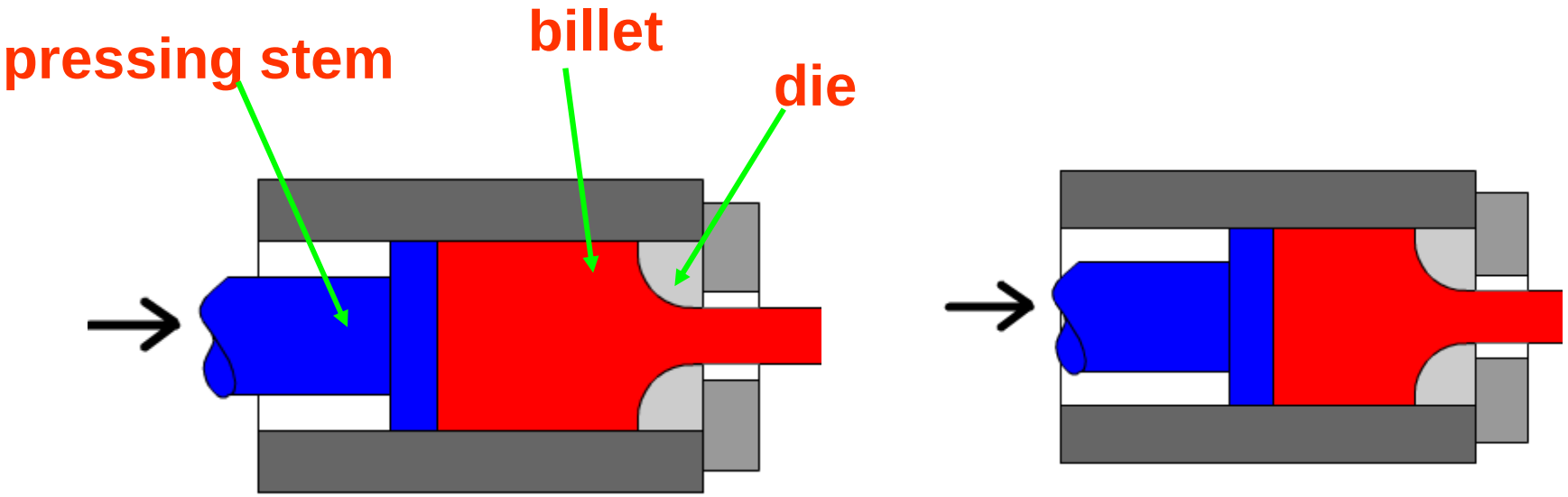
Outline

- **Four types of extrusion processes:**
  - direct extrusion（*正挤*）
  - indirect extrusion （*反挤*）
  - hydrostatic extrusion（*静液挤压*）
  - lateral extrusion （*径向挤*）
- **Process variables:**
  - die angle（*模口角度*）, α
  - extrusion ratio（*挤压比*）, R
  - reduction in cross-sectional area（*断面缩减率*）, ψ
  - extrusion speed
  - billet temperature
  - lubrication
- **Metal flow in extrusion**
  - dead zone（*死区*）
- **Extrusion force and practice**

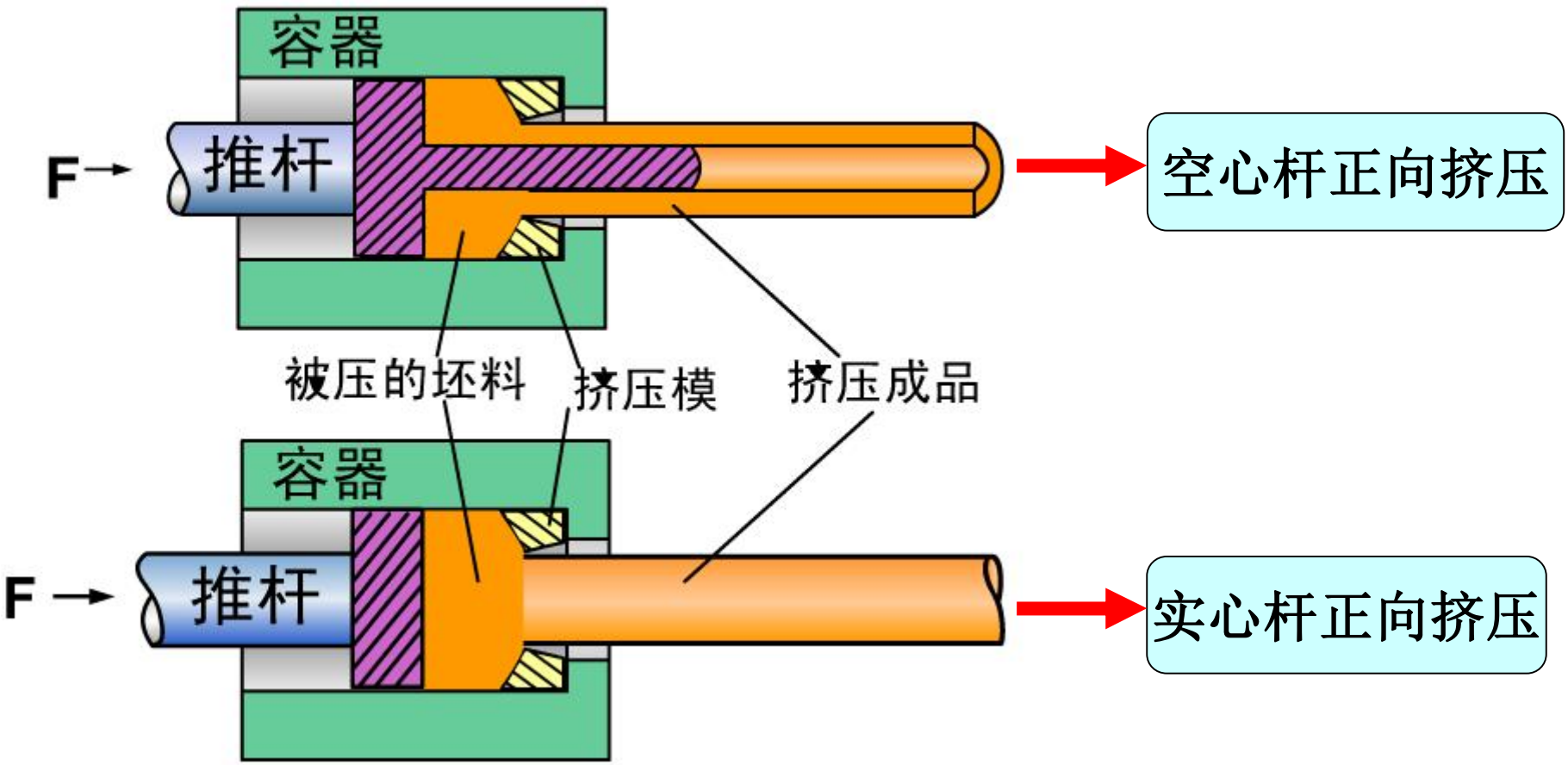
1. Direct Extrusion（*正挤*）

- a round billet is placed in a chamber (container) and forced through a die opening（*模具孔口*） by a hydraulically-driven ram（*液压驱动的柱塞*） or pressing stem（*推杆*）
- also called forward extrusion





The metal flows in the same way that the pressing stem moves.


容器
推杆
F
被压的坯料
挤压模
挤压成品
容器
推杆
F
空心杆正向挤压
实心杆正向挤压

* Characteristics of Direct Extrusion

缺点

1. 挤压过程中挤压筒与金属坯料间的摩擦力大，消耗能量多；
2. 金属变形不均匀；
3. 压余（挤压余料）多，可达10-6%；

优点

4. 更换模具简单、迅速，所需辅助时间少；
5. 制品表面质量好。

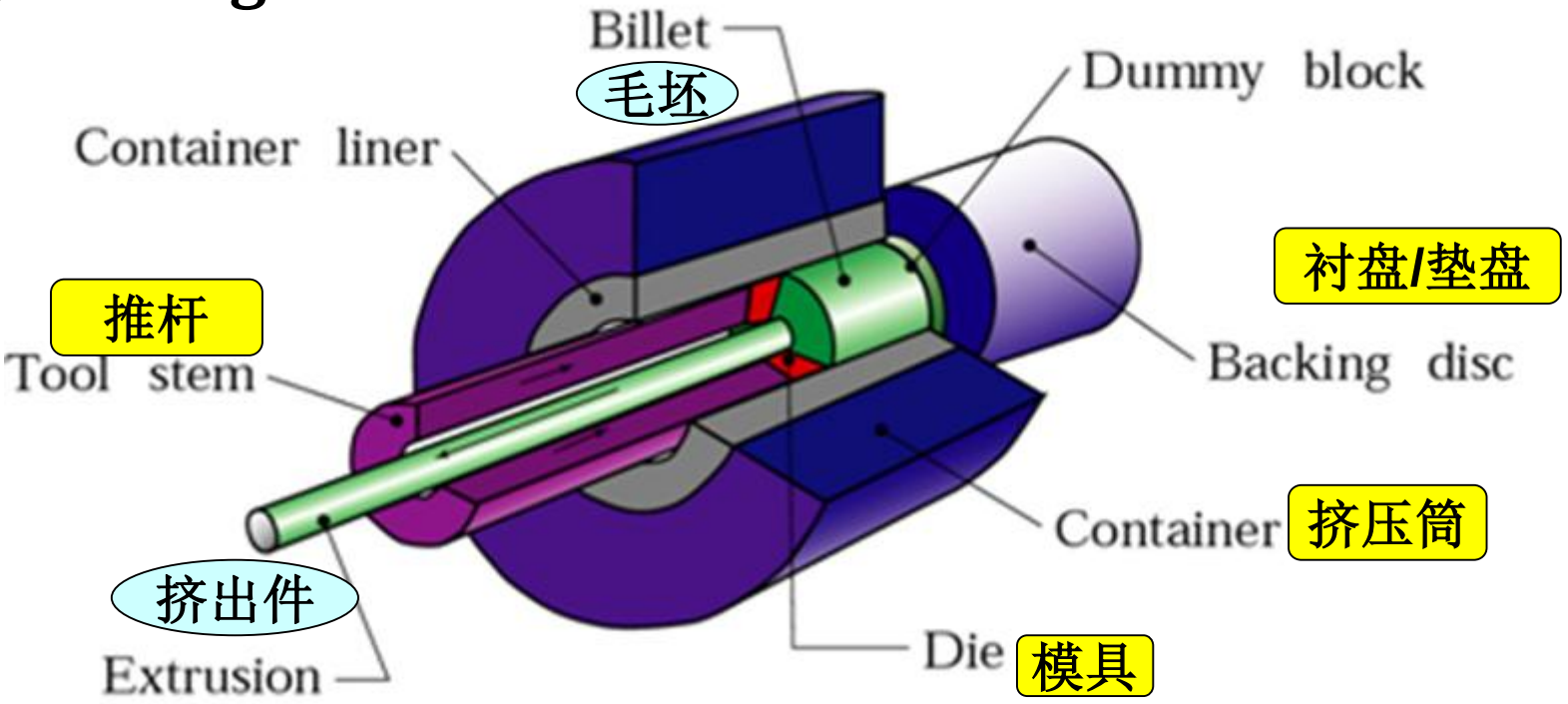
2. Indirect Extrusion （反挤）

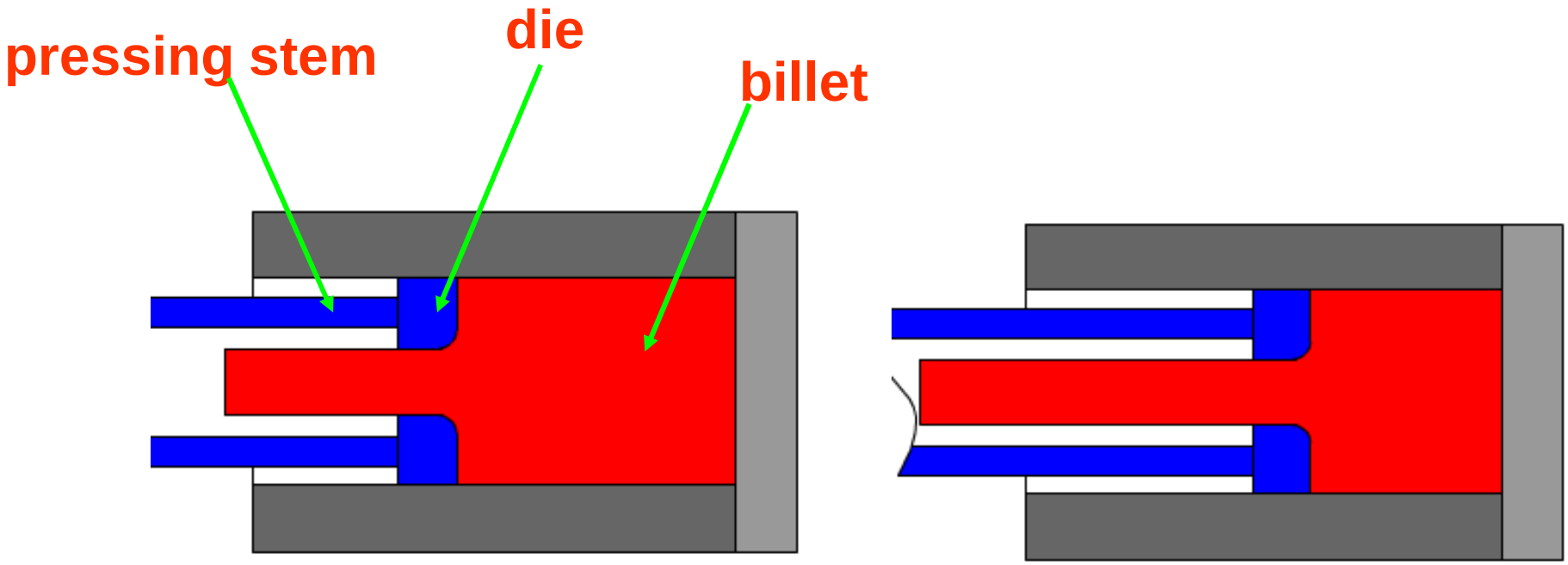
– the die moves toward the billet

– also called backward (reverse, or inverted) extrusion

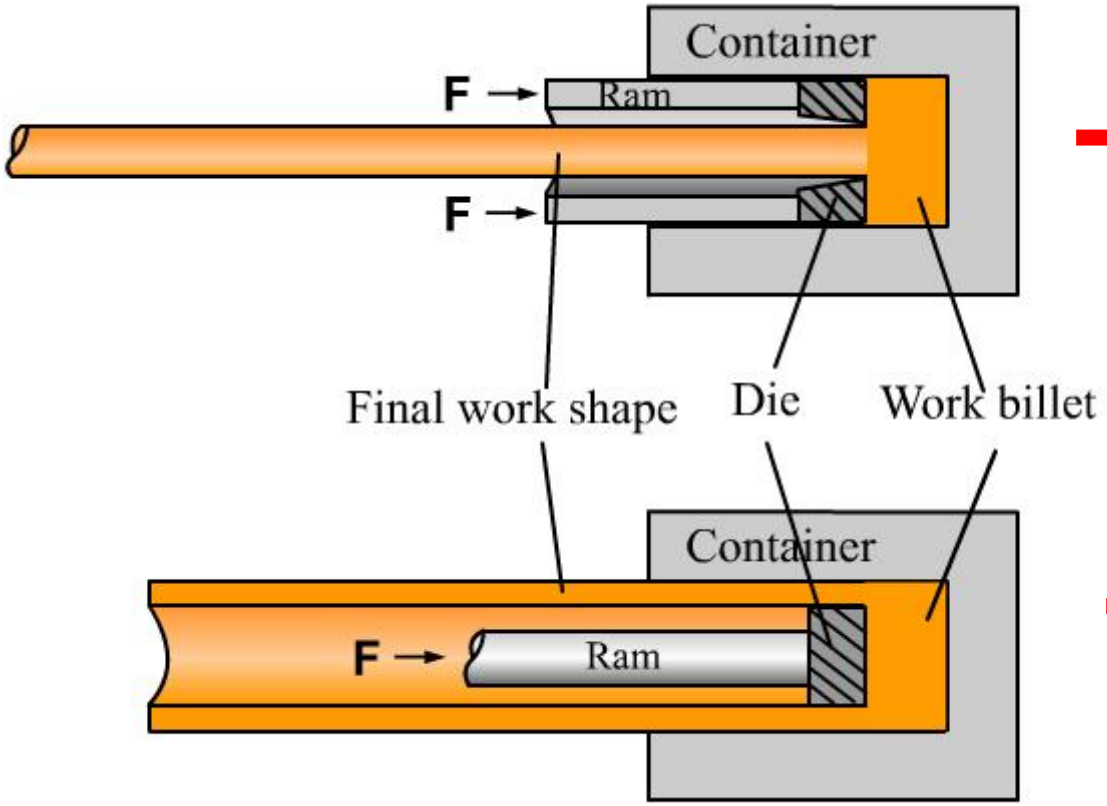
– having no billet-container friction

– used on materials with very high friction, such as high-strength steels.





