ME260
Mechanical Engineering Design II

- Instructor notes

Metal Casting Fundamentals

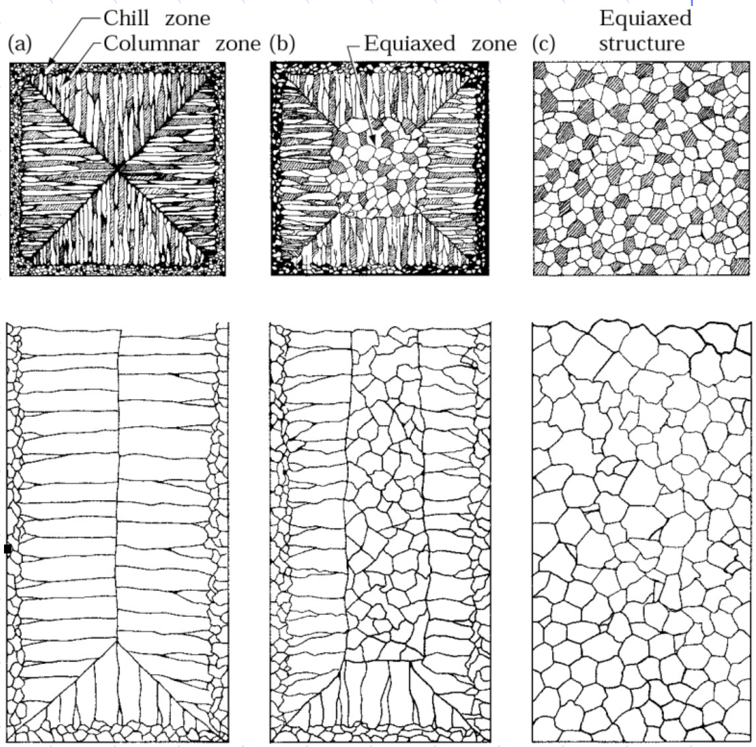
- Definition of casting: pouring material in liquid form into a mold, where the mold has the shape of the part to be manufactured.

- Three steps involved:
  1- pouring of liquid material into mold
  2- allowing it to solidify
  3- removing the part from the mold

Just like
cake making

Metal Casting Fundamentals

- Melting/Solidification temperatures:
  - For a pure metal the melting/freezing temperature is clearly defined
  - For an alloy, solidification begins once temperature drops below T_L (the liquidus) and is complete when temperature reaches T_S (the solidus).
- The structure of the solidified metal/alloy depends on its composition and on the cooling rate.



The important thing to remember is that structure affects the mechanical properties

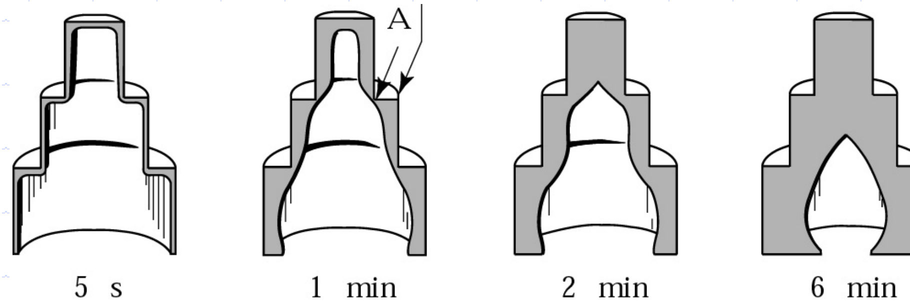
Fluidity of Molten Metal

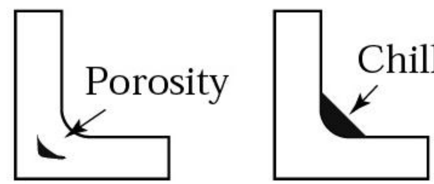
- Viscosity: honey is more viscous than water. ↑ ↓ Fluidity
- Surface tension: higher surface tension is not good for filling in sharp corners. ↑ ↓ Fluidity
- Inclusions: such as dirt/sand in ingots. More inclusions means more viscosity and hence less fluidity ↑ ↓ Fluidity

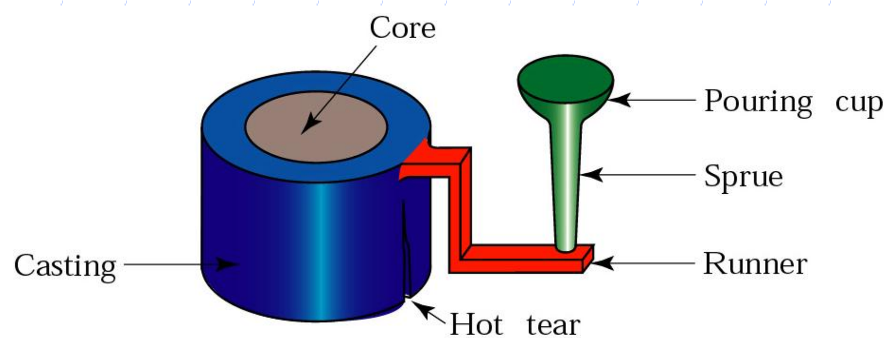
The better the fluidity, the easier it is to cast the metal into the mold

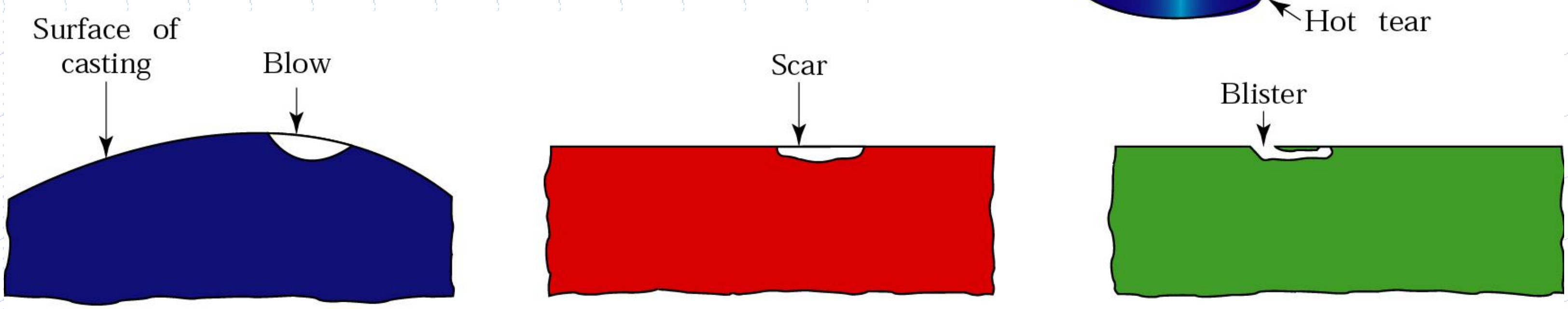
Casting Issues

- Solidification takes time $\propto C\,(\text{Volume/Surface area})^2$. C is a constant that depends on the mold and metal materials as well as temperature.
- Shrinkage: happens with cooling.
- Defects: surface discontinuities, cracking, and porosity (from shrinkage, gasses or both)









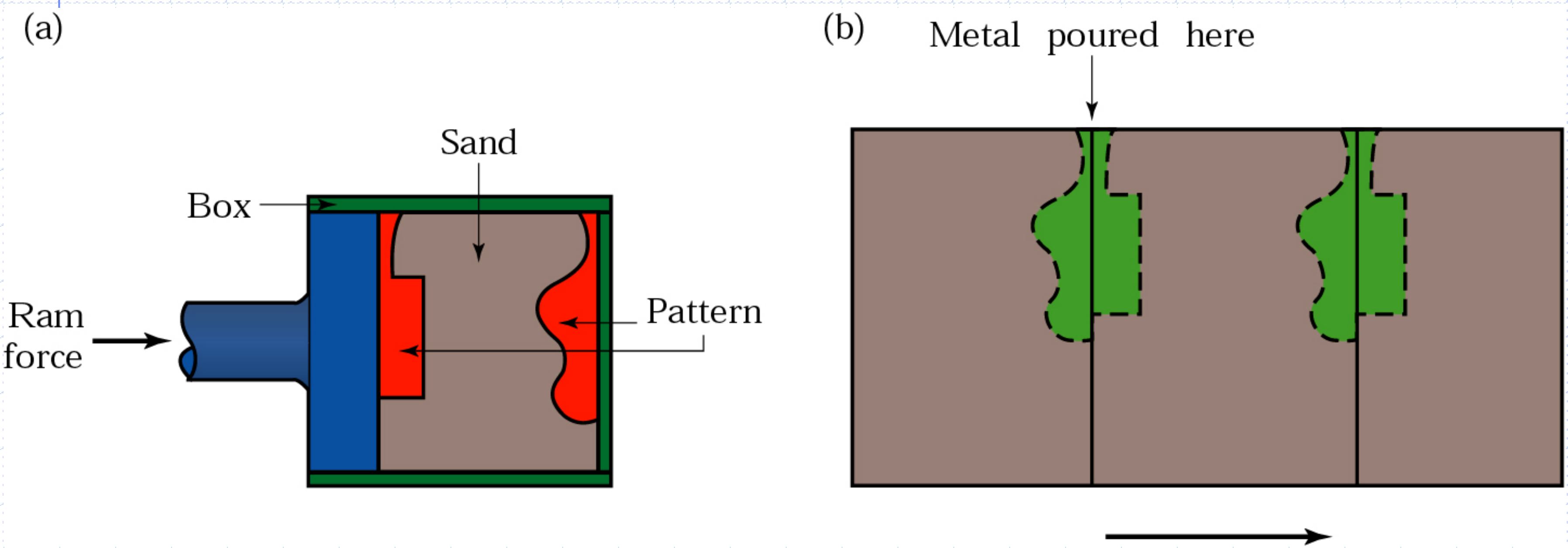
Classification of Casting Practices

- Expendable-Mold Casting Processes (sand casting, shell mold, plaster mold, ceramic mold, evaporative pattern, investment casting). → The mold is sacrificed/broken after every use

- Permanent-Mold Casting Processes. → The mold has repeated uses

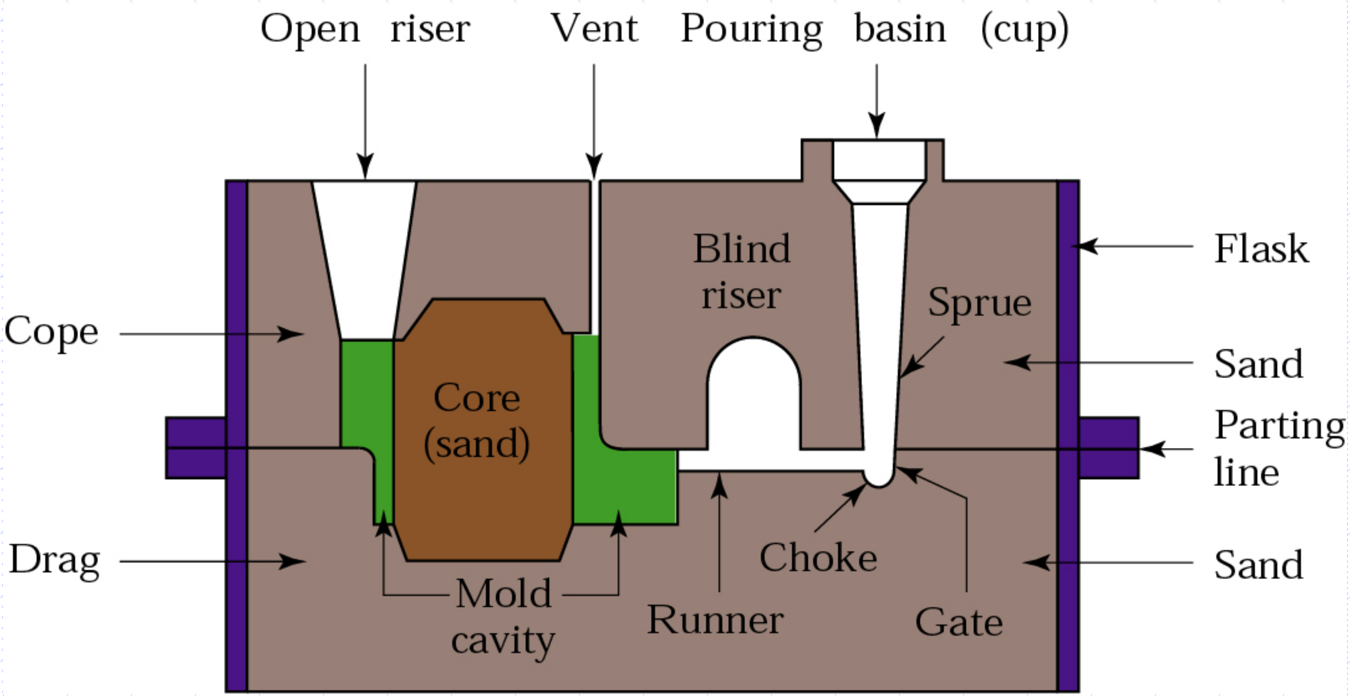
Sand Casting

- Need two carved halves that are mated together.
- Refractory, meaning it can withstand high temperatures of molten metal.



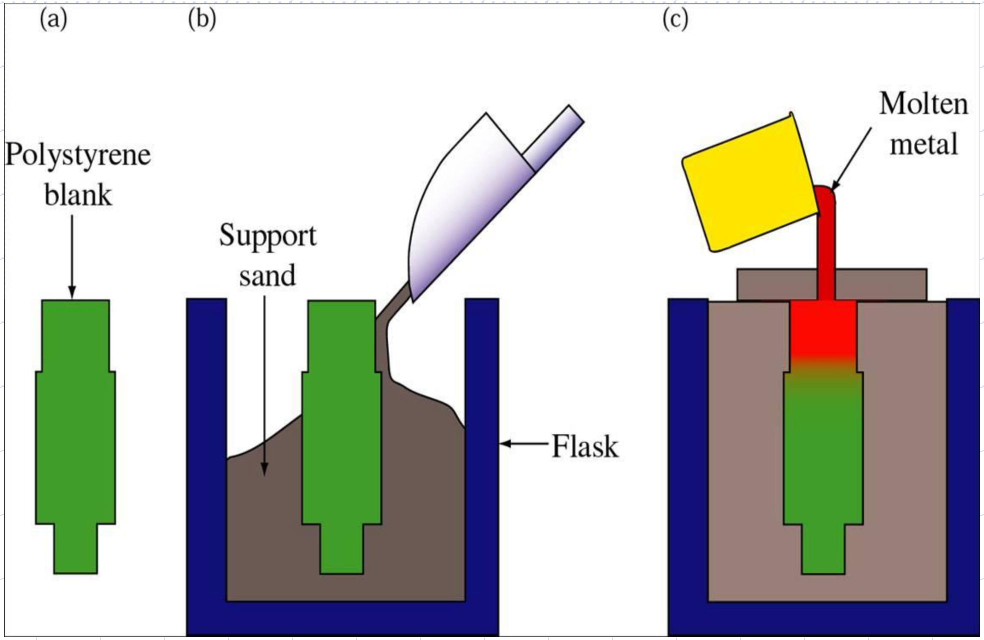
Sand Mold Design

- Sprue to pour in the metal
- Vents to get rid of gasses.
- Risers to compensate for metal shrinkage during cooling.
- Cores to create cavities in a part



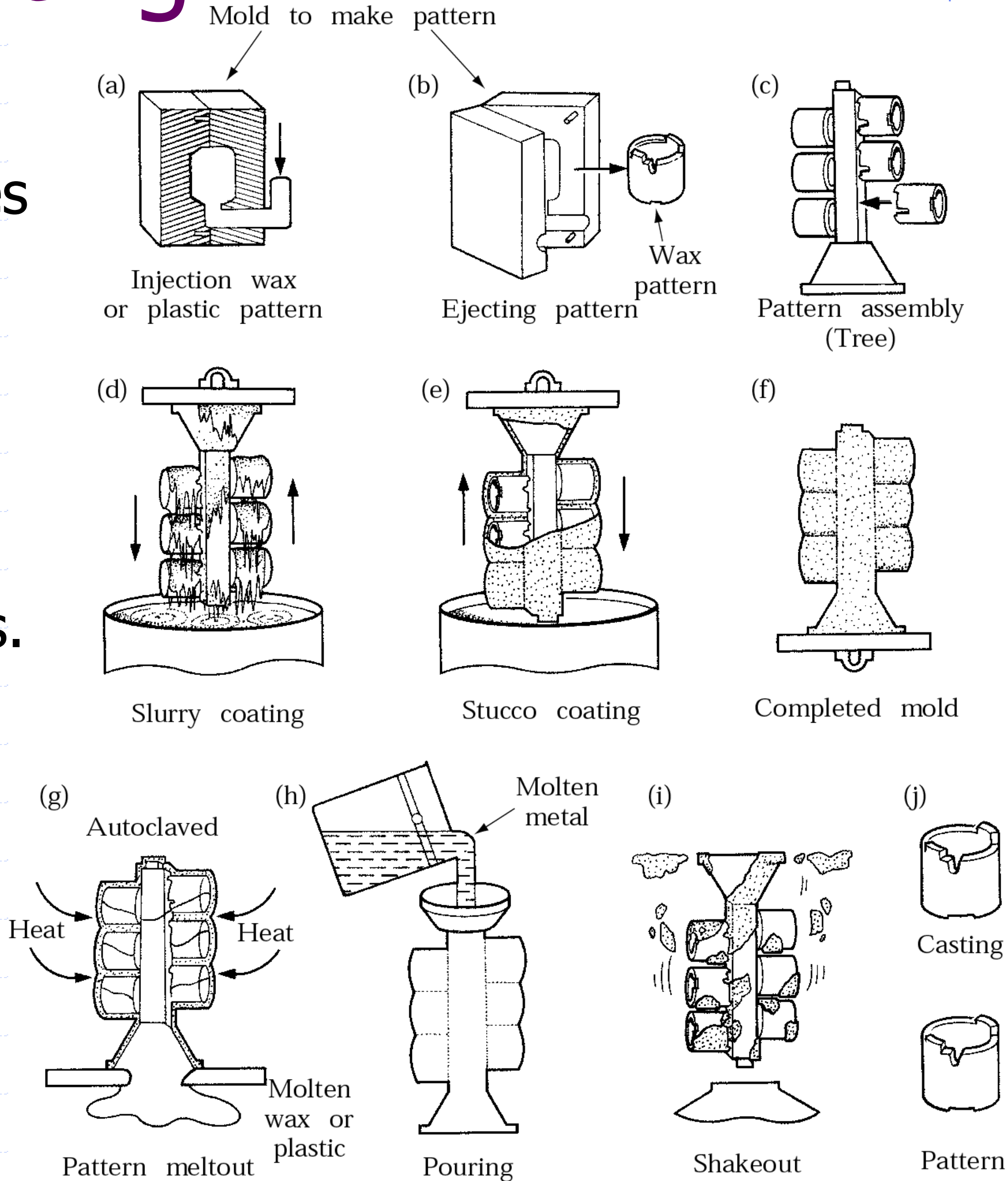
Evaporative-Pattern Casting (lost-foam process)

- Plastic is sacrificed.
- The pattern takes the shape of the final product. Need to replace every time.
- Can make complex shapes/details.