The direction of the metal flows is opposite to that the pressing stem moves



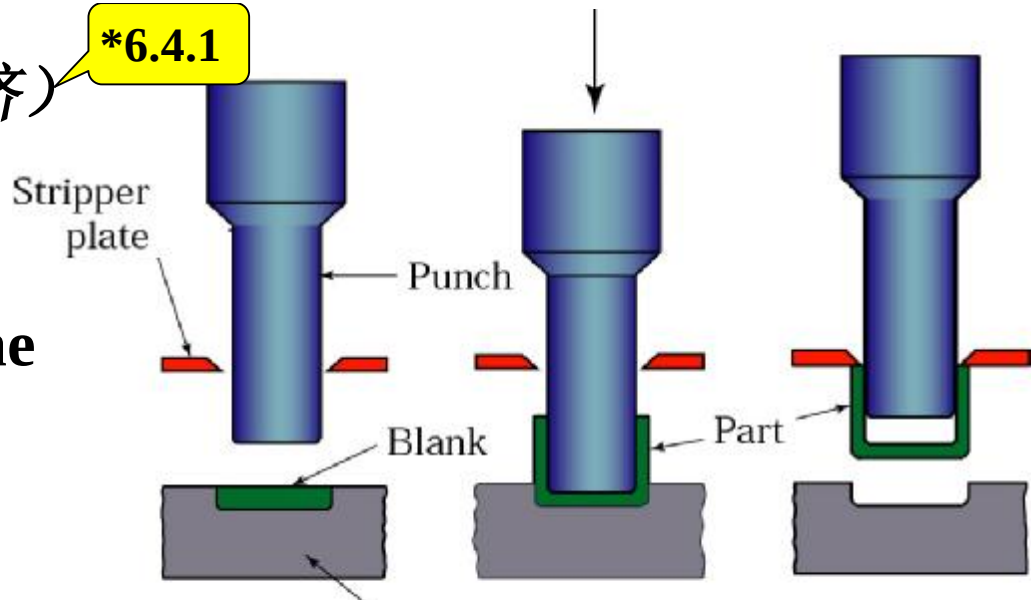
实心杆反向挤压

空心杆反向挤压

- **Impact Extrusion**（冲挤）

*6.4.1

- Similar to indirect extrusion
- Punch descends rapidly on the blank, which is extruded backward



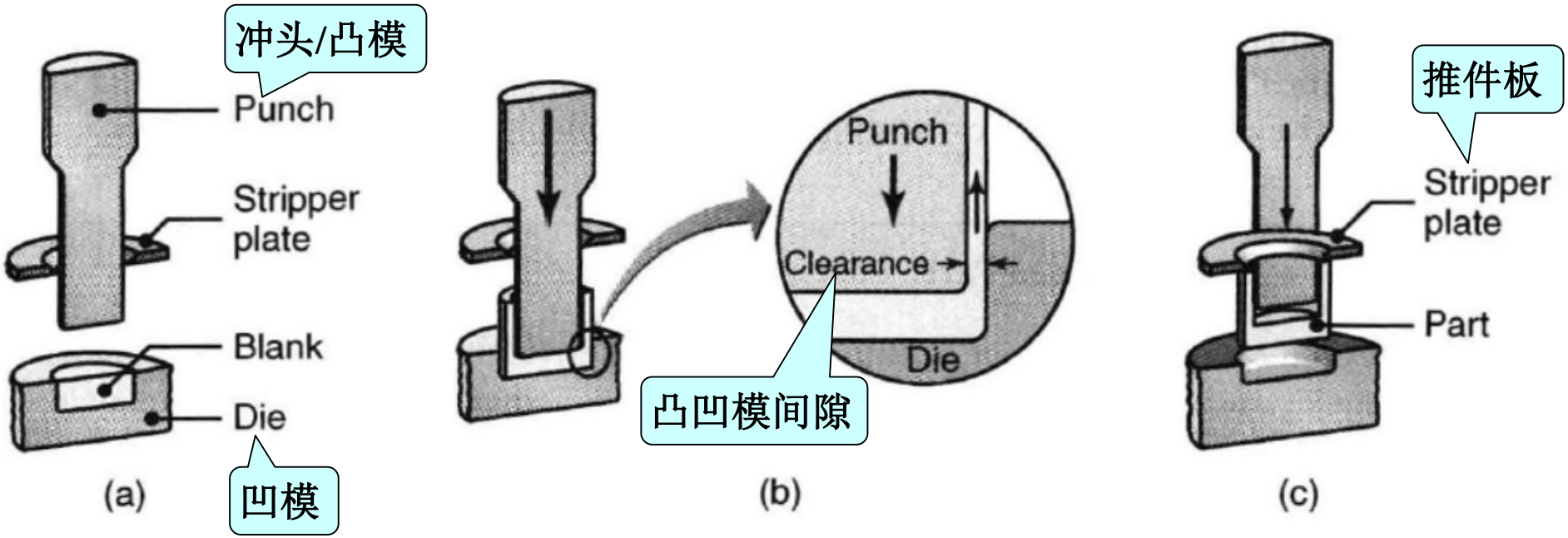


FIGURE 6.15 Schematic illustration of the impact-extrusion process. The extruded parts are stripped by the use of a stripper plate, because they tend to stick to the punch.

* Characteristics of Indirect Extrusion

1. 除位于死区附近的金属与挤压筒有相对滑动外，其他部分的金属与挤压筒壁并不发生相对滑动，因此没有摩擦，变形区仅集中在模孔附近处。
2. 反挤压时，由于变形区小，流动均匀，因此挤压缩尾和压余少，挤出件的力学性能沿长度方向较均匀。
3. 所需挤压力小；
4. 挤压筒和模具磨损少，使用寿命长。

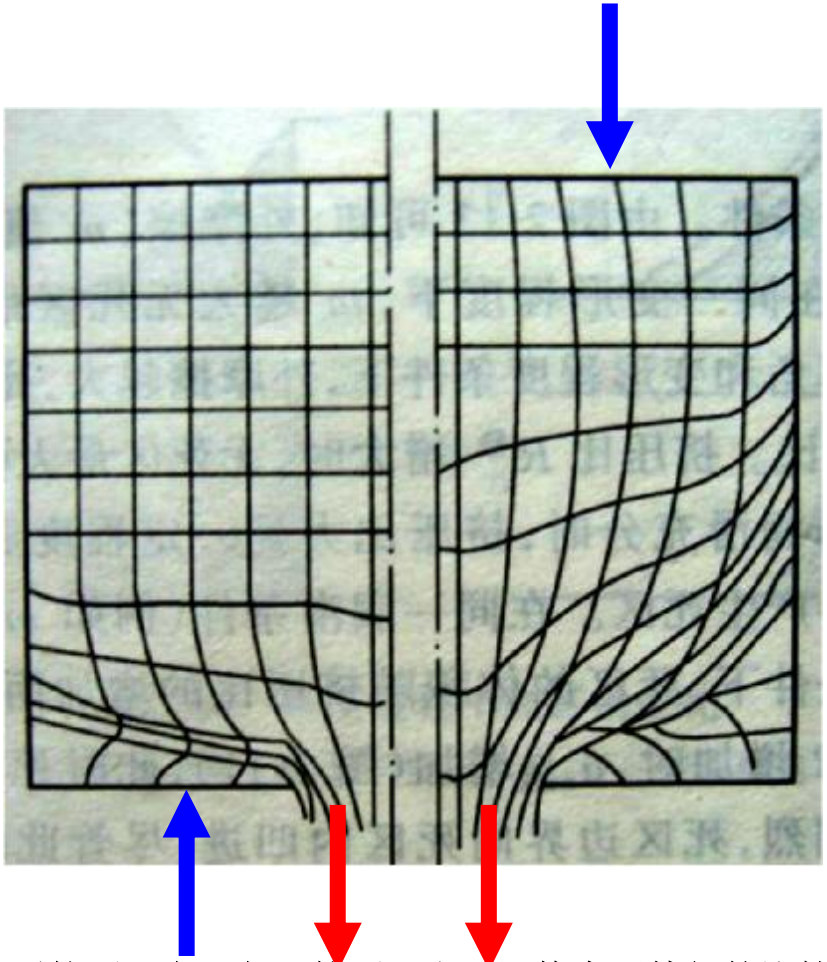
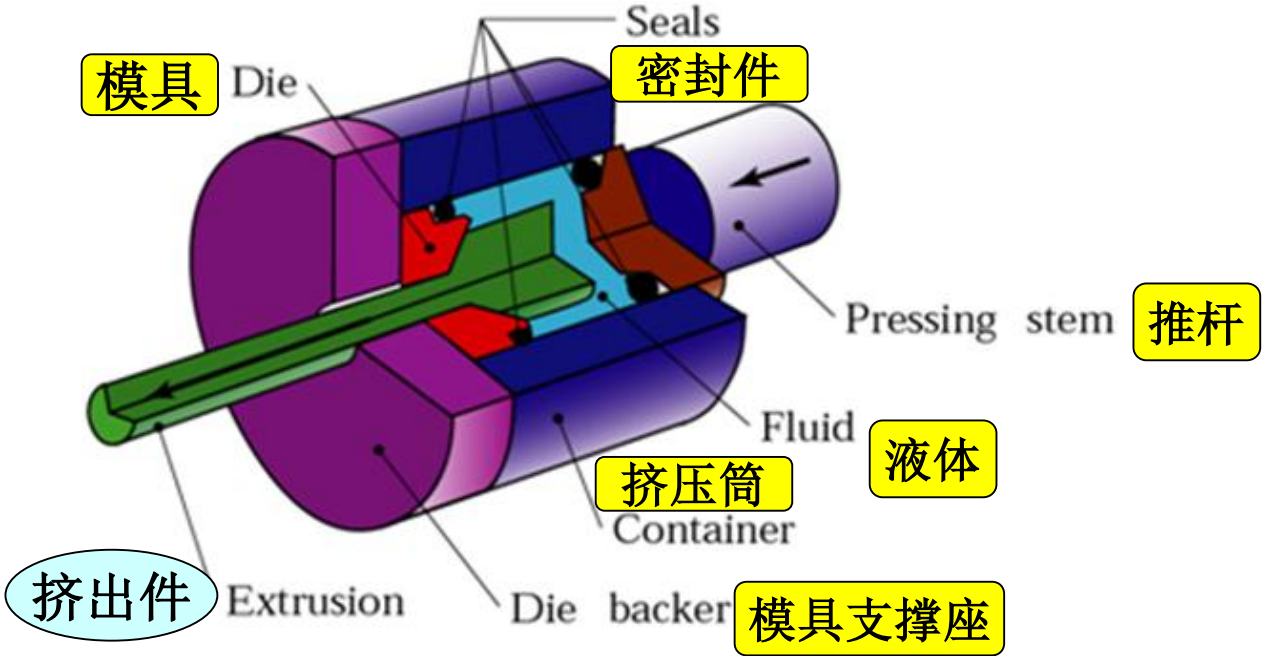


图 反挤压（左）与正挤压（右）网格变形特征的比较

3. Hydrostatic Extrusion（静液挤压/等静挤压）

- the billet is smaller in diameter than the chamber, which is filled with a fluid（高压介质：粘性液体或粘塑性体）
- the pressure is transmitted to the fluid by a ram（柱塞）
- the fluid pressure results in triaxial compressive stresses acting on the workpiece and thus improved formability
- much less friction to overcome along the container walls



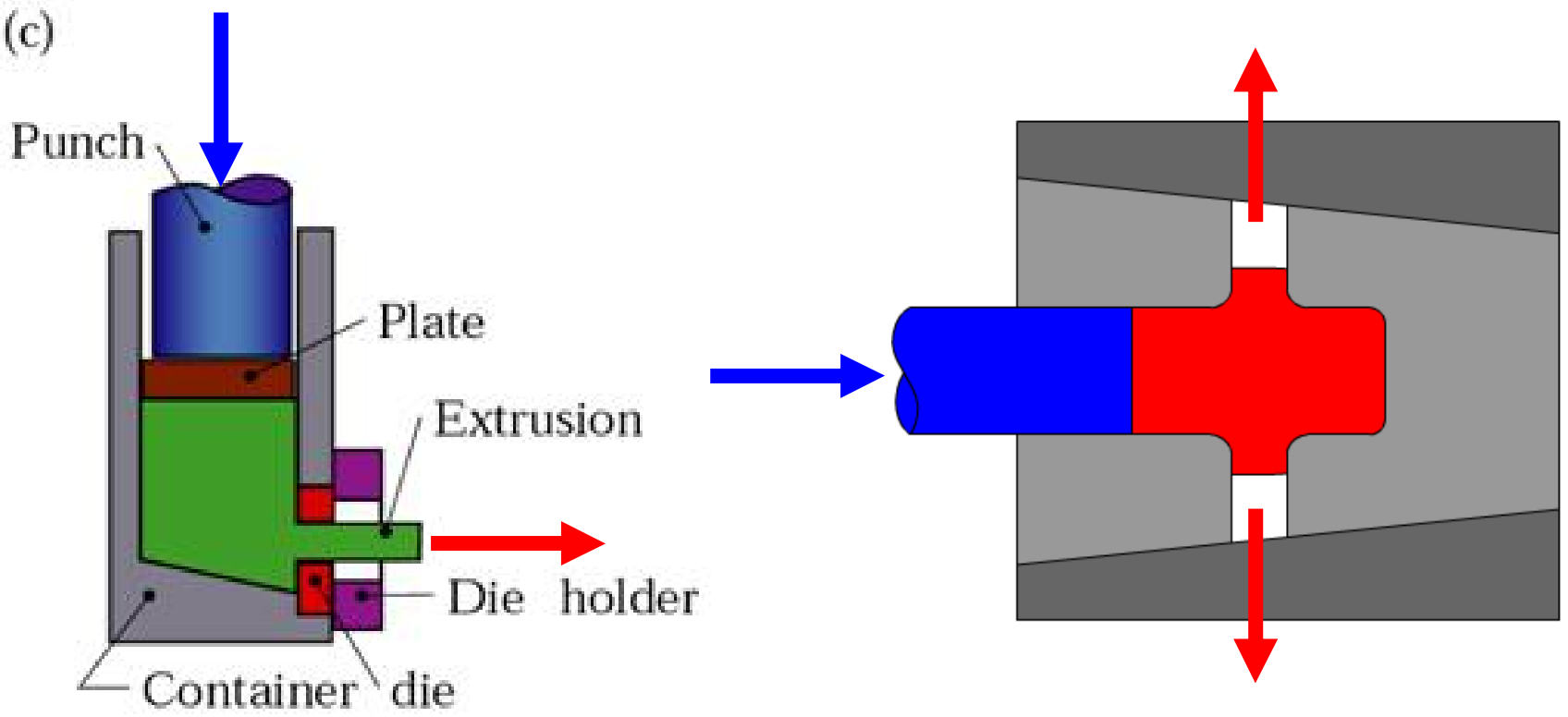
* Characteristics of Hydrostatic Extrusion

1. 毛坯与挤压筒内壁不直接接触，金属变形极为均匀，产品质量也比较好；
2. 由于毛坯周围有高压液体，挤压时不会弯曲。因此，毛坯可以采用大的径高比，以至可以挤压线材；
3. 毛坯与模具间处于流体力学润滑状态，摩擦力极小，模具磨损少，制品表面粗糙度低。
4. 制品的力学性能在断面上和长度上都很均匀；
5. 挤压力小，可采用大挤压比；
6. 可以挤压断面复杂的型材和复合材料，也可以挤高强度、高熔点和低塑性的材料；
7. 高温静液挤压的液体温度与压力都很高，需进一步解决耐高温、密封性能好的压力介质。

4. Lateral Extrusion （径向挤压）

– metal flows radially（径向地） or laterally（横向的/侧向的）

– also called side extrusion



Four Types of Extrusion Processes

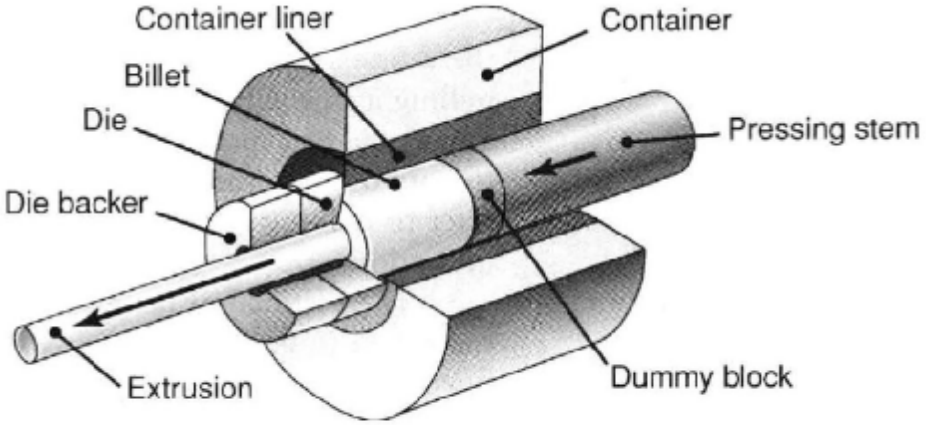


FIGURE 6.1 Schematic illustration of the direct-extrusion process.