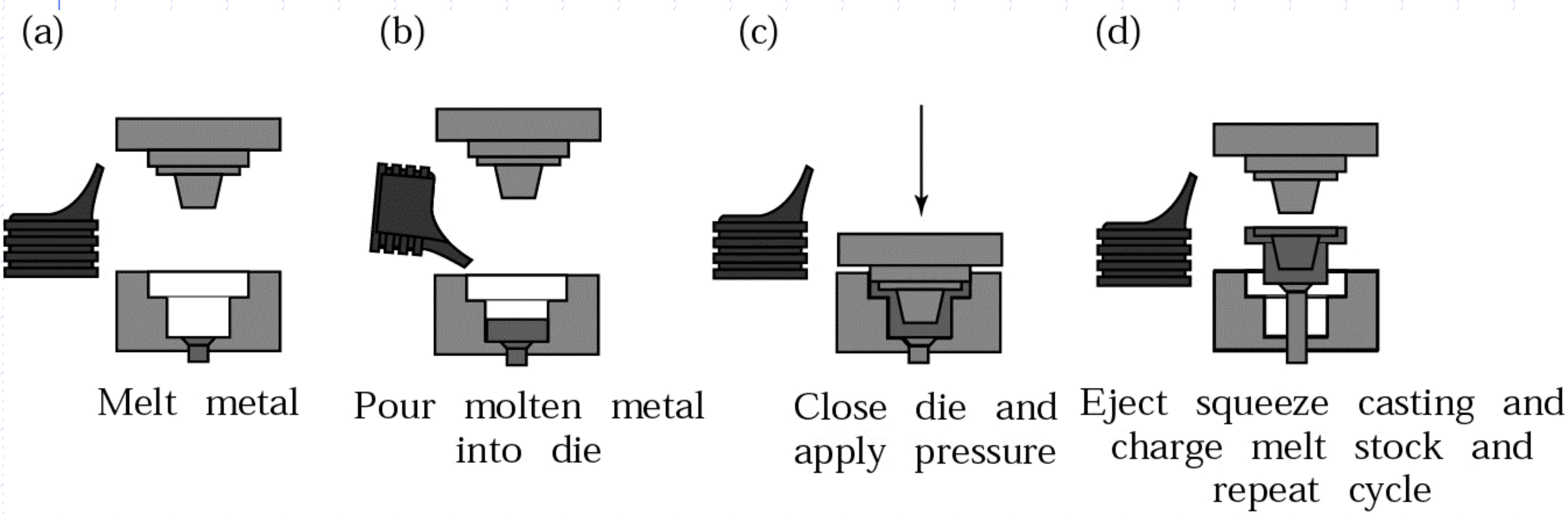
Investment Casting

- Can make multiple pieces simultaneously.
- Can produce good surface finish, close dimensional tolerances, and work for casting high-melting-point alloys.



Example of Permanent-Mold Casting

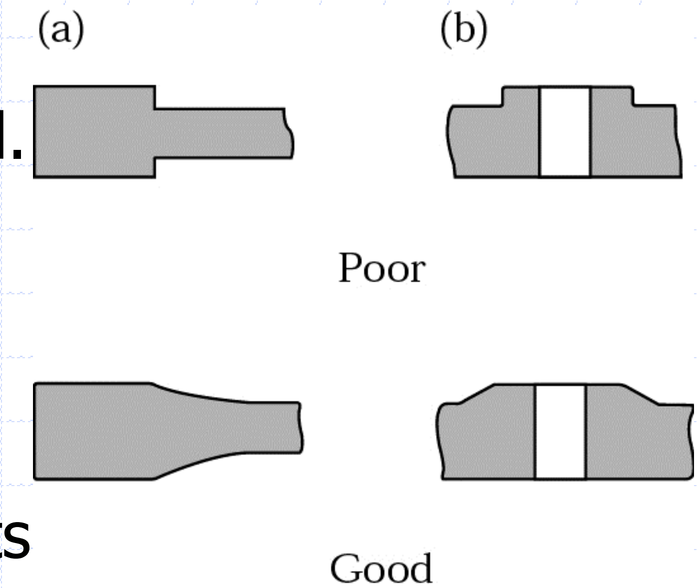
- Squeeze-casting.



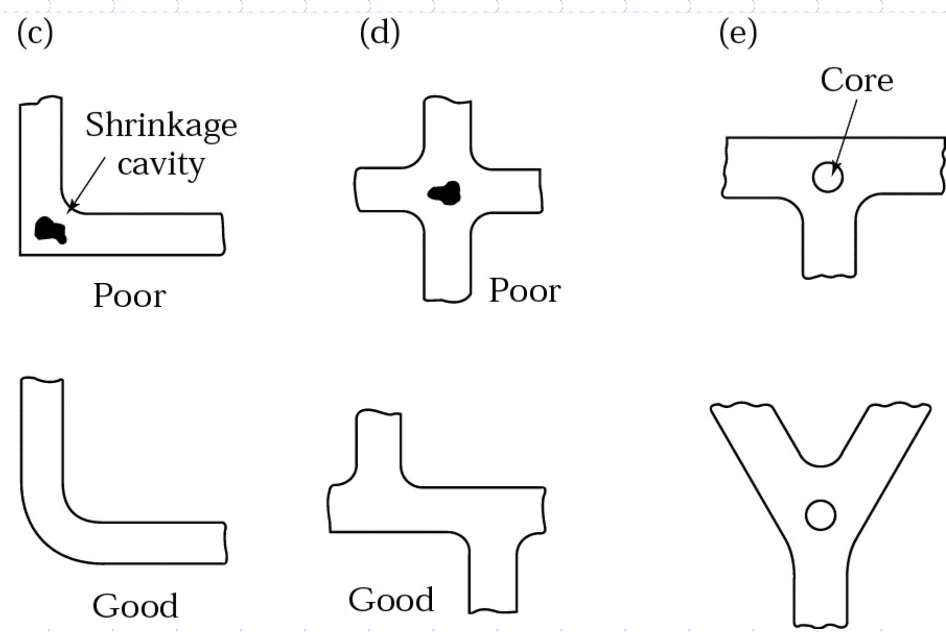
- In Permanent-Mold Casting, the mold material is resistant to erosion and thermal fatigue (examples: cast iron, steel, bronze, graphite or refractory metal alloys).

Design Considerations in Casting

- Sharp corners are not recommended.



- Avoid, as much as possible, hot spots and try to maintain uniform thickness.



Castability Tables

- Castability Tables to choose a casting material.

Type of alloy	Application	Castability*	Weldability*	Machinability*
Aluminum	Pistons, clutch housings, intake manifolds	E	F	G–E
Copper	Pumps, valves, gear blanks, marine propellers	F–G	F	F–G
Ductile iron	Crankshafts, heavy-duty gears	G	D	G
Gray iron	Engine blocks, gears, brake disks and drums, machine bases	E	D	G
Magnesium	Crankcase, transmission housings	G–E	G	E
Malleable iron	Farm and construction machinery, heavy-duty bearings, railroad rolling stock	G	D	G
Nickel	Gas turbine blades, pump and valve components for chemical plants	F	F	F
Steel (carbon and low alloy)	Die blocks, heavy-duty gear blanks, aircraft undercarriage members, rail-road wheels	F	E	F
Steel (high alloy)	Gas turbine housings, pump and valve components, rock crusher jaws	F	E	F
White iron	Mill liners, shot blasting nozzles, railroad brake shoes, crushers and pulverizers	G	VP	VP
Zinc	Door handles, radiator grills,	E	D	E

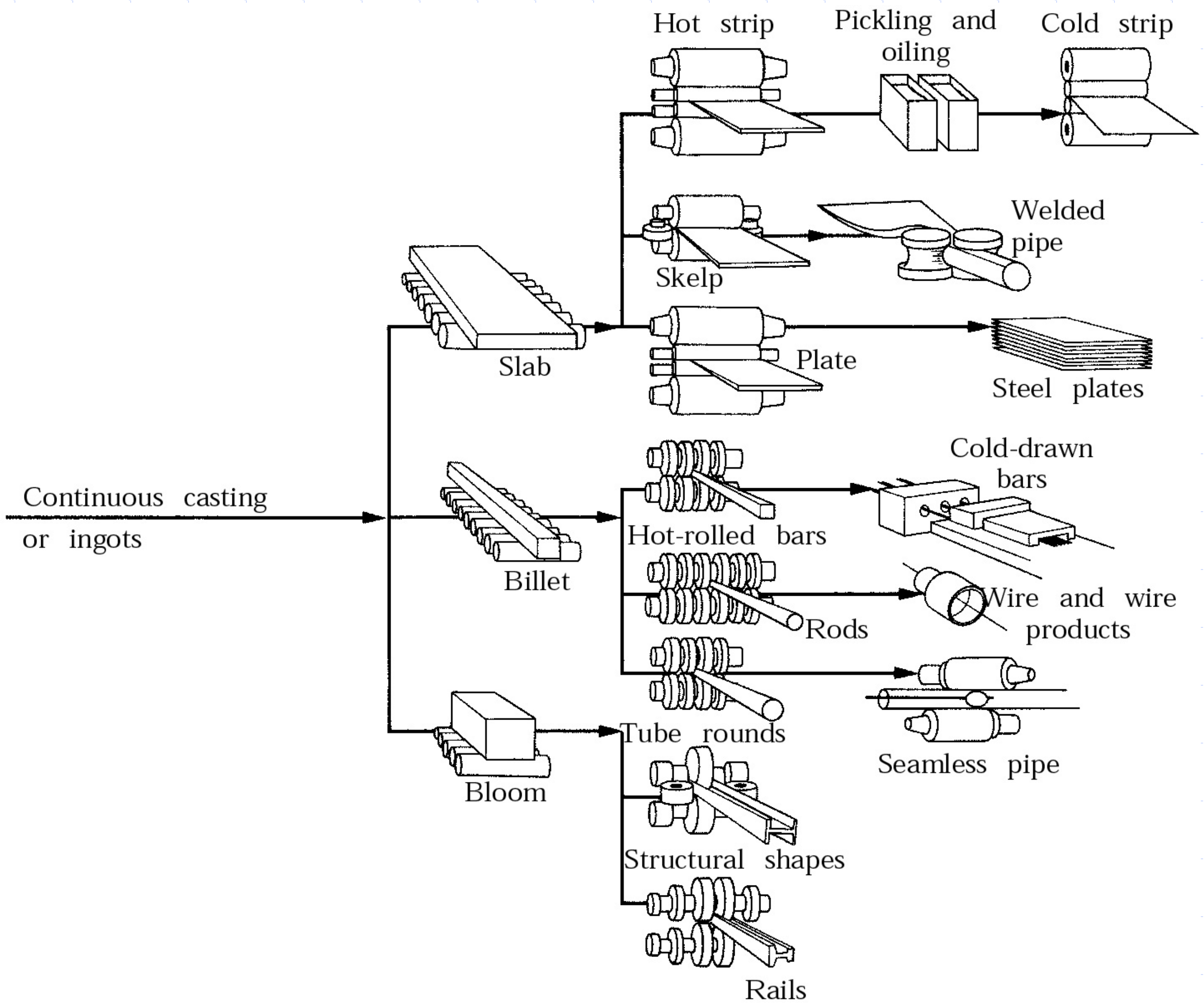
*E, excellent; G, good; F, fair; VP, very poor; D, difficult.

Forming and Shaping Processes/Equipment

- Casting.
- Rolling (metals)
- Forging (metals)
- Extrusion and Drawing (metals)
- Sheet-metal Forming
- Metal-Powder Processing
- Glass and Ceramic Processing
- Forming and Shaping Plastics/Composites
- Rapid Prototyping
- Machining Operations

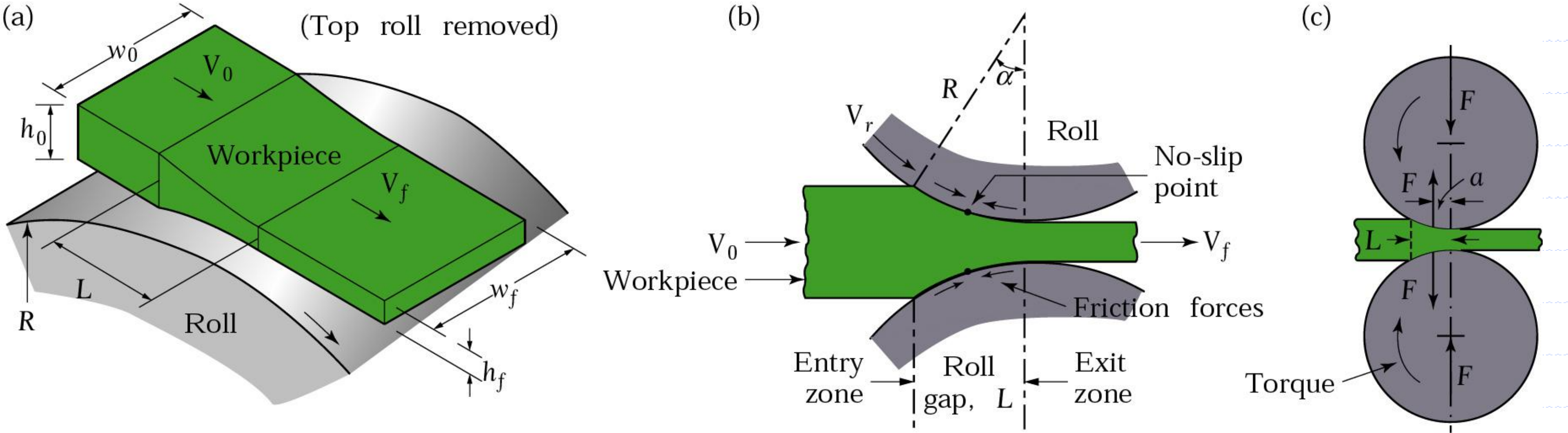
Rolling of Metals

- Similar to rolling dough in cooking or asphalt in street paving.



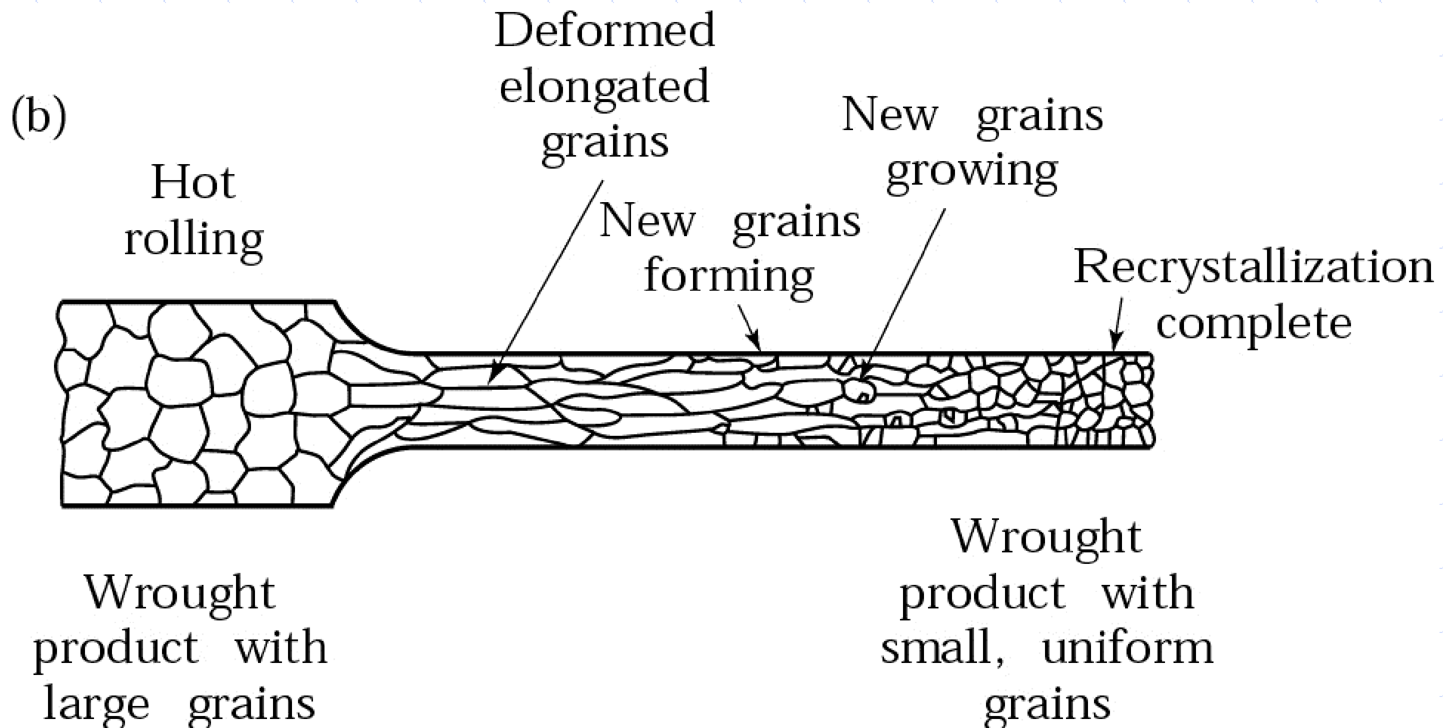
Roll or Rolling Force, F

- Needed to produce reduction in thickness.
- Can be reduced by:
  - reducing friction (e.g. using lubrication)
  - taking smaller reductions-per-pass to reduce the contact area
  - rolling at elevated temperatures to lower the strength of the material
  - applying tension to the strip



More on Rolling

- Flat-Rolling produces elongated grain structure immediately after a pass. Hot rolling can transform these elongated grains into finer, more equiaxed grain structure (good for material strength).