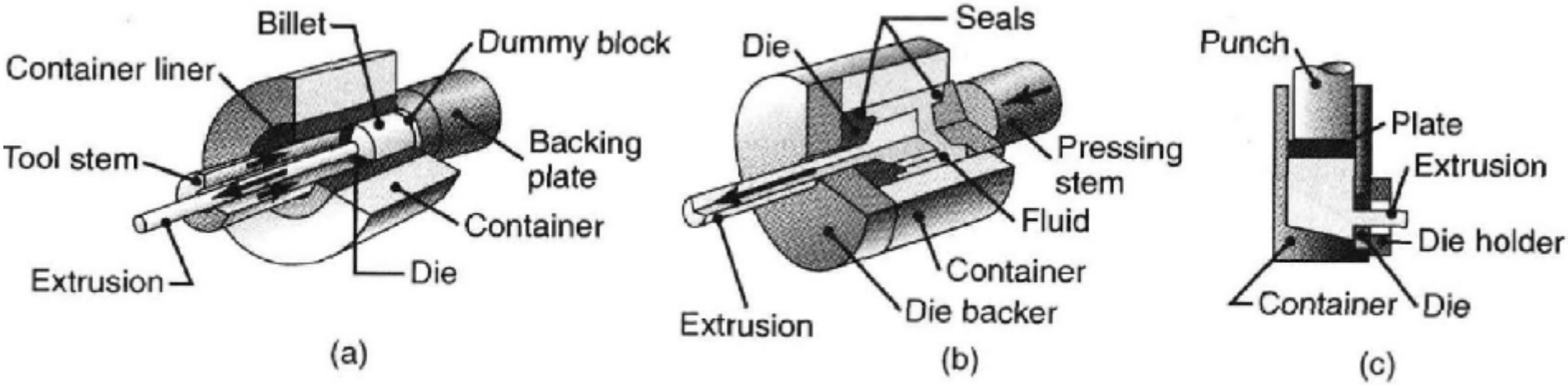


FIGURE 6.3 Types of extrusion: (a) indirect; (b) hydrostatic; (c) lateral.

Process Variables（工艺变量/工艺参数）

① die angle（模口角度）, α

② extrusion ratio（挤压比）

$R=A_0/A_f$ $(R > 1)$

③extrusion speed（挤出速度）

④ billet temperature（毛坯温度）

⑤ lubrication（润滑）

A_o: cross-sectional area of billet
A_f: cross-sectional area of extruded product

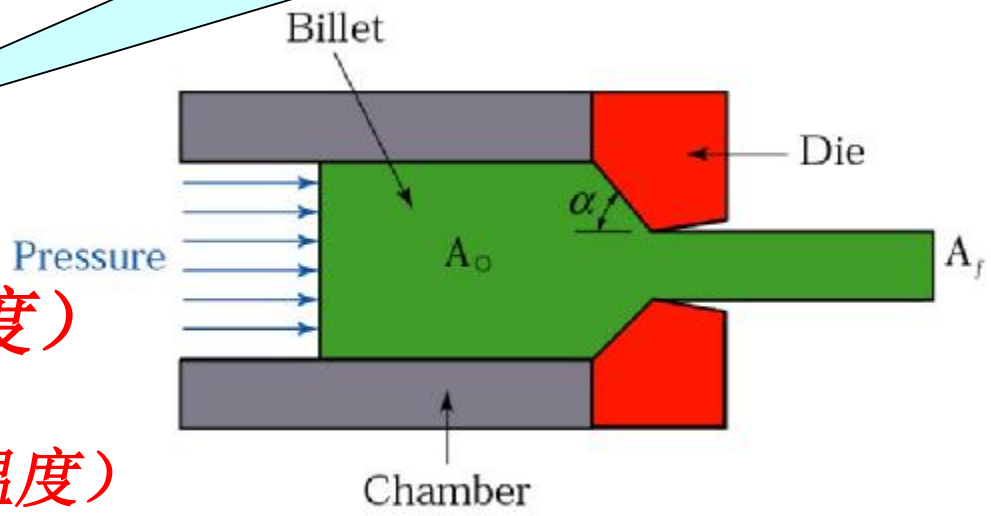


Figure 6.4 Process variables in direct extrusion The die angle, reduction in cross-section, extrusion speed, billet temperature, and lubrication all affect the extrusion pressure.

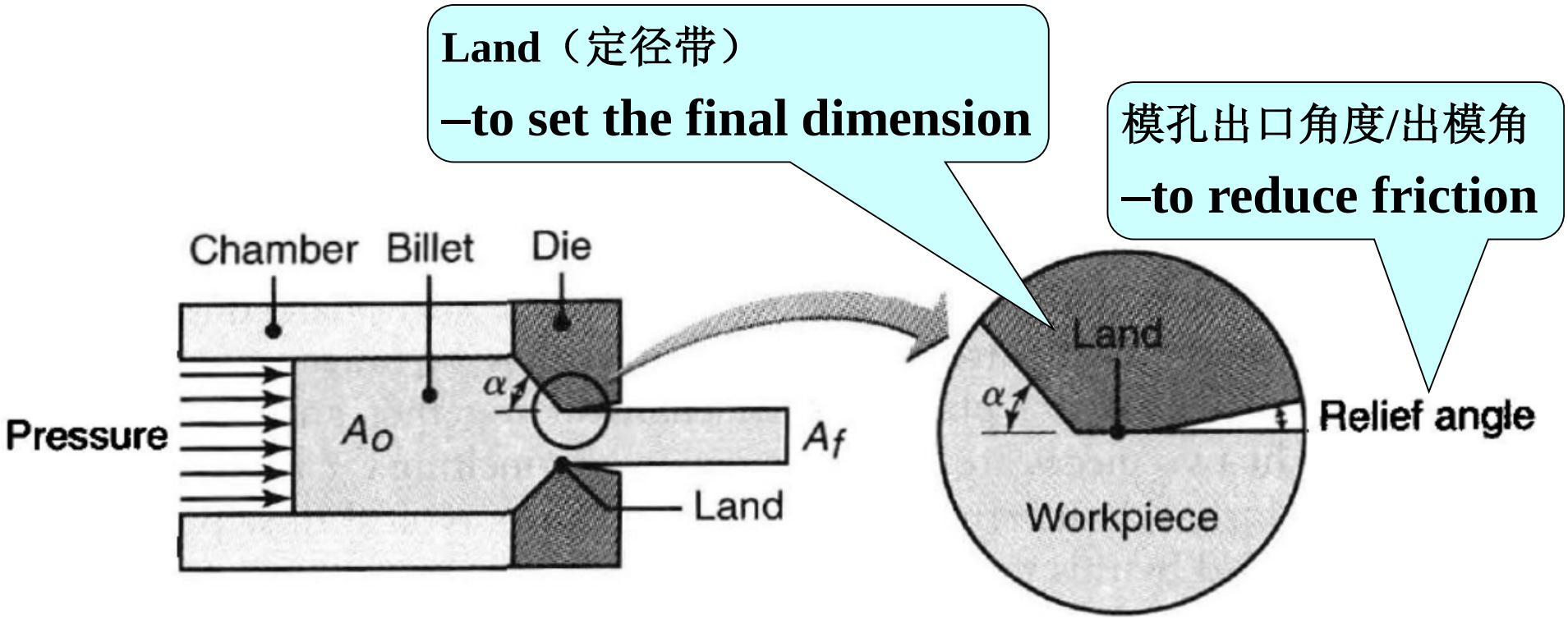


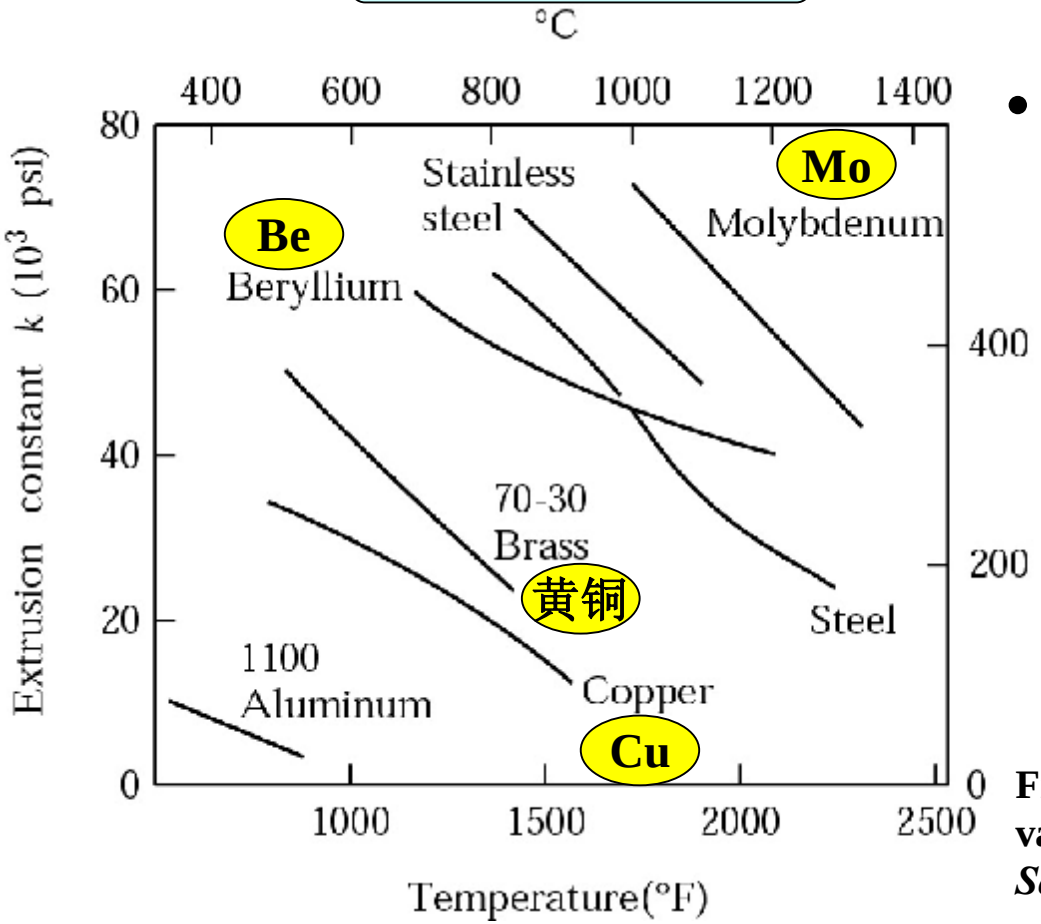
FIGURE 6.4 Process variables in direct extrusion. The die angle, reduction in cross section, extrusion speed, billet temperature, and lubrication all affect the extrusion pressure.

Extrusion Force

$$F = A_o k \ln(A_o / A_f)$$

extrusion ratio, *R*

***k*: extrusion constant（挤压常数）**
A_o, A_f : billet and extruded product areas



- **influence factors of *k*:**
  - **– the ductility of metal**
  - **– temperature**
  - **– friction condition**

Figure 6.6 Extrusion constant *k* for various metals at different temperatures. *Source*: P. Loewenstein.

Metal Flow in Extrusion

- **Metal flow pattern influences:**
  - **ø the quality of the final product;**
  - **ø the mechanical properties of the final product.**
- **Material flows longitudinally, which results in elongated（*延伸的/拉长的*） grain structure**
  - **ø preferred orientation（*择优取向/优先取向*）**
- **Improper metal flow can produce various defects**

Types of Metal Flow in Extruding with Square Dies（平底凹模）（$\alpha=90^o$）

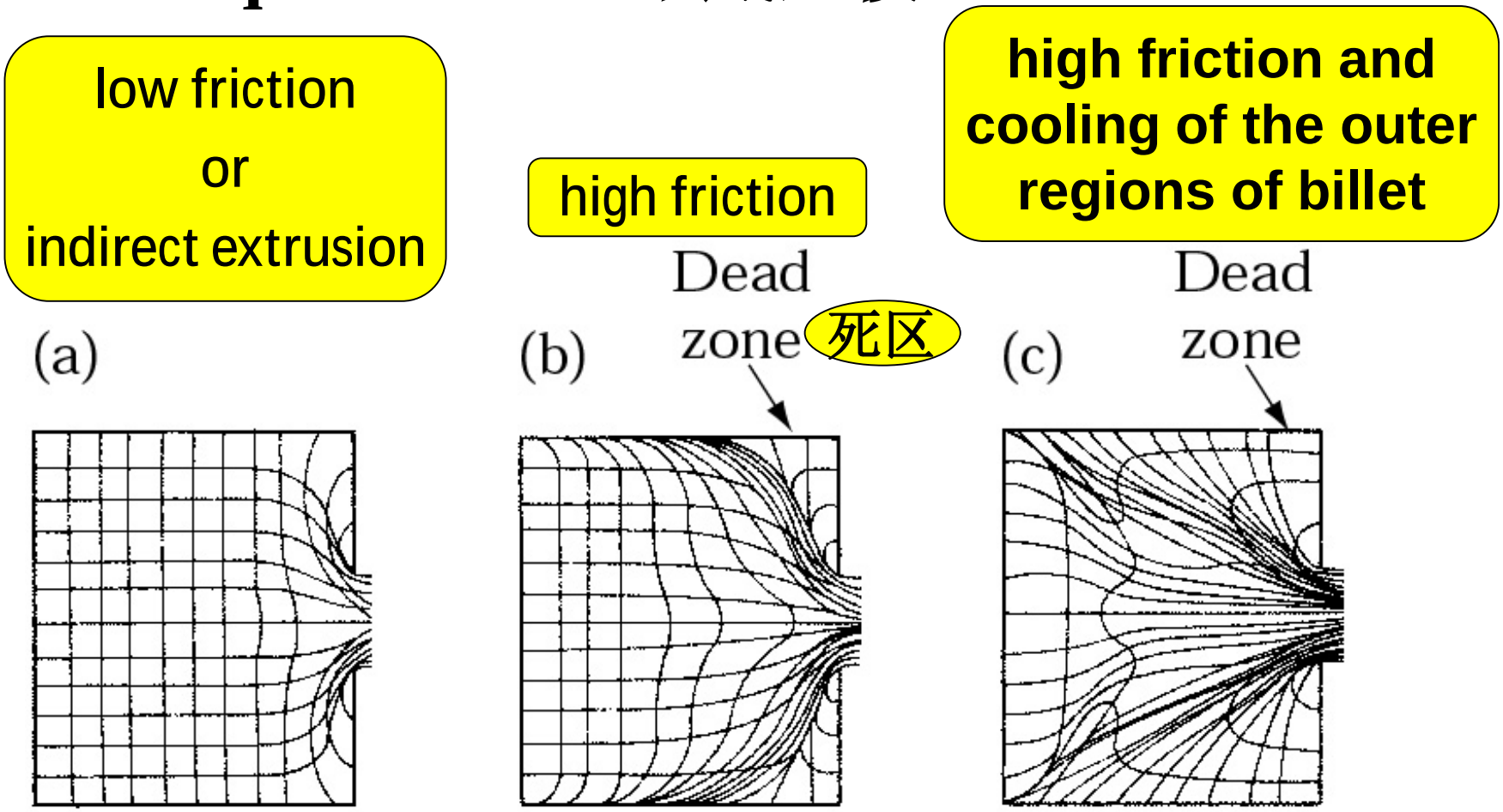


Figure 6.7 Types of metal flow in extruding with square dies. (a) Flow pattern obtained at low friction, or in indirect extrusion. (b) Pattern obtained with high friction at the billet-chamber interfaces. (c) Pattern obtained at high friction, or with cooling of the outer regions of the billet in the chamber. This type of pattern, observed in metals whose strength increases rapidly with decreasing temperature, leads to a defect known as pipe（缩尾）, or extrusion defect.