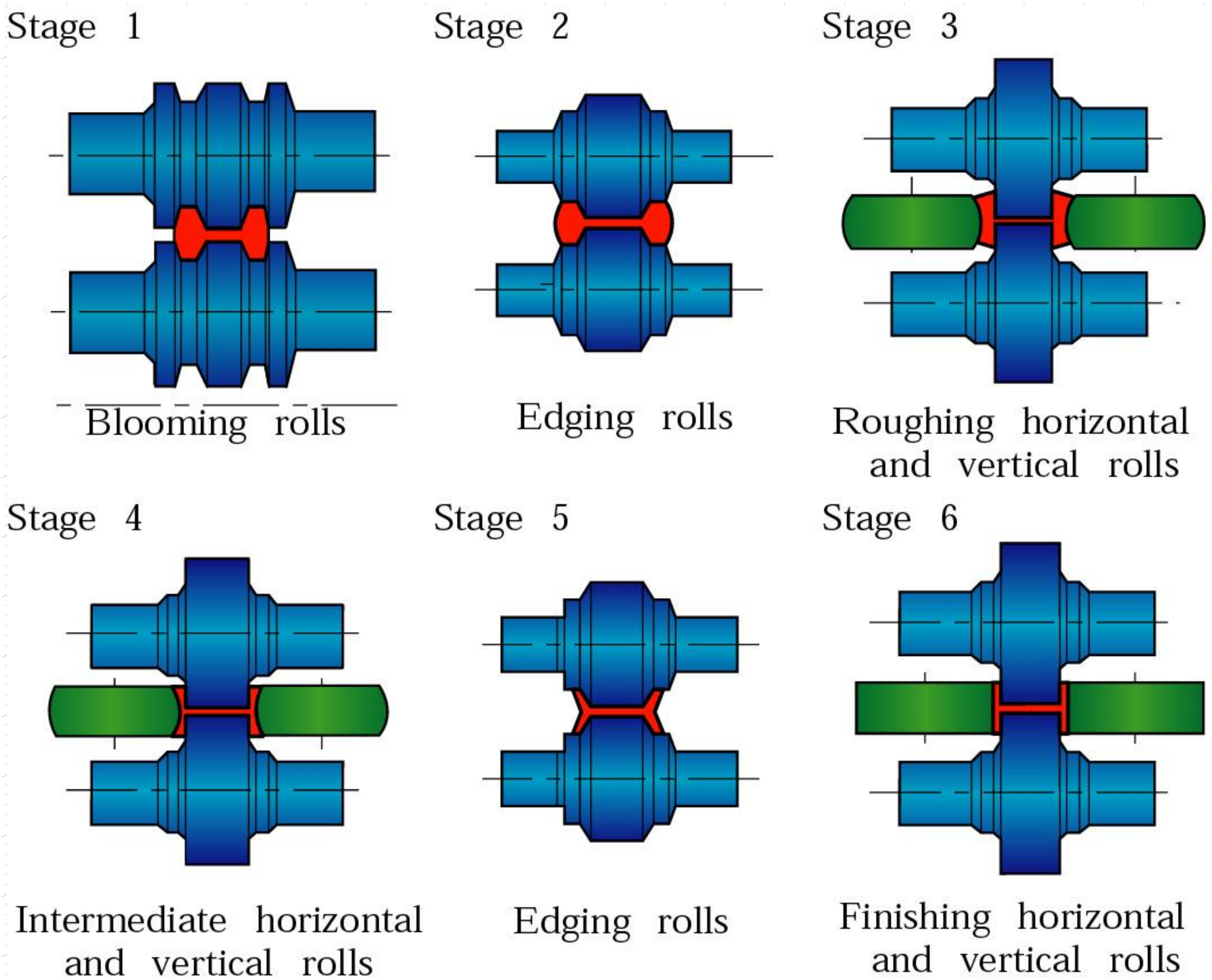


More on Rolling

- Two types of flat-rolling:
  - Hot rolling
  (Done at temperatures above the recrystallization temperature of the metal, e.g. 450^{o}C for aluminum alloys, enhances ductility with fine grains)
  - Cold rolling
  (Done at room temperature, produces better surface finish, i.e. no scale, better dimensional tolerances, and stronger product, i.e. due to strain hardening)
- Roll material needs to be strong and resistant to wear

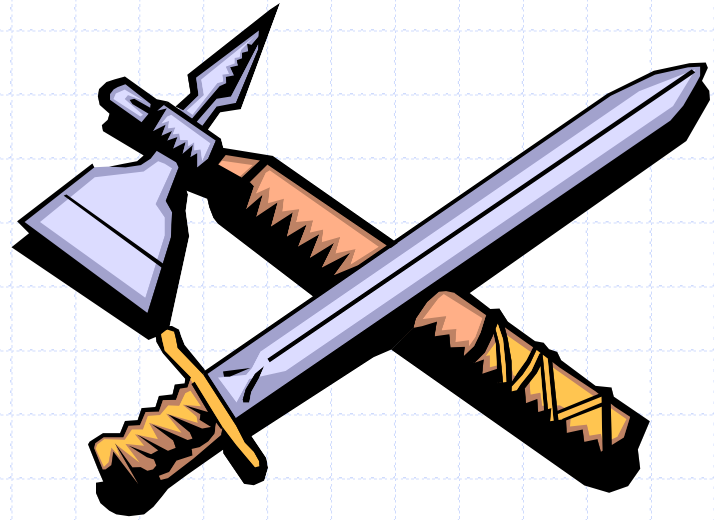
Example of Rolling Operations

- Shape or Profile Rolling
  e.g. to produce an I-beam



Forging of Metals

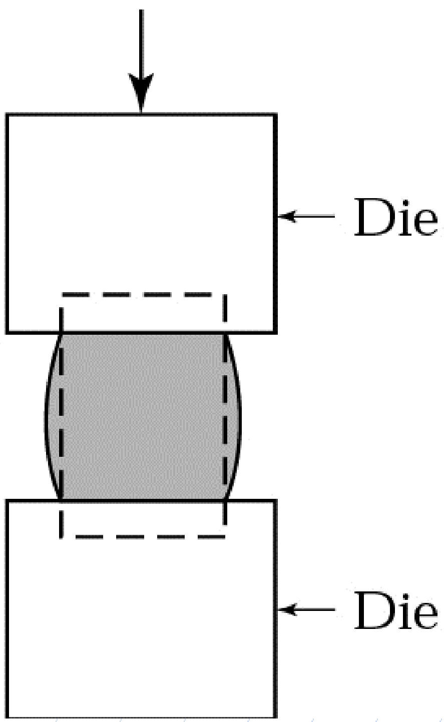
- Shaping a workpiece through compressio forces, or hammering, with the aid of dies and various tools.
- Old method to make coins, jewelry and swords.