- **Dead zone**

– **where the metal at the corners is essentially stationary（*静止的*）**

– **mainly due to friction**

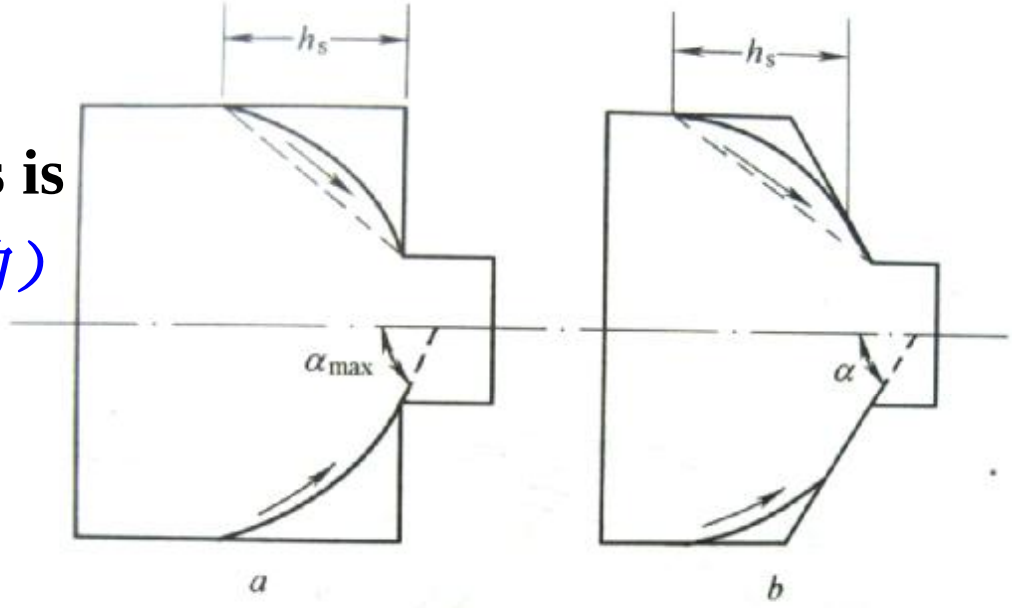


图 2-11　挤压死区形状示意图

a—平模挤压；*b*—锥模挤压

根据最小阻力定律（law of minimum resistance），金属会选择一条较易流动的路径流动，从而在挤压过程中形成图示的死区

The parameters related to the die zone:

- **(1) die angle, *a*: *a*↑, dead zone ↑**
- **(2) friction: external friction ↑, dead zone ↑**
- **(3) *R*: *R*↑, dead zone ↑**
- **(4)temperature: *T* ↑ → external friction ↑ → dead zone ↑**

*a*大，死区大，但制品表面质量好；
*a*小，死区小，但制品表面质量差。

* Process Parameters

1. Extruded Materials:

- commonly used and easily extruded:
  - Ø wrought Al（锻铝）, Cu, Mg, and their alloys
  - Ø steels and stainless steels
- difficultly extruded with considerable die wear
  - Ø other metals such as Ti and refractory metals

2. Extrusion Ratios, *R*: 10～100

- higher for special application (400 for softer nonferrous metals)
- lower for less ductile materials, usually ≥4 (to deform the materials plastically through the bulk of the workpiece

* Process Parameters

3. Extruded Length: usually <7.5m, max:30m

4. Ram Speeds: up to 0.5m/s

- Lower speeds: Al, Cu, Mg
- Higher speeds: steels, Ti, refractory metals

5. Dimensional Tolerance: ±0.25mm ～ 2.5mm

- increase with increasing cross-section

* Process Parameters

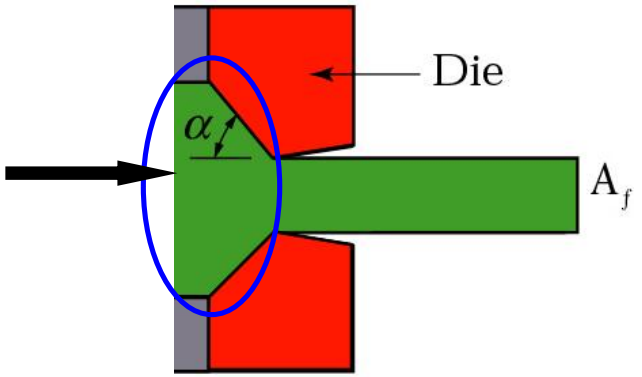
6. Subsequent Operations

- **Most extruded products require straightening（*校直*）and twisting（*弯曲*）, particularly for small cross-sections**
- **accomplished by stretching and twisting in a hydraulic stretcher（*液压拉伸矫直机*）equipped with jaws（*爪盘*）**

* Process Parameters

7. Scrap or Butt End （*废料或平头端/挤压余料*）

- a small portion of the end of the billet to remain in the chamber after the operation has been completed
- caused by the presence of a die angle
- is subsequently removed by cutting off the extrusion at the die exit
- may use another billet or a graphite block（*石墨垫*） placed in the chamber to extrude the piece remaining from the previous extrusion.



* Process Parameters

8. Coaxial Extrusion and Cladding（*同轴/包覆挤压*）

– coaxial（*同轴的*）billets are extruded together, provided that（*只要*）the strength and ductility of the two metals are compatible（*一致的/兼容的*）

– an example is copper clad with silver

9. Stepped Extrusion（*阶梯挤压/分段式挤压*）

– To extrude the billet partially（*部分的*）in one die, then in one or more larger dies.

10. Lateral Extrusion

– used for the sheathing（*包覆*）of wire and the coating（*涂覆/涂层*）of electric wire with plastic.

6.3 Hot Extrusion（热挤）

Outline

- **Process temperature and reasons**
- **Common problems in hot extrusion and solutions**
- **Die design**

- **Hot Extrusion**

– **Is carried out above recrystallization temperature**

- **Reasons:**

① **To process metals and alloys that do not have sufficient ductility at room temperature;**

② **In order to reduce the forces required .**

- **Same situation for other hot working operations（*热加工工艺/热成形工艺*）:**

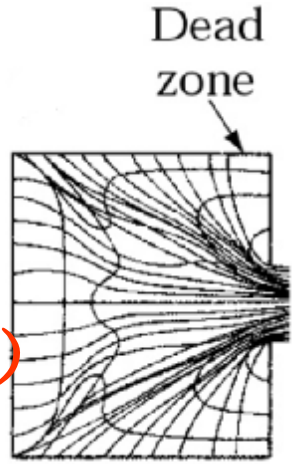
  ø hot rolling

  ø hot forging

Table6.1 Typical Extrusion Temperature Ranges for Various Metals and Alloys

	°C
Lead 铅	200–250
Aluminum and its alloys	375–475
Copper and its alloys	650–975
Steels	875–1300
Refractory alloys 高温/难熔合金	975–2200

Common Problems in Hot Extrusion



① Highly nonuniform deformation（不均匀变形）

results from cooling of the hot billet in the chamber

② Develop an oxide film（氧化层） in the billet

– abrasive （粗糙的/有磨蚀作用的）

– affects the flow pattern of the material

– also affects surface finish of extrusion products

– can be avoided if heated in an inert-atmosphere（惰性气体）

③ Die wear （模具磨损）can be excessive（过大的）

Solutions

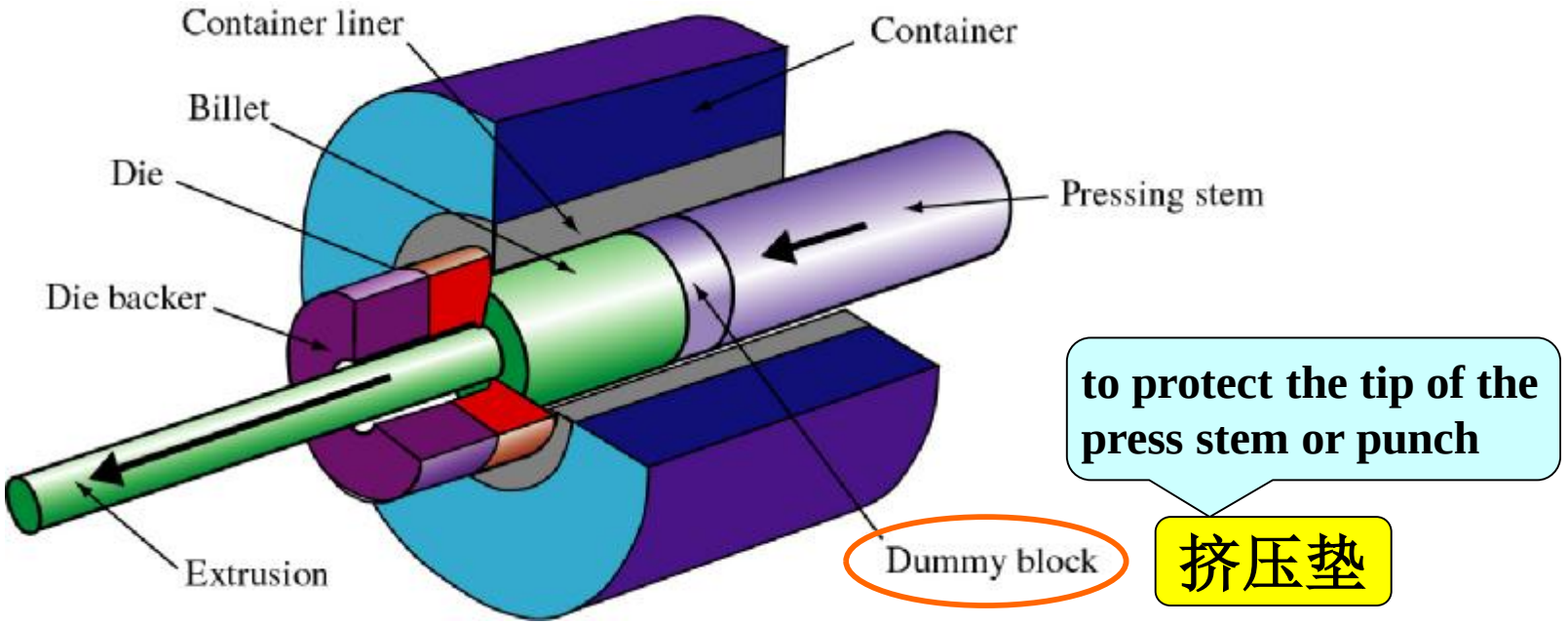
① Using preheated dies

- to reduce cooling of the billet
- to prolong（延长） die life

② Using the dummy block （挤压垫）

- a little smaller in diameter than the container
- placed ahead of the ram
- to avoid the formation of oxide films on the hot extruded product.

Dummy Block

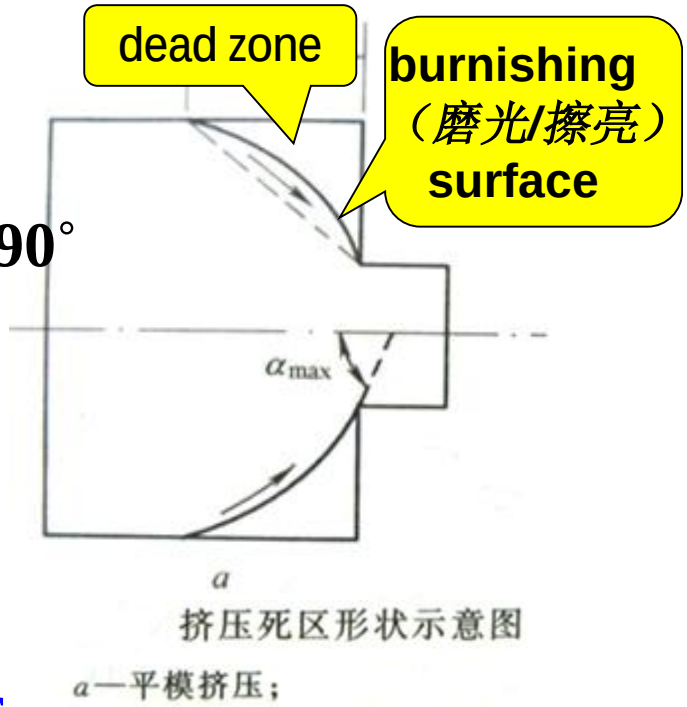


- **As a result, a thin cylindrical shell (skull)（*壳/壳体*）, consisting mainly of the oxidized layer, is left in the container.**
- **The extruded product is thus free of oxides;**
- **The skull is later removed from the chamber.**

Die Design

① **Square die(shear die)（*平模/平底模*）*a* =90°**

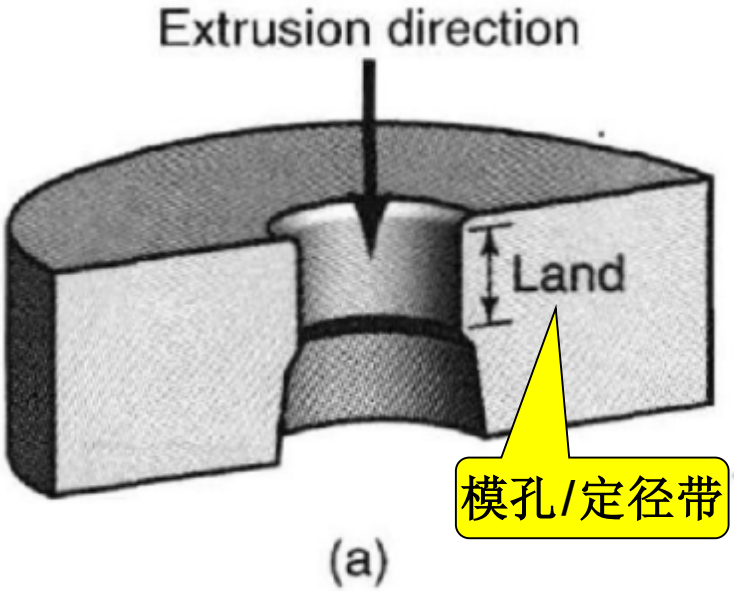
- **usually used in extruding nonferrous metals（*有色金属*）, especially Al**
- **develops dead-metal zones**
- **produces extrusions with bright finishes**



a

挤压死区形状示意图

a—平模挤压；



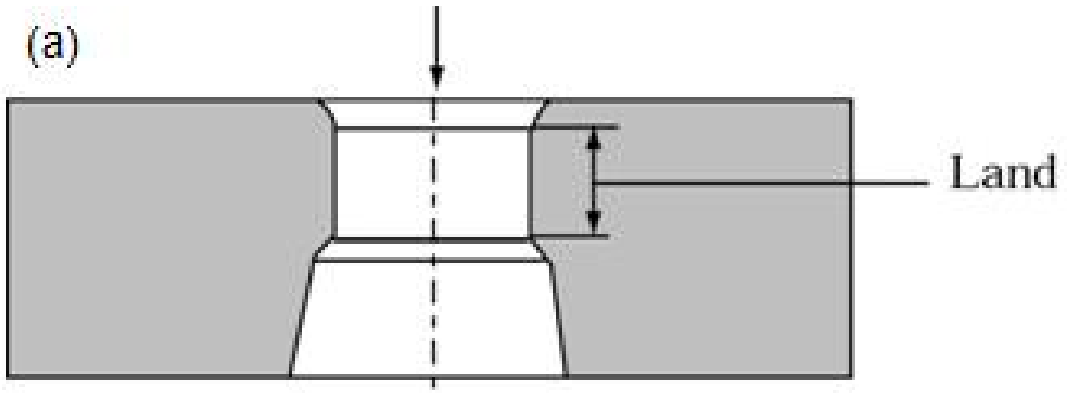
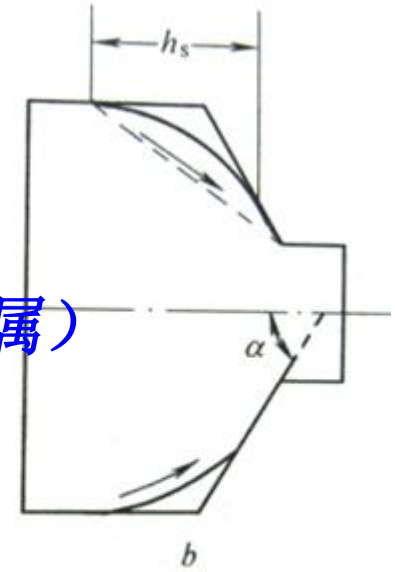