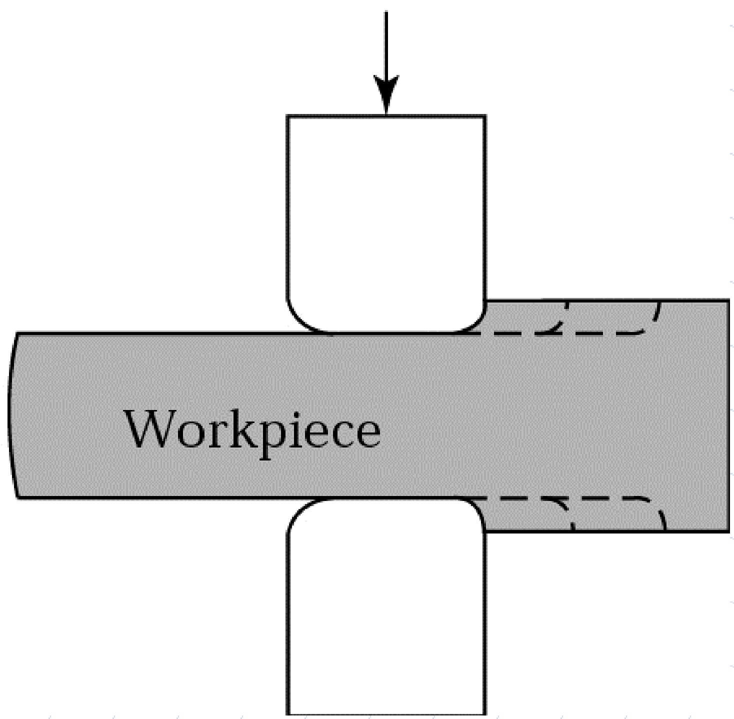


Types of Forging Operations

- Open-Die Forging
- Closed-Die Forging

Examples of Open-Die Forging

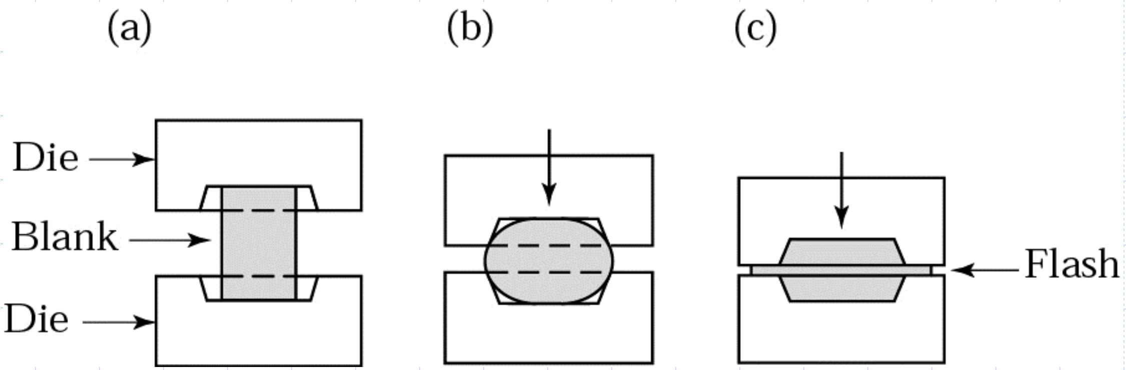




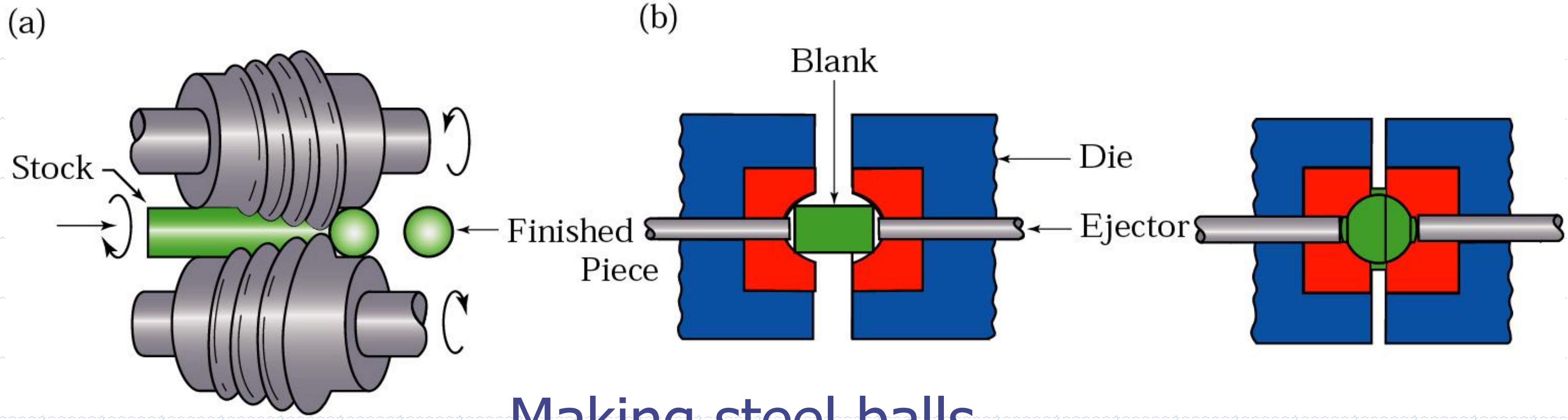
Types of Forging Operations

- Open-Die Forging
- Closed-Die Forging

Examples of Closed-Die Forging: Note flash formation



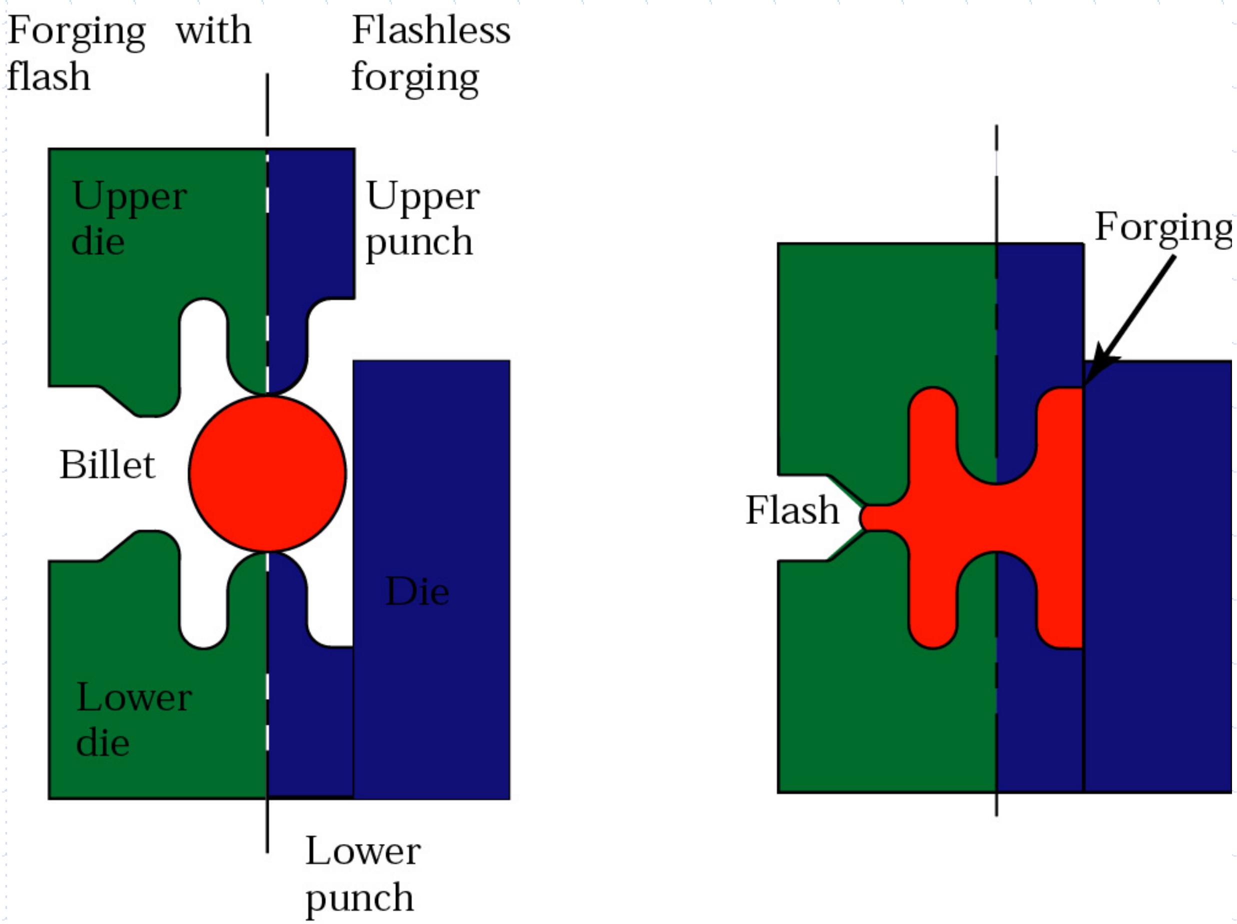
Flash needs to be removed as a finishing operation