Figure 6.7 Typical extrusion-die configurations: (b) die for ferrous metals;

Die Design

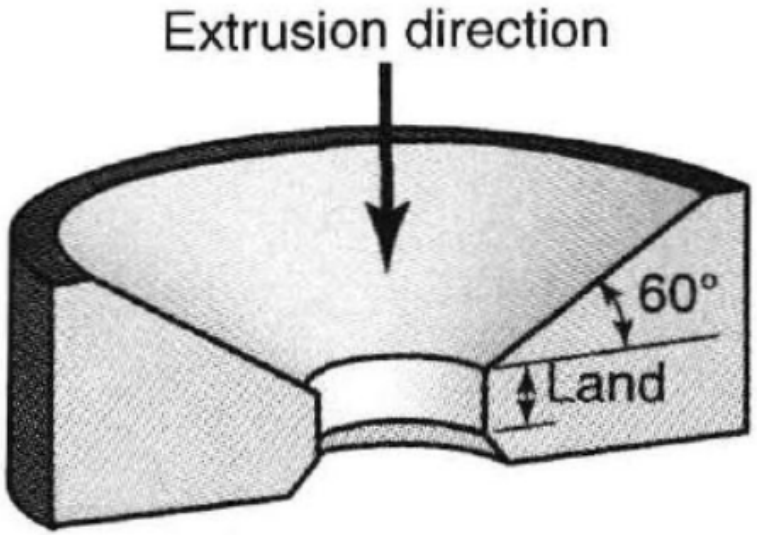
② **Tapered die（锥底凹模） *a* =60°**

- **usually used in extruding ferrous metals（黑色金属）**
- **develops less dead zone**
- **produces extrusions with less bright finishes**



挤压死区形状示意图

b—锥模挤压



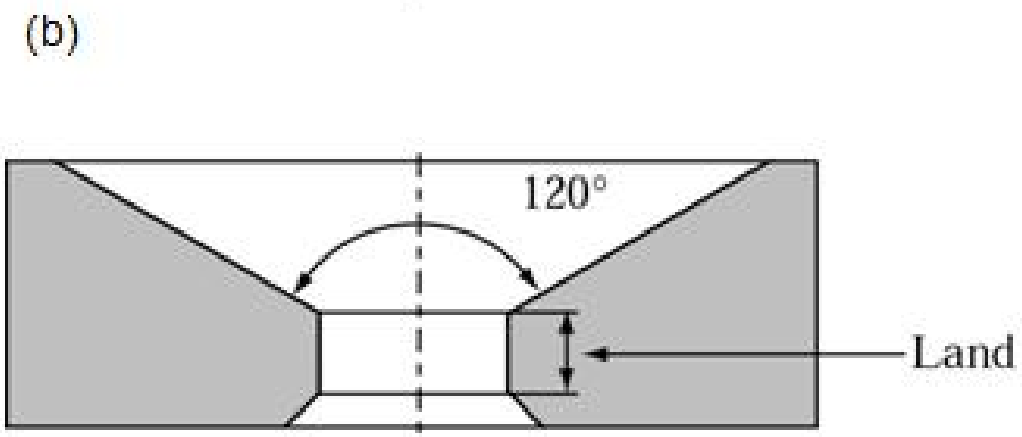


Figure 6.7 Typical extrusion-die configurations: (b) die for ferrous metals;

Die Design

- Made of hot-worked die steel

  （热作模具钢）

- Use molten glass as a lubricant
  - reduce friction
  - act as a thermal barrier（隔热层）

    between the hot workpiece and

    the relatively cool die

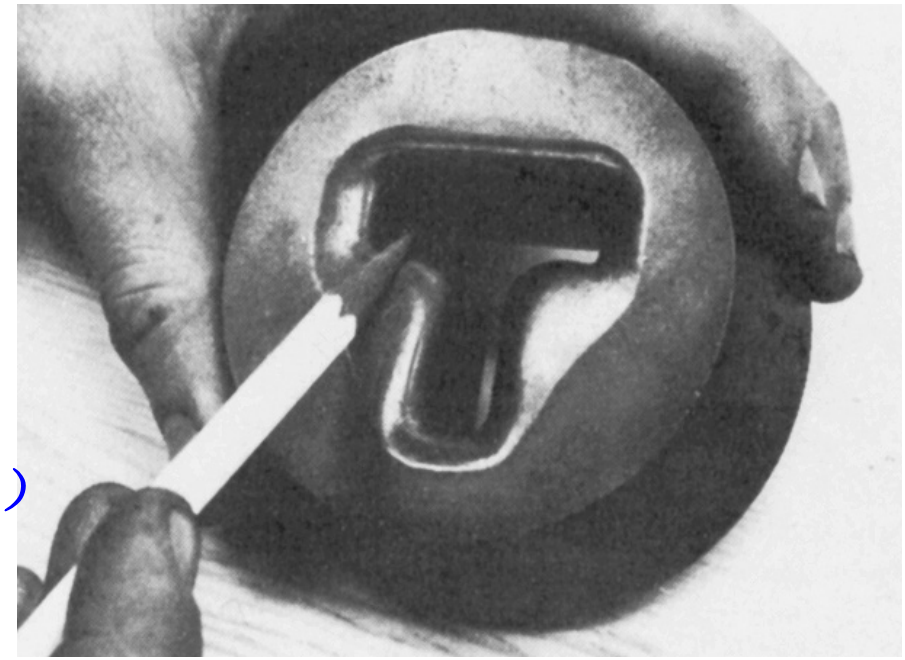


Figure 6.7 Typical extrusion-die configurations: (c) die for T-shaped extrusion, *Source* for (c): Courtesy of LTV Steel Company.

Die Materials

- **Hot-work die steels（*热作模具钢*）**
  - **usually used for hot extrusion**
- **Coatings（*镀层/涂层*）such as partially stabilized zirconia may be applied to extend their life**
- **Partially stabilized zirconia（*部分稳定氧化锆*）dies**
  - **used for hot extrusion of tubes and rods**
  - **but not suitable for extruding complicated shapes, because of the severe（*剧烈的/严重的*）stress gradients（*应力梯度*）developed in the die, which may lead to their premature failure（*早期失效/过早失效*）.**

无机非金属材料

* Lubrication

- **Important in hot extrusion because of its effects on:**
  - **material flow during extrusion**
  - **surface finish and integrity（*完好/完整*）**
  - **product quality**
  - **extrusion forces**
- **Glass is an excellent lubricant**
  - **for steels, stainless steels, and high-temperature metals and alloys**
  - **thin layer of glass melts and acts as a lubricant at he die interface**

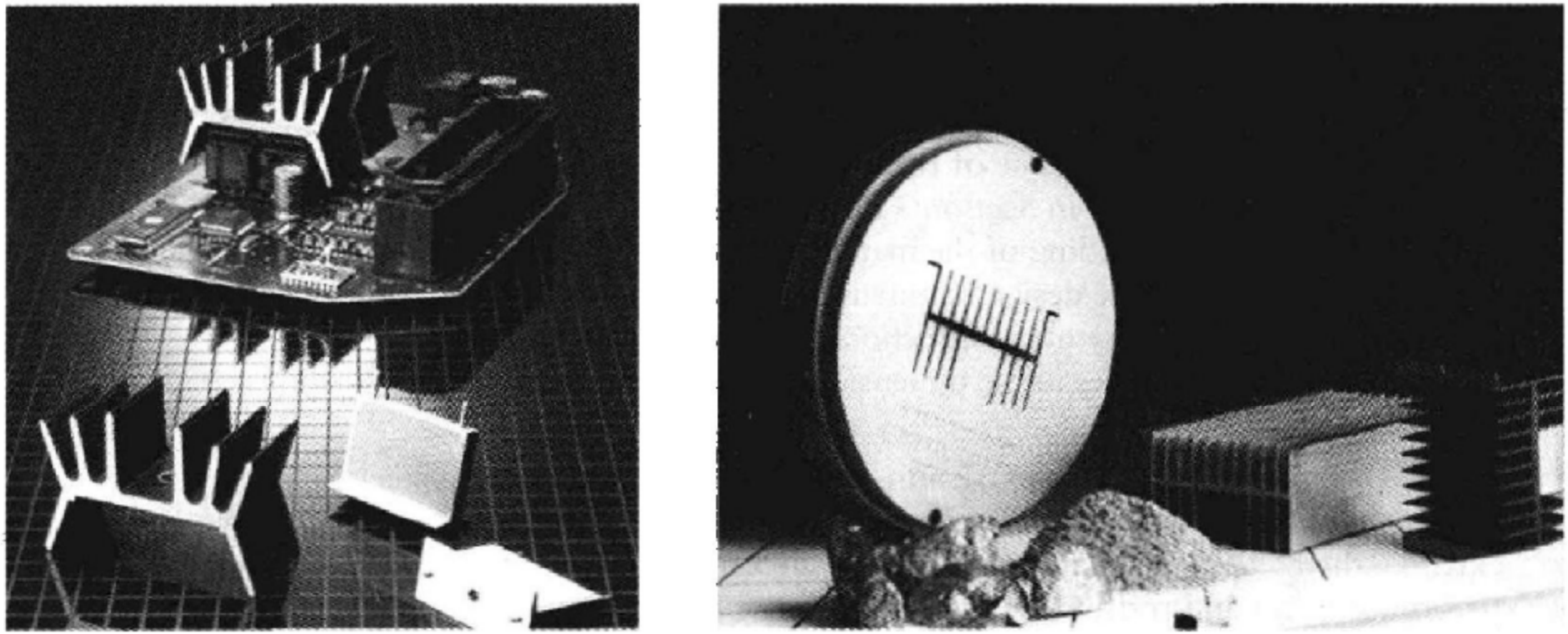


FIGURE 6.11 (a) Aluminum extrusion used as a heat sink for a printed circuit board, (b) Extrusion die and extruded heat sinks. *Source*: Courtesy of Aluminum Extruders Council.

6.4 Cold Extrusion（冷挤压）

Outline

- **Process**
- **Advantages of cold extrusion**
- **Considerations in cold extrusion**

- **Cold Extrusion（冷挤压）**

– **done at room temperature**

– **generally means a combination（组合） of operations, such as direct and indirect extrusion and forging .**

– **developed in the 1940s**

to produce discrete parts

– **has gained wide acceptance in industry, particularly for tools and for components in automobiles, motorcycles, bicycles, appliances, and transportation and farm equipment（交通及农用设备）.**

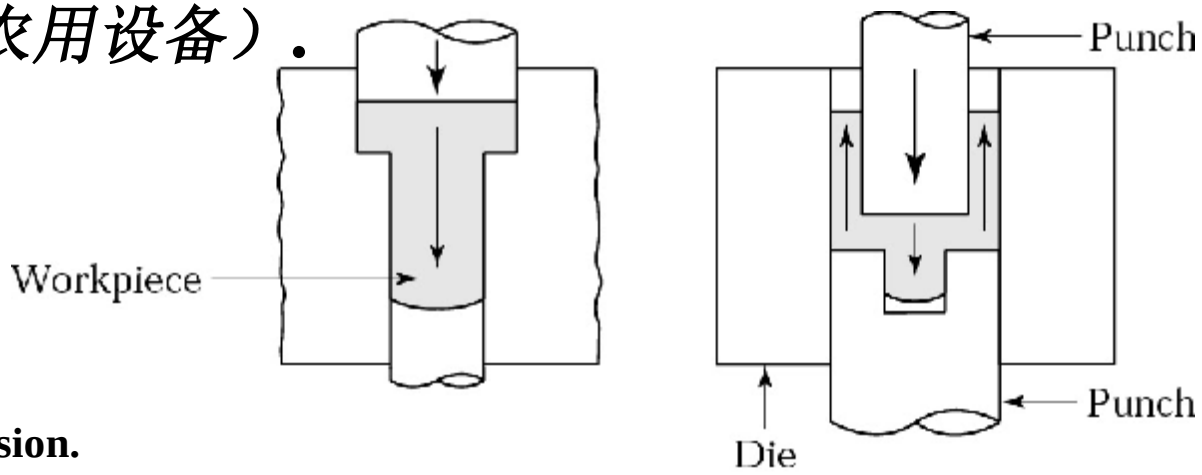
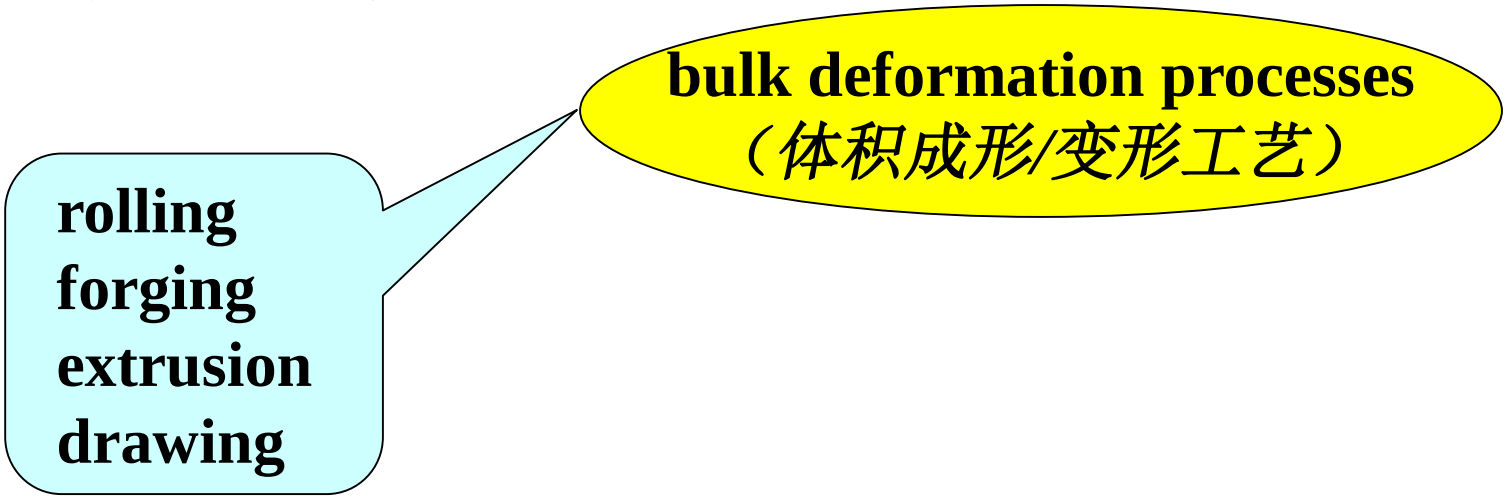


Figure 6.11 Two examples of cold extrusion. Thin arrows indicate the direction of metal flow during extrusion.