Making steel balls

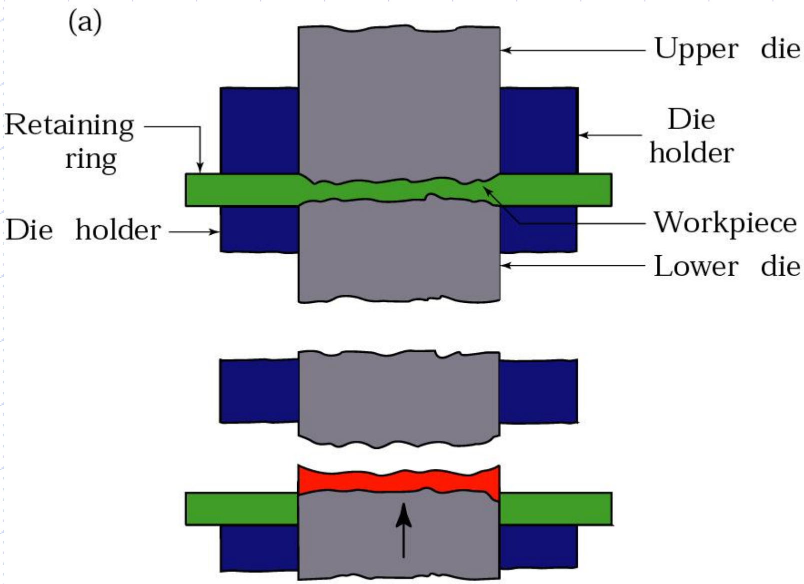
Flashless or Precision Forging

- Be inventive in the die design

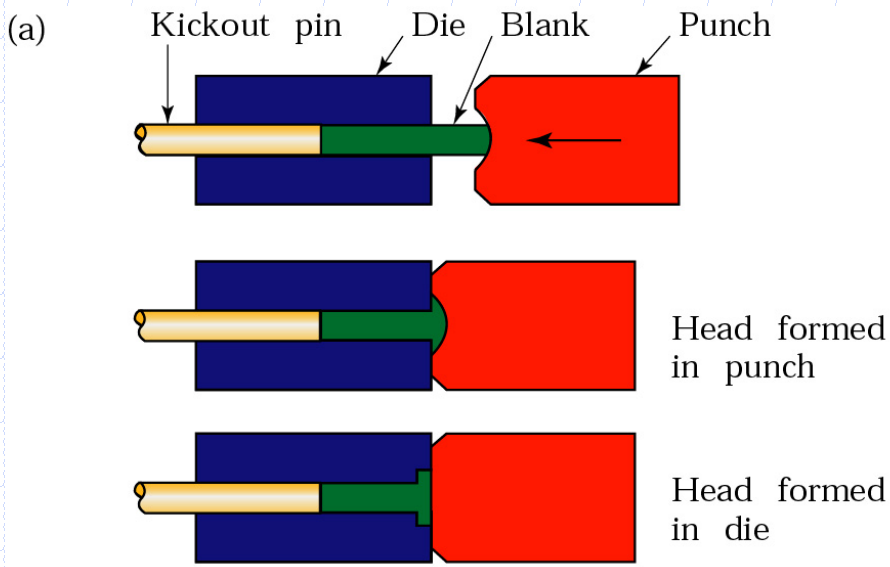


(a) Start of stroke (b) End of stroke

Examples of Forging Operations



Coining



Heading,
for nail/rivet heads

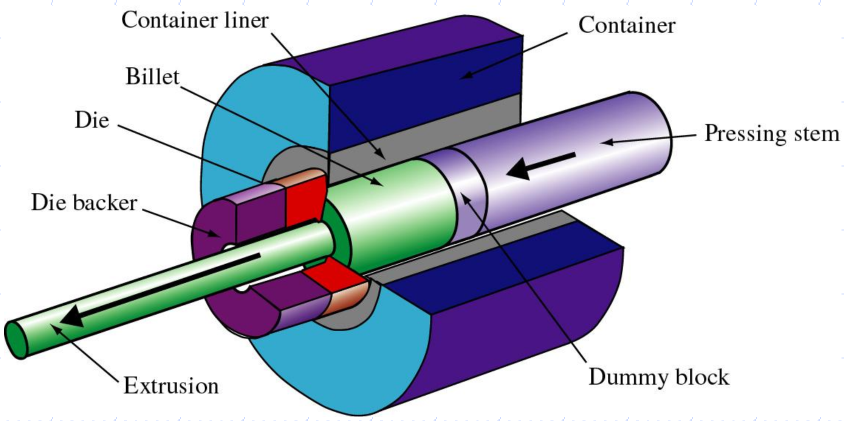
Requirements for Die Material

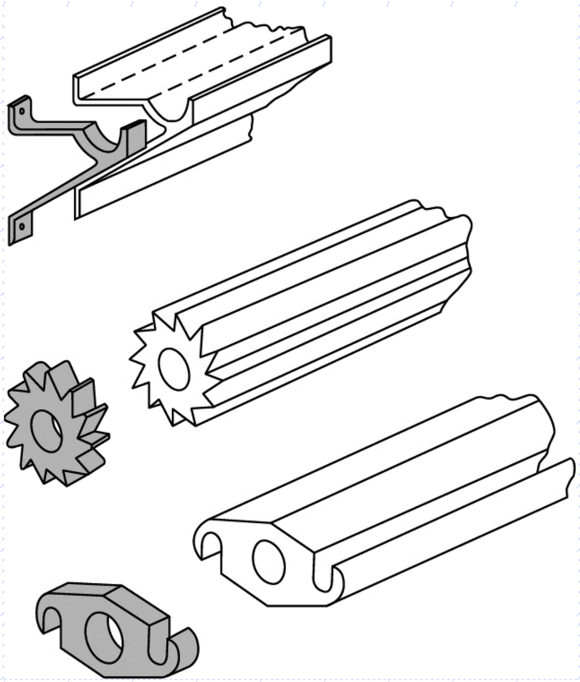
- Strength at elevated temperatures
- Toughness at elevated temperatures
- Wear resistance

Examples of such materials are tool and die steels containing chromium, nickel, molybdenum and vanadium

Extrusion and Drawing of Metals

- Extrusion: *pushing* a metal through a die by force. The metal takes on the cross-sectional shape of the die
- Drawing: *pulling* a metal through a die by force. The metal takes on the cross-sectional shape of the die





Extrusion and Drawing of Metals

- Two types of Extrusion/Drawing:
  - Hot Extrusion/Drawing
  - Cold Extrusion/Drawing (room temperature)
- Extrusion/Drawing force can be reduced by using:
  - Lubricants (less friction)
  - Less extrusion/drawing ratio (A_o/A)
  - Higher temperatures
  - Lesser strong material to be extruded/drawn
- Die material should be strong and resistant to wear

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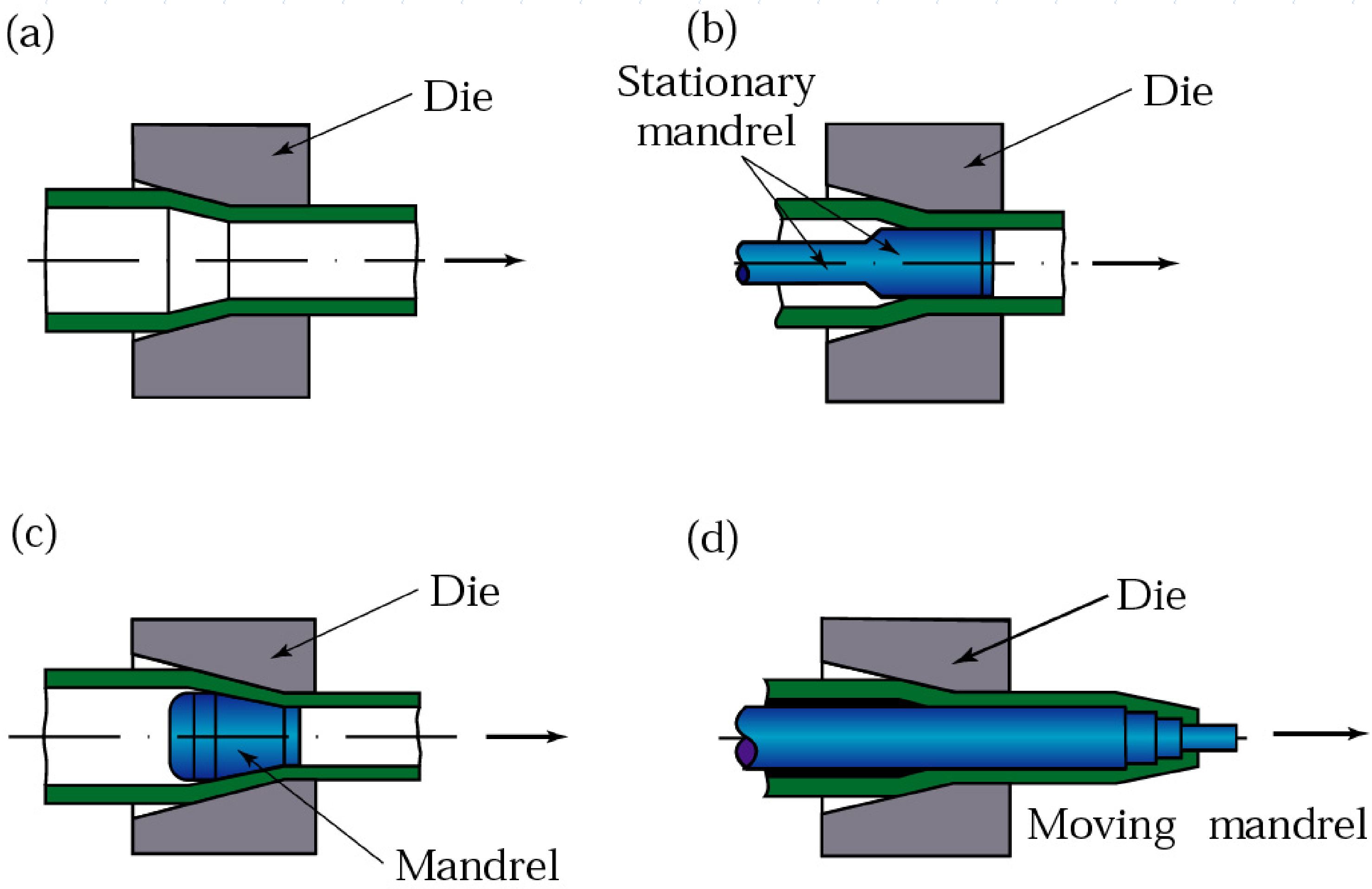
  - Less extrusion/drawing ratio (A_o/A)
  - Higher temperatures
  - Lesser strong material to be extruded/drawn
- Die material should be strong and resistant to wear
- Surface cracking are some of the defects observed