冷挤压

- 冷挤压是将金属毛坯放入模具模腔中，在强大的压力和一定的速度作用下，迫使金属在模腔中变形，从而获得所需形状、尺寸以及具有一定力学性能的挤压件。
- 挤压加工是靠模具来控制金属流动，利用金属体积的大量转移来成形零件的。



Advantages of Cold Extrusion over Hot extrusion

① **Improved mechanical properties**

- **resulting from work hardening, provided that（只要） the heat generated by plastic deformation and friction does not recrystallize the extruded metal**

② **Good control of dimensional tolerances, reducing the need for subsequent machining or finishing operations**

③ **Improved surface finish**

- **due partly to the absence of oxide film and provide that lubrication is effective**

④ **Production rates and costs that are competitive（有竞争力的）**

- **some machines can produce more than 2000 parts per hour**

Considerations in Cold Extrusion

① Very high stresses

– especially for steel and specialty-alloy（*特种合金*）workpieces

② Requirements for tools:

– sufficient hardness（*足够的硬度*）

- punch （*凸模/冲头*）: 60-65HRC (critical component)
- die（*凹模*）: 58-62HRC

– sufficient toughness（*足够的刚度*）

– resistance to wear and fatigue（*耐磨性与抗疲劳性*）

– tool and die material is also crucial（*关键的*）

Considerations in Cold Extrusion

③ Requirements for workpiece:

- material quality
- accuracy of slug dimensions
- surface condition
- specialty alloys（特种合金） have been developed

④ Lubrication

- is critical, especially with steels, because of the possibility of sticking（粘着）(seizure（咬粘）) between the workpiece and the tooling if the lubricant breaks down.
- the most effective means: application of a phosphate conversion coating（磷酸盐转化膜）on the workpiece, followed by a coating of soap（皂/脂肪酸盐） or wax（蜡）

磷化+皂化

Cold Extruded Spark Plug（火花塞）

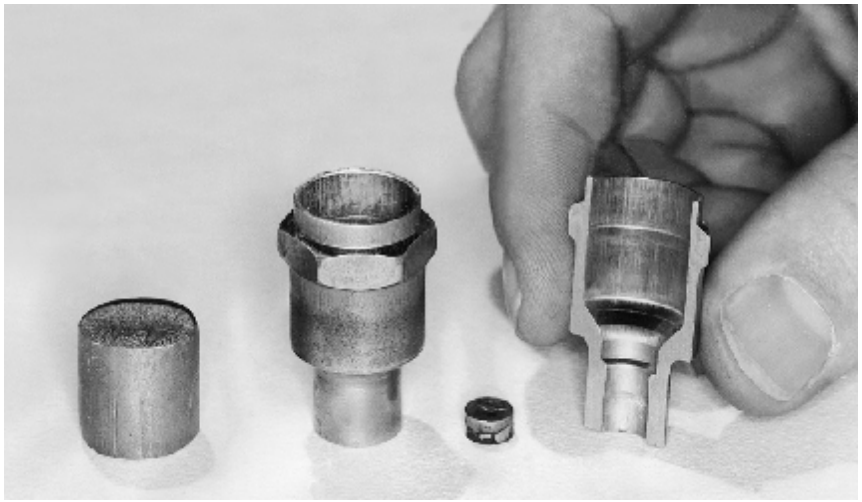


Figure 6.12 Production steps for a cold extruded spark plug.
***Source*: National Machinery Company.**

Figure 6.13 A cross-section of the metal part in Fig. 6.12, showing the grain flow pattern.
***Source*: National Machinery Company.**

Examples of Cold Extruded Parts

6.6 Extrusion Equipment —— Press

1. Horizontal Hydraulic Press（卧式液压机）

- suitable for extrusion, because the stroke and speed of the operation can be controlled.
- capable of applying a constant force over a long stroke; thus, long billets can be used, and the production rate increased.
- hydraulic presses with a ram-force capacity as high as 120MN (14,000 tons) have been built, they are used for hot extrusion of large-diameter billets.

Horizontal Hydraulic-extrusion Press

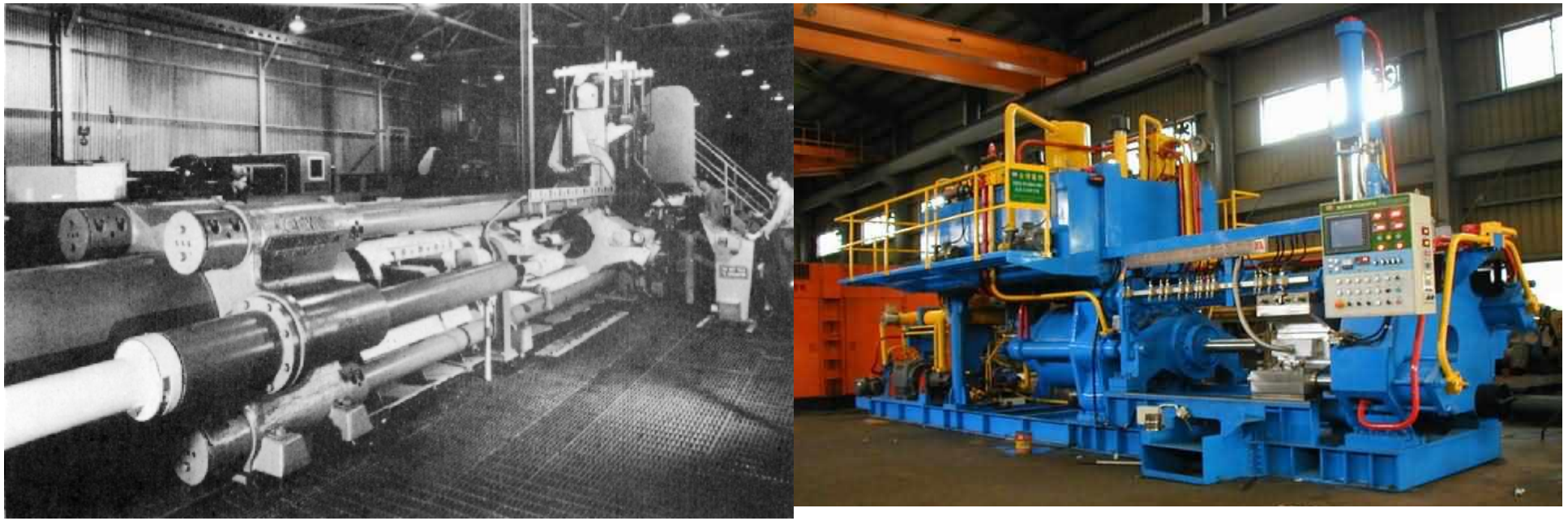


Figure 6.18 General view of a 9-MN (1000-ton) hydraulic-extrusion press. *Source*: Courtesy of Jones & Laughlin Steel Corporation.

2. Vertical Hydraulic Press（立式液压机）

- generally has less capacity and is used for cold extrusion.
- takes up less floor space（占地少）

3. Other Equipment

- crank-joint mechanical press（曲柄压力机）
- knuckle-joint mechanical press（肘杆式压力机）
- is used for cold extrusion and for impact extrusion（冲挤）, to mass produce（大批量生产） small components.
- multistage operations（多工位/多工序生产） are also carried out on specially designed presses.

Vertical Hydraulic Press

6.7 The Drawing Process（拉拔工艺）

Outline

- **Process**
- **Major variables:**
  - die angle, α
  - reduction in cross-sectional area, ψ
  - drawing speed
  - temperature
  - friction and lubrication
- **Drawing force**
- **Drawing of other shapes:**
  - tubes（管件）
  - flat strips（条料）

Drawing :

– the cross-section of a long round rod or wire is reduced or changed by pulling it through a draw die（拉拔模/拉丝模）

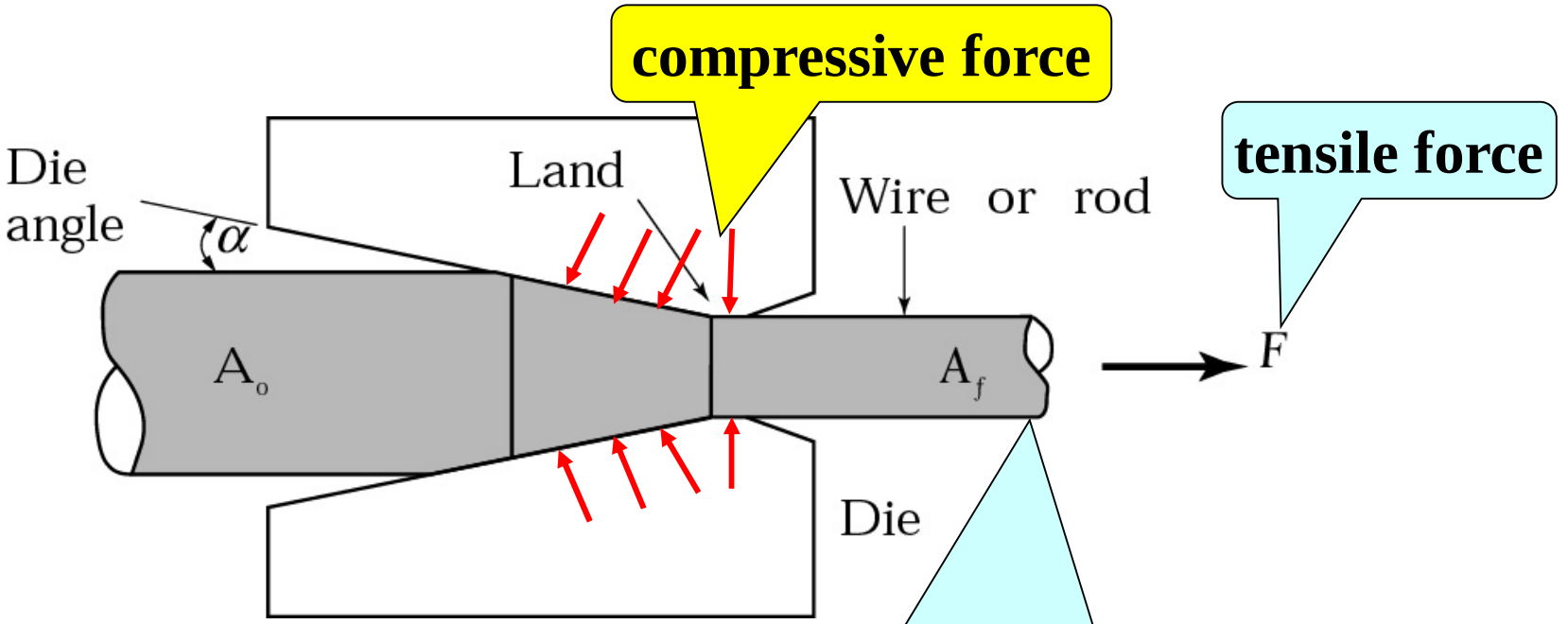


Figure 6.19 Process variables in wire drawing. The die angle, the reduction in cross-sectional area per pass, the speed of drawing, the temperature, and the lubrication all affect the drawing force, *F*.

- the tip must be reduced in cross section in order to fed through the die opening and be pulled
- done by swaging or pointing (端头锻细/锻头）

Major Variables in Drawing

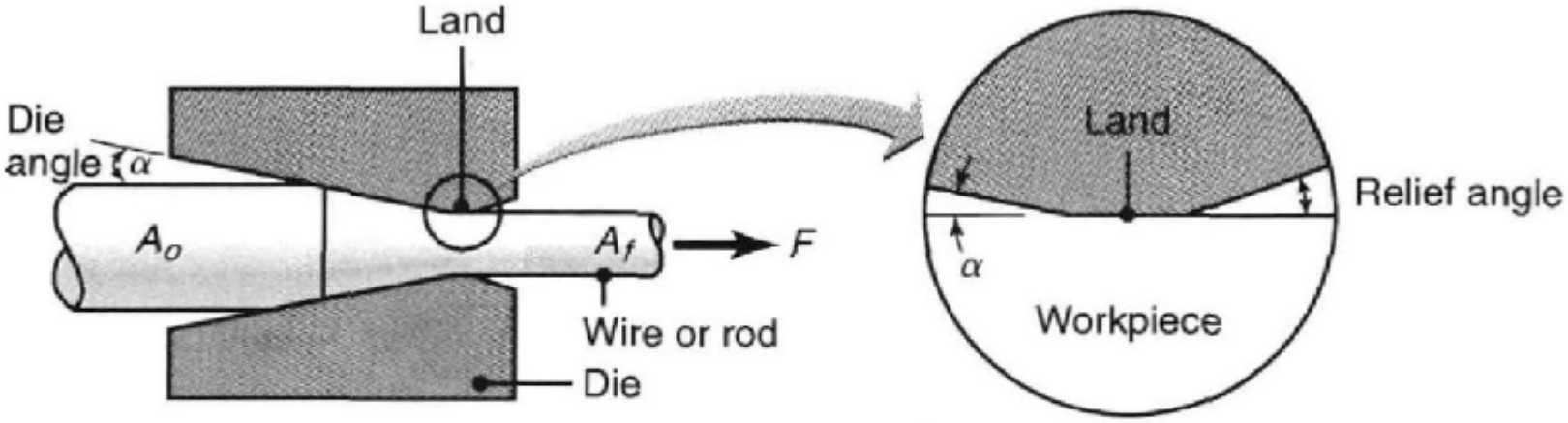


FIGURE 6.19 Process variables in wire drawing. The die angle, the reduction in cross-sectional area per pass, the speed of drawing, the temperature, and the lubrication all affect the drawing force, *F*.

① **die angle，α**

② **reduction in cross-sectional area，ψ（$\psi < 1$）**

③ **speed of drawing**

④ **temperature**

⑤ **friction and lubrication**

They all affect the drawing force, *F*.

Drawing Force

- **under frictionless conditions:**

Y_{avg}: the average true stress of the material in the die gap

A_o, A_f : billet and drawn product areas

$$F = Y_{avg} A_f \ln(A_o / A_f)$$

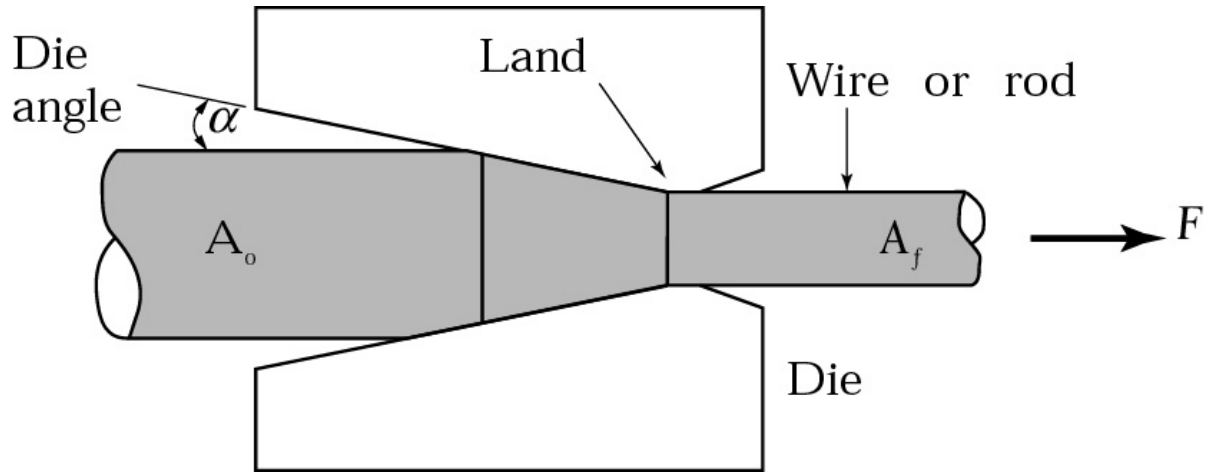
- **under actual conditions:**

friction → **drawing force**

$\psi=(A_0-A_f)/A_0$

there has to be a limit to the magnitude of the force

reduction in area → drawing force



- When the tensile stress（拉应力） reaches the yield stress（屈服应力） of the material being drawn, the workpiece will simply yield, eventually（最终）, break（断裂）.

deform plastically（塑性变形）

Drawing of Other Shapes

- **Various solid cross-sections can be produced**
  - **initial（*最初的*）cross-section is usually round or square**
  - **by drawing through dies with different profiles（*轮廓/形状*）**
- **Proper die design and the proper selection of reduction sequence per pass required considerable experience**
  - **ensure proper material flow**
  - **reduce internal or external defects**
  - **improve surface quality**

* Drawing of Other Shapes

- **Tube drawing processes（*拉管工艺*）**
  - **the wall thickness, diameter, or shape of tubes that have been produced by extrusion or by other processes can be further reduced or changed**
  - **tubes as large as 0.3m in diameter can be drawn by these techniques.**
  - **mandrels（*芯轴/芯棒*） of various profiles are available for these operations.**

Examples of Tube-Drawing Operations

Video:

- 退火 (annealing)
- 清洗、磷化、皂化
- 缩颈 (necking)
- 拉拔 (clod drawing)
- 热处理 (thermal treatment)
- 校直 (straightening)
- 检测 (testing)
- 标记 (marking)
- 锯切 (sawing)

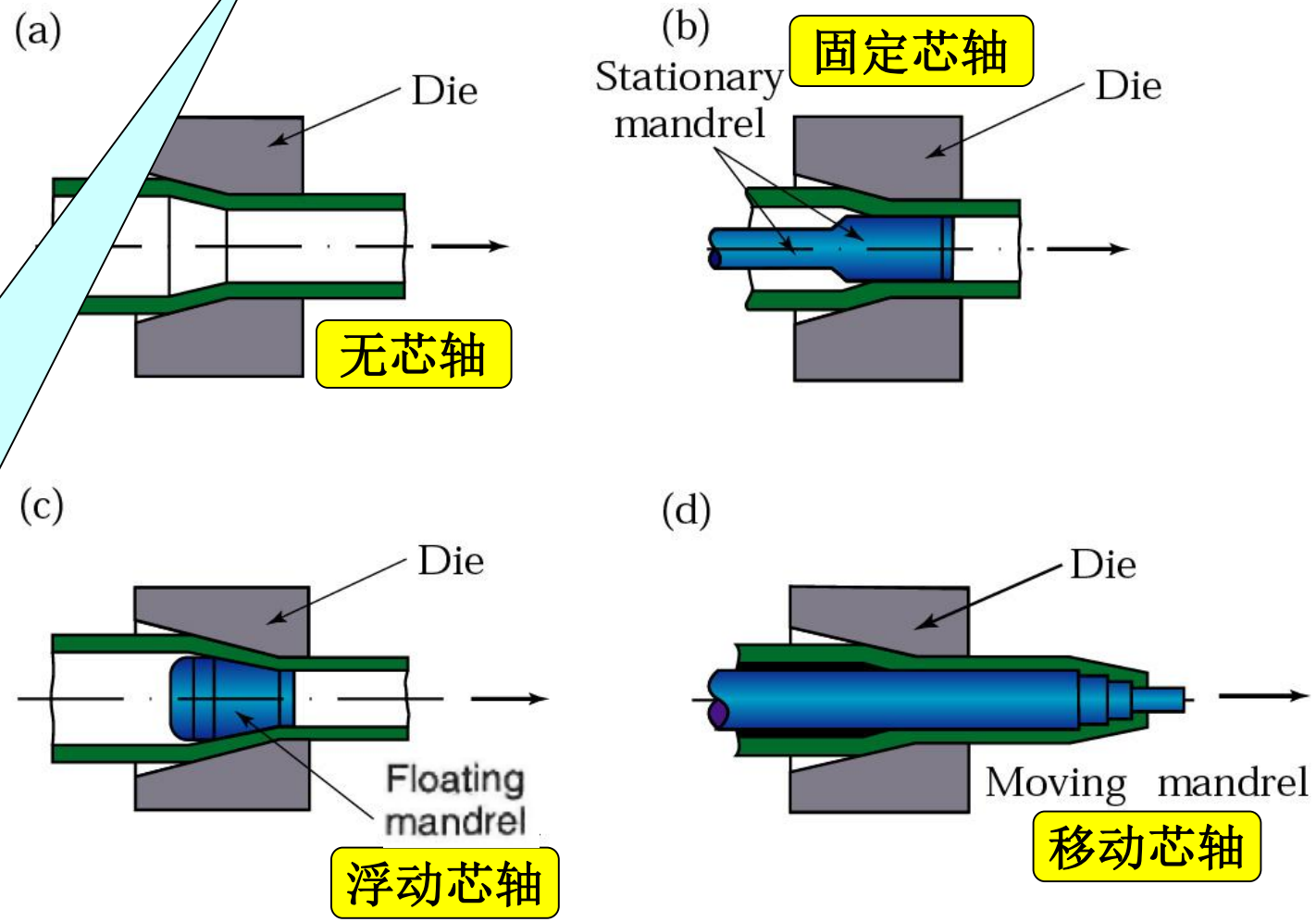


Figure 6.20 Examples of tube-drawing operations, with and without an internal mandrel. Note that a variety of diameters and wall thicknesses can be produced from the same initial tube stock (which has been made by other processes).

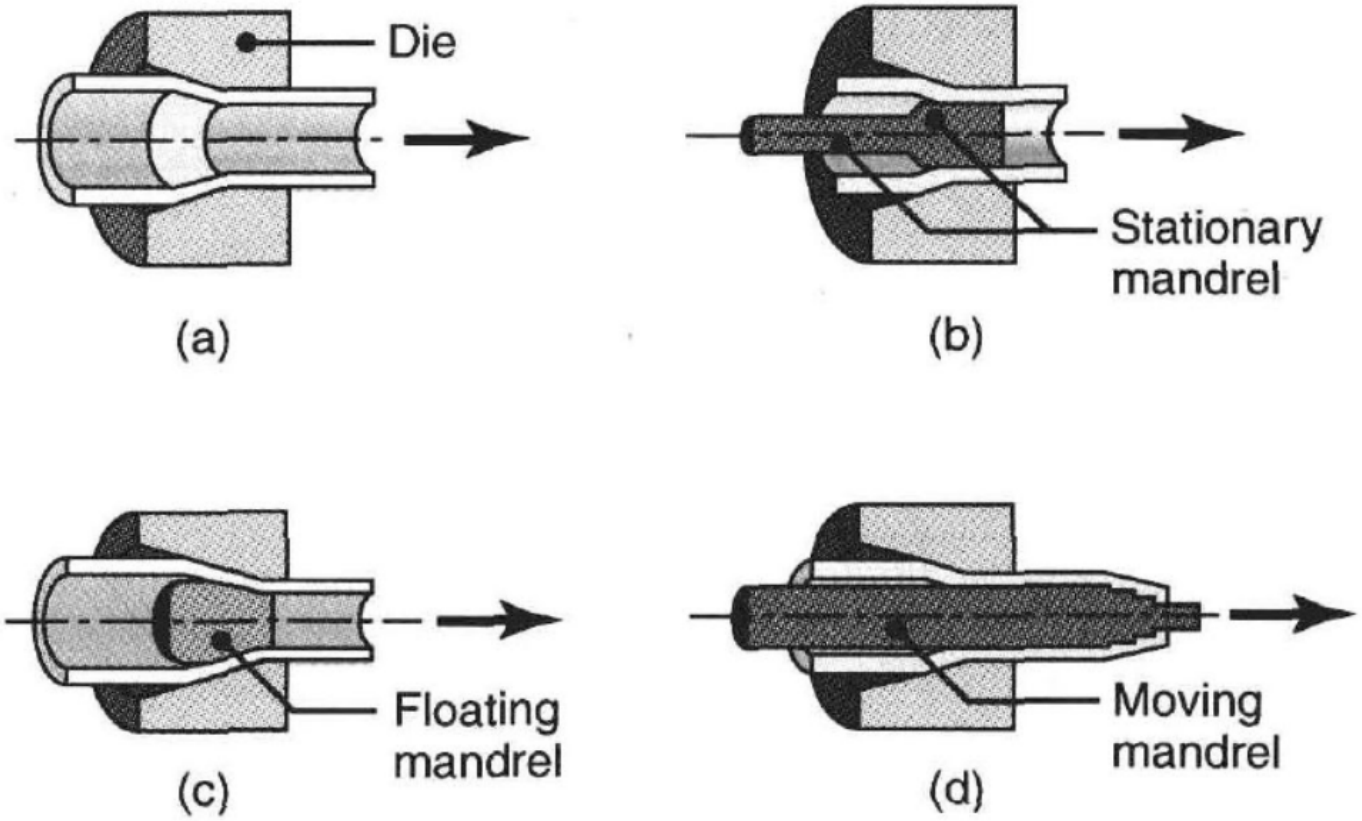
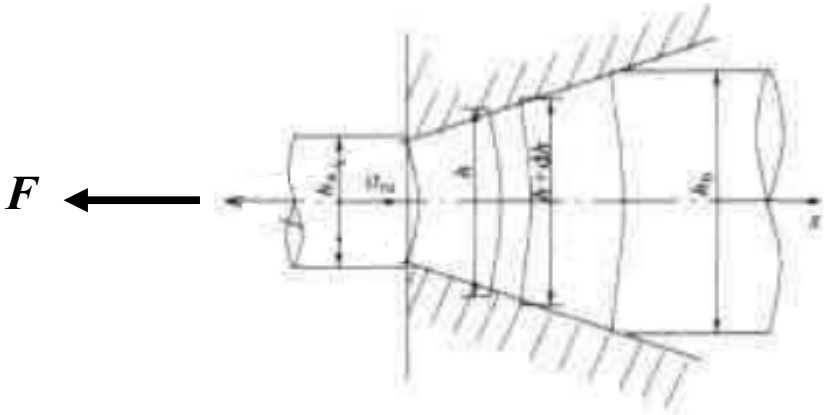


FIGURE 6.20 Examples of tube-drawing operations, with and without an internal mandrel. Note that a variety of diameters and wall thicknesses can be produced from the same initial tube stock (which has been made by other processes).

* Drawing of Other Shapes

- **Drawing flat strips（*拉拔条料*）**
  - **wedge-shaped dies（*楔形模*） are used**
  - **based on the principle of the fundamental deformation mechanism（*变形机理*） in ironing（*变薄拉深*）,used extensively in making aluminium beverage cans**

Chap. 7



* 6.8 Drawing Practice（拉拔应用）

- **Successful drawing requires careful selection of process parameters**
- **ψ (reductions in cross-sectional area) per pass**
  - **range up to about 45%**
  - **usually, the smaller the initial cross-section, the smaller the ψ**
  - **for fine wires: usually 15%~25%；for larger sizes: 20%~25%**
  - **ψ >45% may result in lubricant breakdown（润滑膜破裂）, leading to surface-finish deterioration（退化/恶化）**
  - **a light（轻微的） reduction, called a sizing pass（精整/定径）, may also be taken on rods to improve surface finish and dimensional accuracy.**
  - **Because they basically deform only the surface layers, light reductions usually produce highly nonuniform deformation of the material and its microstructure. Consequently, the properties of the material vary with location within the cross-section.**

* Drawing Practice

- **Drawing Temperature**
  - **mostly done at room temperature**
  - **large solid or hollow sections can be done elevated temperatures in order to reduce forces**
- **Drawing Speeds**
  - **depend on the material and ψ**
  - **for heavy sections（*厚壁型材/大型截面*）: 1m/s~2.5m/s**
  - **for very fine wire: 50m/s**
  - **Because the product does not have sufficient time to dissipate（*消散/散发*） the heat generated, temperatures can rise substantially（*巨大地*） at high drawing speeds and can have detrimental（*有害的/不利的*） effects on product quality.**

* Drawing Practice

- **Intermediate annealing（*中间退火*） between passes may be necessary**
  - **due to work hardening**
  - **to maintain sufficient ductility during cold drawing**
  - **Drawn copper and brass（*黄铜/铜锌合金*）wires are designated（*标示*）by their temper（*回火硬度*）, such as ¼ hard, ½ hard, etc.**
- **High-carbon steel（*高碳钢*）wires for springs and for musical instruments are made by heat treating (patenting)（*铅浴淬火/钢丝韧化处理*）the drawn wire**
  - **The microstructure so obtained is fine pearlite（*细珠光体*）**
  - **These wires have ultimate tensile strength（*极限抗拉强度*）as high as 5GPa and tensile reduction of area（*拉伸断面缩减率*）of about 20%.**

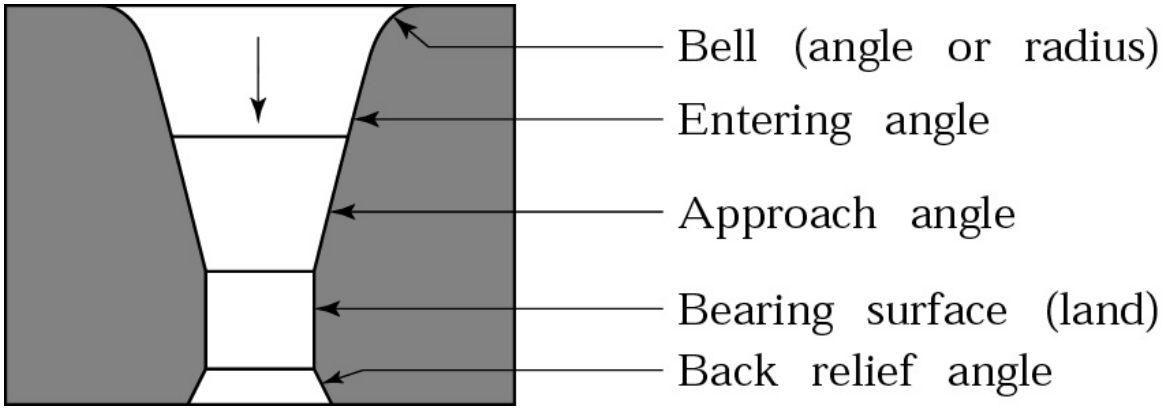
* Bundle Drawing（*捆扎拉拔*）

- **To draw many wires (as many as several thousand) simultaneously（*同时地*） as a bundle**
- **To increase productivity（*生产率*）, especially for very fine wire (as small as 4 μm in diameter)**
- **The wires are separated from one another by a suitable metallic material with similar properties but lower chemical resistance（*耐化学性*）(so that it can subsequently be leached out（*滤出/溶解*）from the drawn wire surface).**
- **Bundling drawing produces wires that are somewhat polygonal（*多边形的*）in cross-section rather than round**

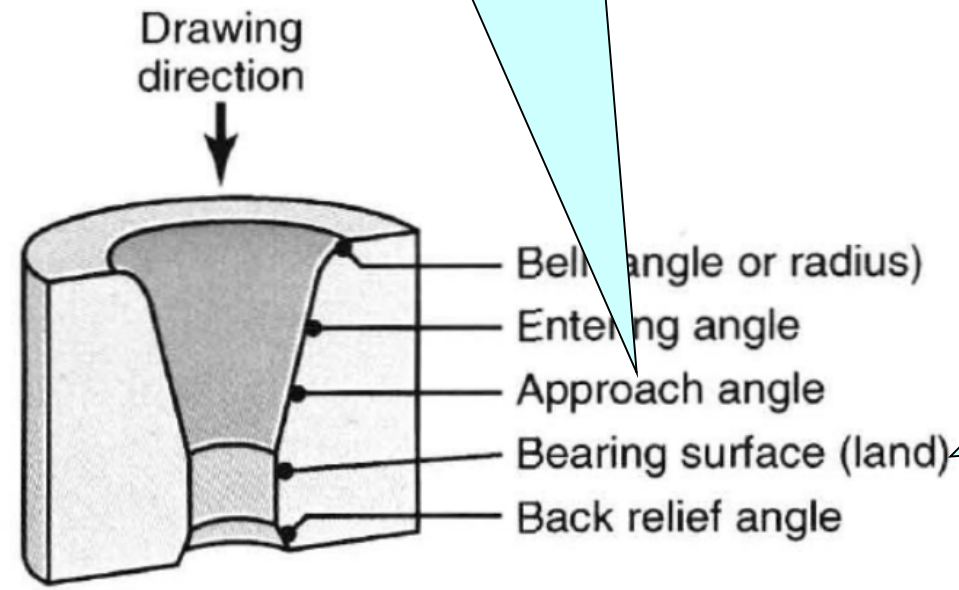
* Bundle Drawing（*捆扎拉拔*）

- **In addition to continuous lengths, techniques have been developed to produce fine wire that is broken into various sizes and shapes.**
- **The wires produced can be as small as 4 μm (0.00016in.) in diameter;**
- **They can be made from such materials as stainless steels, titanium, and high-temperature alloys.**
- **Applications include electrically conductive plastics（*导电塑料*）, heat-resistant and electrically conductive textiles（*耐热及导电纺织品*）, filter media（*过滤介质*）, radar camouflage（*防雷达伪装*）, and medical implants（*医学移植*）.**

Die Design



Die angle：usually 6°~15°



- **land（*定径带/支承面*）：**
  - **to set the final diameter of the product (called sizing);**
  - **to maintain this diameter even with wear on die-workpiece interface**

FIGURE 6.21 Terminology pertaining to a typical die used for drawing a round rod or wire.

Die Insert

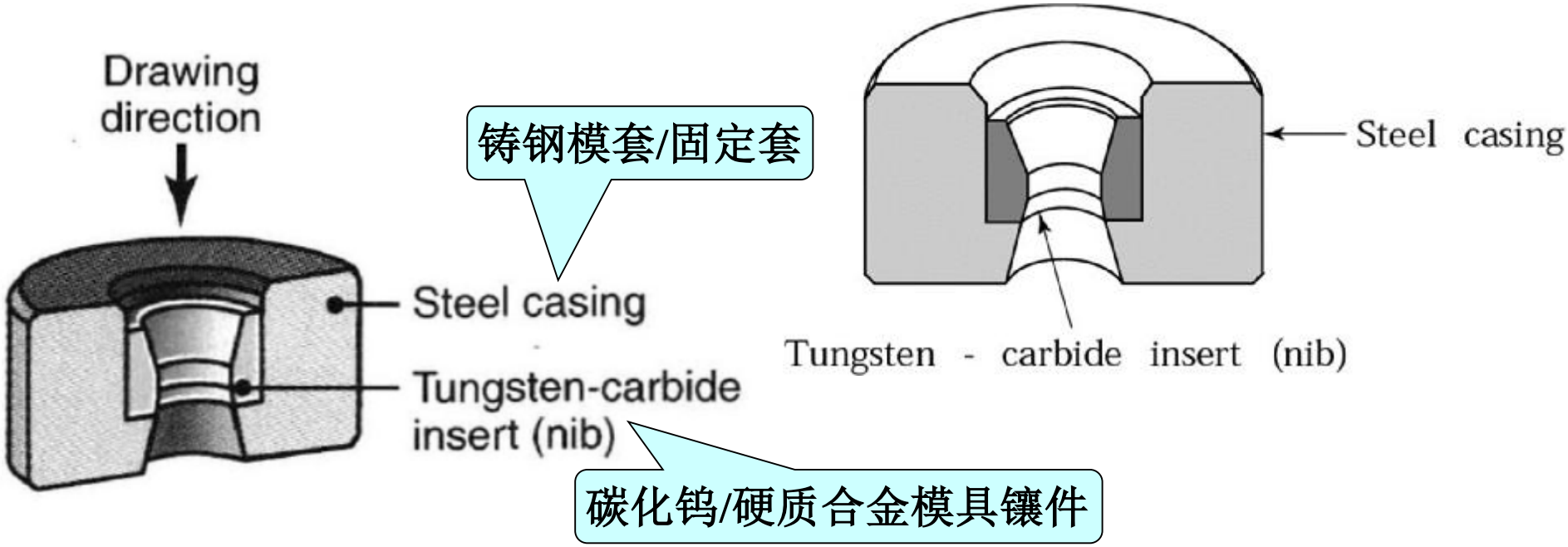


FIGURE 6.22 Tungsten-carbide die insert in a steel casing. Diamond dies used in drawing thin wire are encased in a similar manner.

金刚石拉丝模

硬质合金模——拉制钢丝（钢线）一般采用硬质合金模具(Tungsten carbide nib) 这种模具的典型结构为一个圆柱形（或略带锥度）的硬质合金模芯紧密地镶嵌在一个圆形钢套(case)中，模芯内孔中有喇叭口(Bell radius)、入口锥(Entrance angel)、变形（工作）锥（approach angle)、定径带(bearing)及出口角(back relief)。

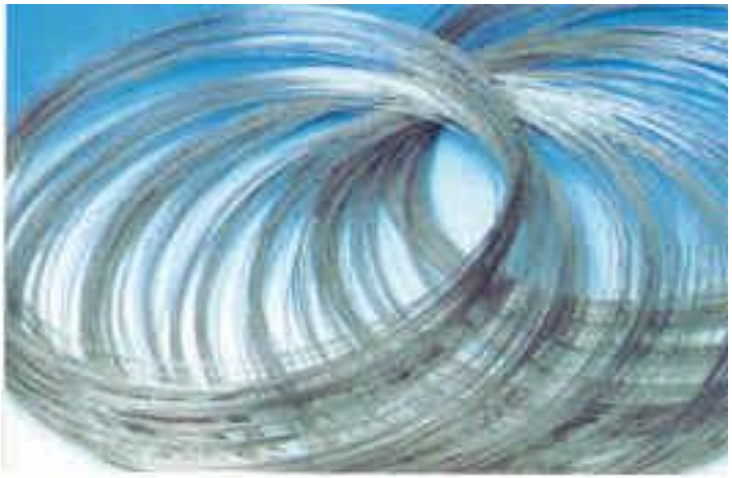
* Die Materials

- **Typically used materials are tool Steels（*工具钢*） and carbides（*硬质合金*）**
- **For Hot drawing, cast-steel（*铸钢*）dies are used because of their high resistance to wear at elevated temperatures（*高温耐磨损性*）.**
- **Diamond dies （*金钢石模*） are used for fine wire with diameters ranging from 2μm to 1.5mm. They may be made from a single-crystal diamond（*单晶金刚石*）or in polycrystalline form（*多晶形式*） with diamond particles in metal matrix（*金属基*）(compacts/*聚晶金刚石复合片*).**
- **Because of their very low tensile strength and toughness, carbide and diamond dies are use as insert（*镶件*） or nibs（*模芯*）, which are supported in a steel casing（*模套*）(Fig.6.22).**
- **For improved wear resistance, steel dies may be chromium plated（*镀铬*）, and carbide dies may be coated with titanium nitride（*渗钛*）.**

* Lubrication

- **Proper lubrication is essential in drawing, in order to improve die life and product surface finish, and to reduce drawing forces and temperature,**
- **Lubrication is critical, particularly in tube drawing, because of the difficulty of maintaining a sufficiently thick lubricant film at the mandrel-tube interface.**
- **In drawing of rod, a common method of lubrication uses phosphate coating（*磷酸盐保护层/磷化膜*）.**

Cold Drawn Rod/Wire/Bar



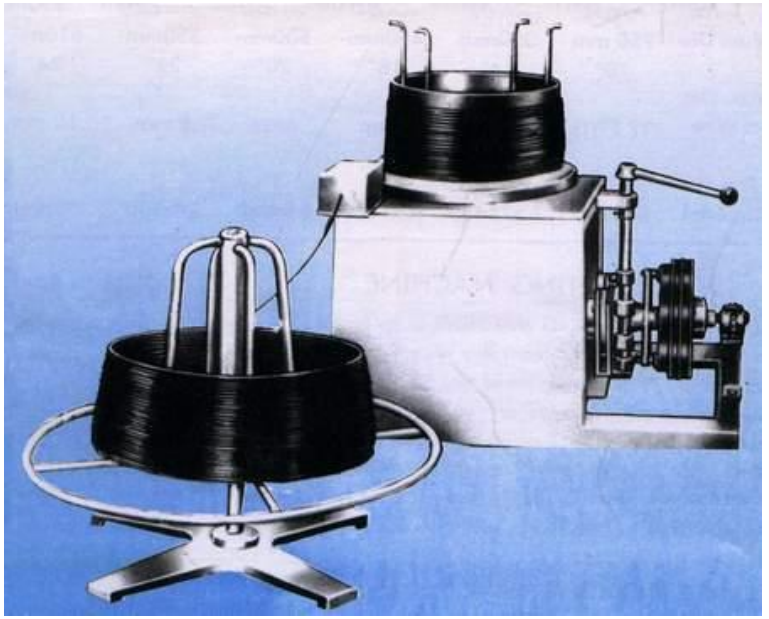
Drawing Dies

6.10 Drawing Equipment（拉拔设备）

- **Basically two types：**

  ø draw bench（拉拔机/冷拔机/拉床）

  ø drum/bull block（拉丝机/卷丝机）



- **Draw bench（*拉拔机/冷拔机/拉床*）**
  - **contains a single die**
  - **similar to a long, horizontal tension-testing machine（*拉伸试验机*）**
  - **pulling force is supplied by a chain drive（*链传动*） or is activated hydraulically（*液压驱动*）**
  - **used for a single-length drawing of straight rods and tubes with diameters larger than 20mm and lengths up to 30m**
  - **machine capacities:**
    - **Ø pulling force: reach 1.3MN**
    - **Ø speed: range to 6 to 60m/min**

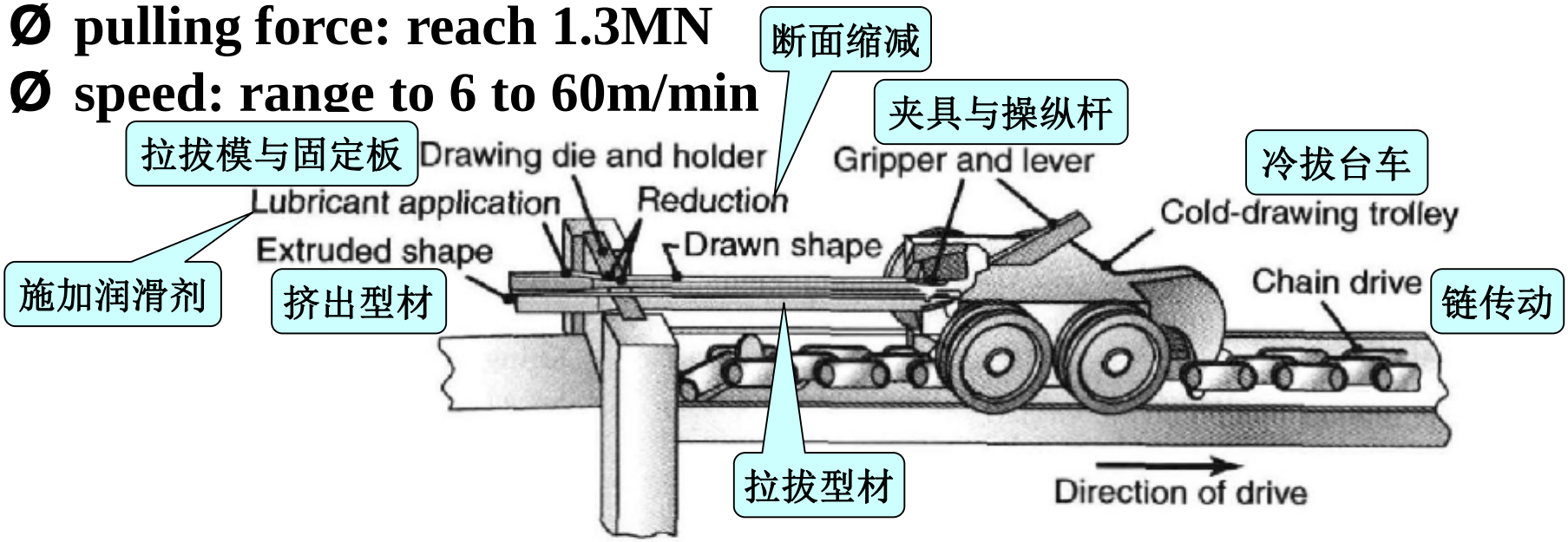
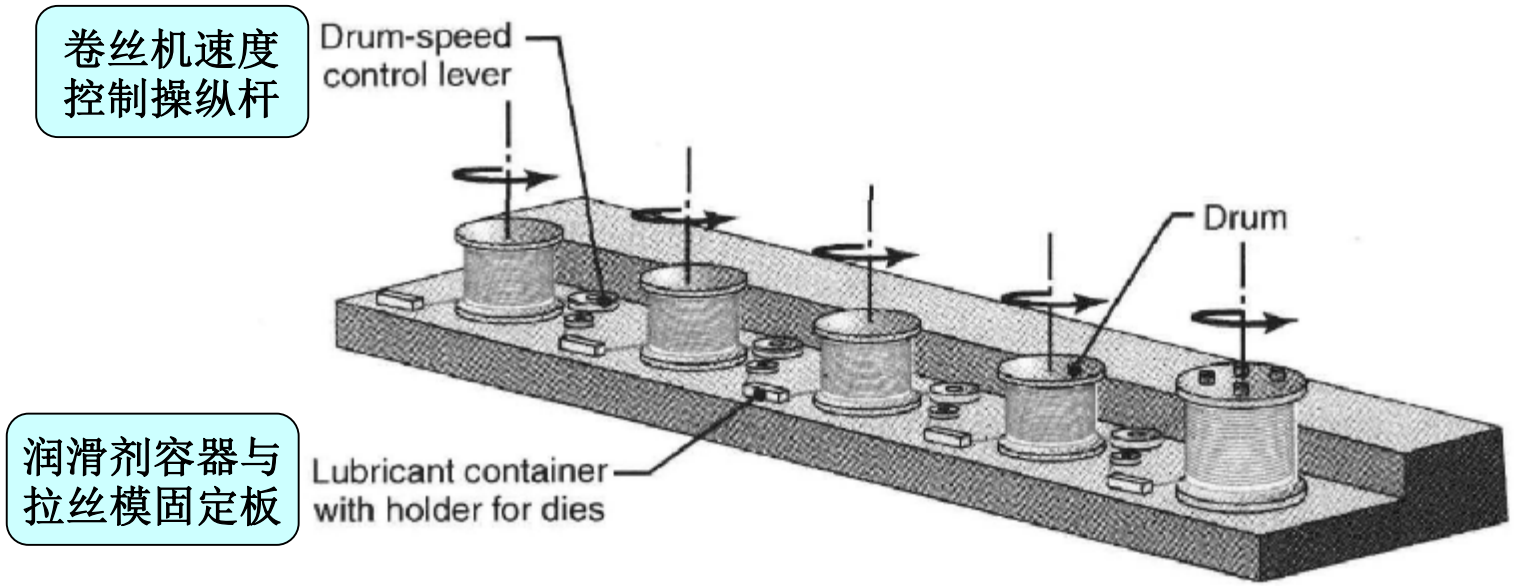


FIGURE 6.23 Cold drawing of an extruded channel on a draw bench to reduce its cross section. Individual lengths of straight rods or of cross sections are drawn by this method.

- **Drum/bull block** ***（拉丝机/卷丝机）***

  – **Very long rods and wire (many kilometers) and wire of smaller cross section, usually less than 13mm, are drawn by a rotating drum（bull block or capstan（*绞盘*））**

  – **The tension in this setup provides the force required for drawing the wire, usually through multiple dies (tandem drawing)** ***（串列式拉拔）***



（多工位线材拉拔）

FIGURE 6.24 An illustration of multistage wire drawing typically used to produce copper wire for electrical wiring. *Source*: After H. Auerswald.

KEY TERMS

- **Bamboo defect** 竹节状缺陷
- **Bridge die** 空心件挤出模, 桥式孔型挤出模
- **Bull block** 拉丝机
- **Bundle drawing** 捆扎拉拔
- **Canning** 外皮包覆，罐装
- **Capstan** 绞盘，卷筒，主动轮
- **Center cracking** 中心开裂
- **Chevron cracking** 人字形裂纹
- **Circumscribing-circle diameter** 外切圆直径
- **Ironing** 挤拉法，变薄拉深，压平
- **Jacketing** 套筒，套式冷却（加温）

- **Cold extrusion** 冷挤压
- **Conversion coating** 转化涂层
- **Dead-metal zone** 金属死区
- **Draw bench** 拉伸（拉拔）机，拉丝机
- **Drawing** 拉拔，拉伸
- **Extrusion** 挤压，挤出
- **Extrusion constant** 挤出常数
- **Extrusion defects** 挤出缺陷
- **Extrusion ratio** 挤出比
- **Fir-free cracking** 冷杉状裂纹
- **Hydrostatic extrusion** 液力静挤压，静水压挤压

- **Patenting** 钢丝韧化处理, (线材的)拉拔(拉丝)后的退火处理
- **Pipe defect** 管缺陷
- **Porthole die** 多孔拉拔（挤压）模
- **Rod** 杆，棒材
- **Seam** 接缝
- **Sejournet process** Sejournet工艺
- **Shear die** 剪切模
- **Sizing pass** 定径工艺
- **Speed cracking** 高速开裂
- **Spider die** 异形孔挤压模
- **Turk’s head** 互成直角的四辊轮拉丝模装置
- **Wire** 丝，线材

Review Questions

1. **What is the extrusion process ?**
2. **What is drawing ?**
3. **What is the distinction between the terms rod and wire ?**
4. **What is the difference between direct extrusion, indirect extrusion, hydrostatic extrusion and lateral extrusion?**
5. **Describe the process variables in extrusion.**
6. **What is CCD ?**

7. What is the shape factor ?

8. What causes the dead zone ?

9. List the reason for using hot process.

10. Describe the advantages of cold extrusion.

11. What's the equipment used in extrusion?

12. What are the major variables in drawing?

13. What are the basic types of drawing equipment?