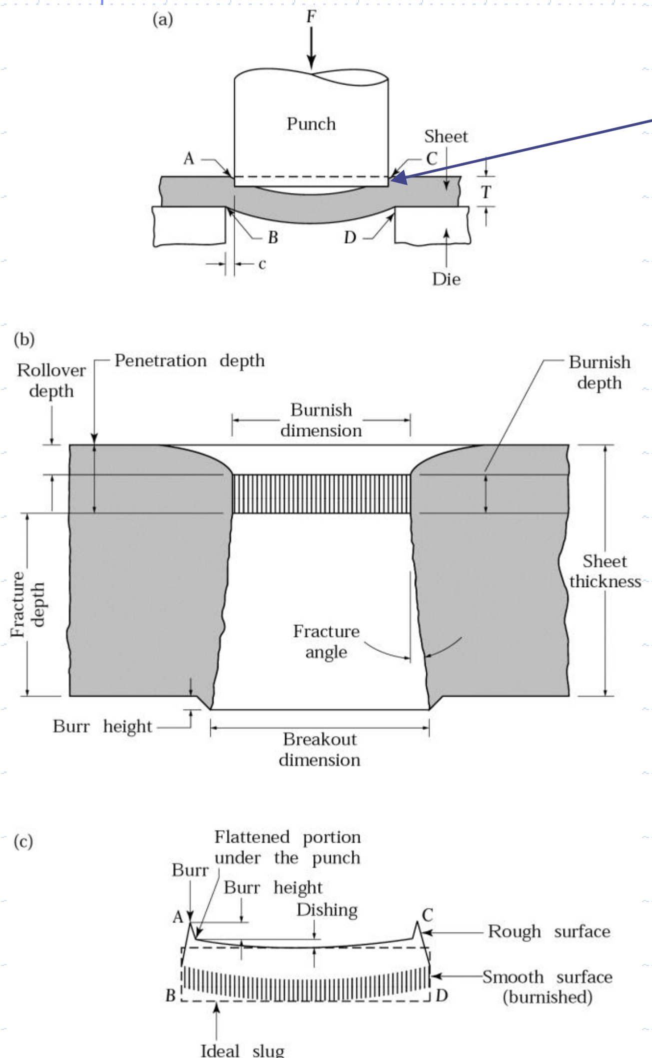
Examples of Drawing Operations

- Tube-drawing operations

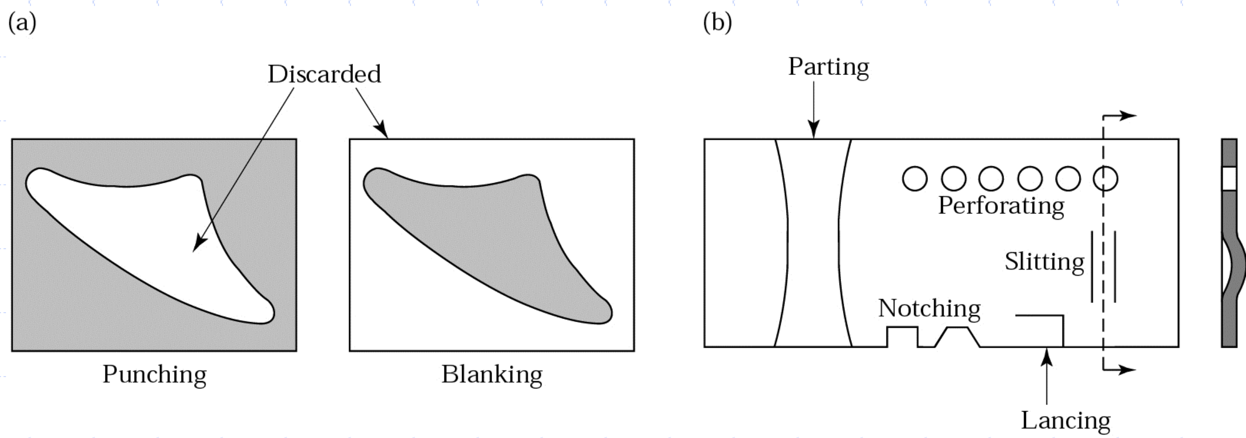


Sheet-Metal Forming/Working

- Any operations of thin/thick sheet metals to form them, i.e. change their shape and/or geometry
- Common operations are slitting (with scissors or snips) and punching (with a puncher)



Also called Shearing

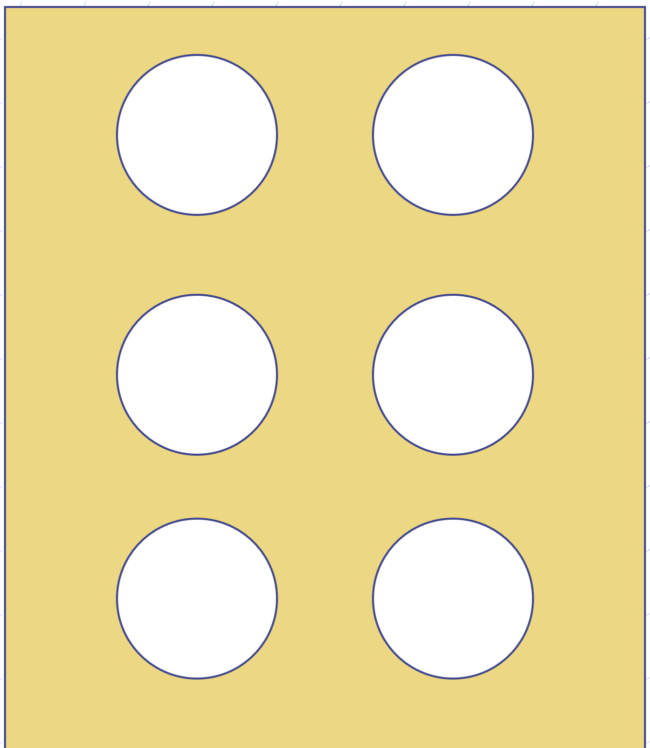


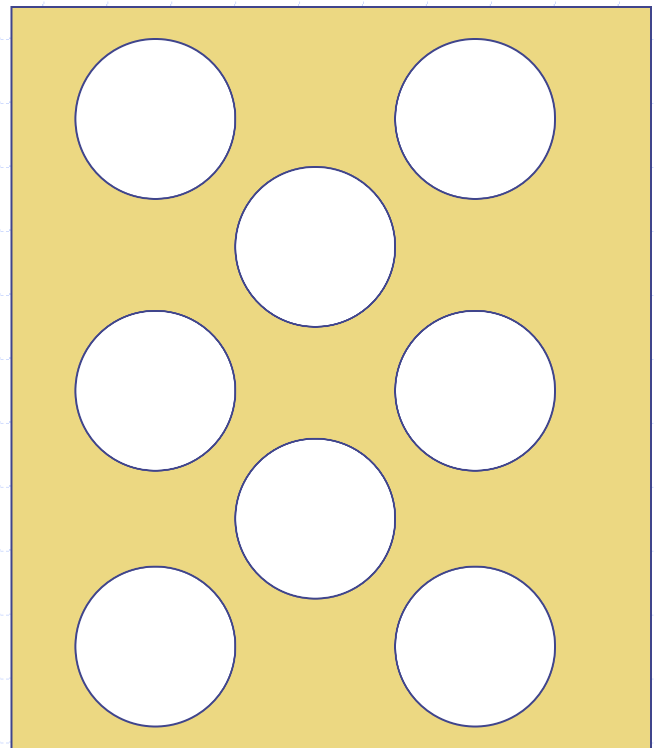
This is similar to cutting cardboard

More on Sheet-Metal Forming/Working

- Maximum punch force: $F = 0.7TL(UTS)$
  , where T is the sheet thickness, L is the total length sheared (such as the perimeter of a hole), and UTS is the ultimate tensile strength of the material sheared
- Die material need to be hard and strong, and wear resistant. Lubrication helps prolong the life of the tool or die
- In shearing, it is important to reduce scrap or wasted material. See example below

OK

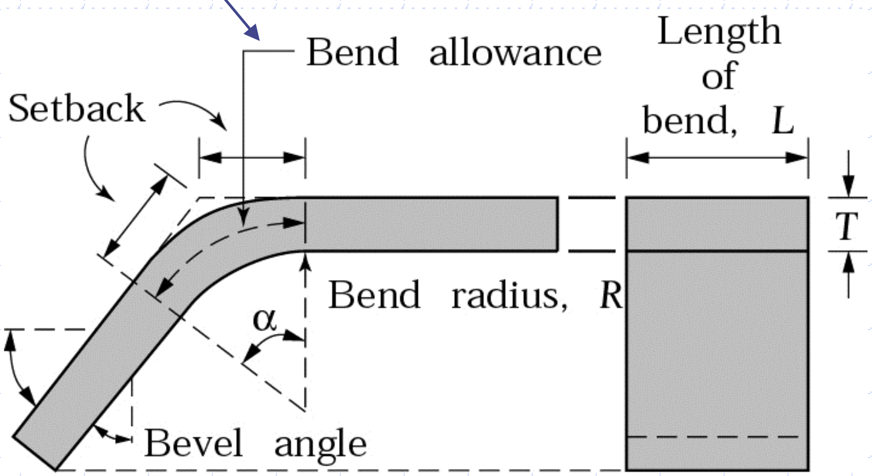


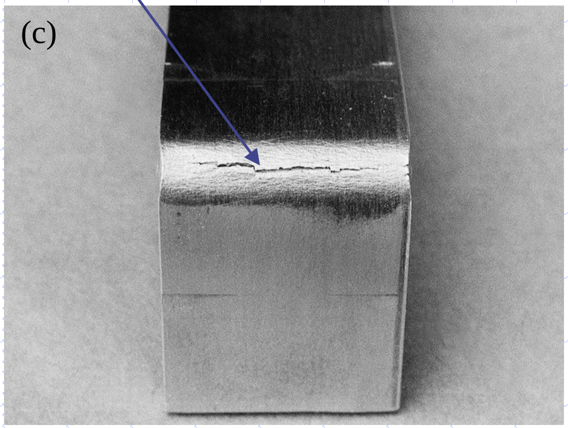


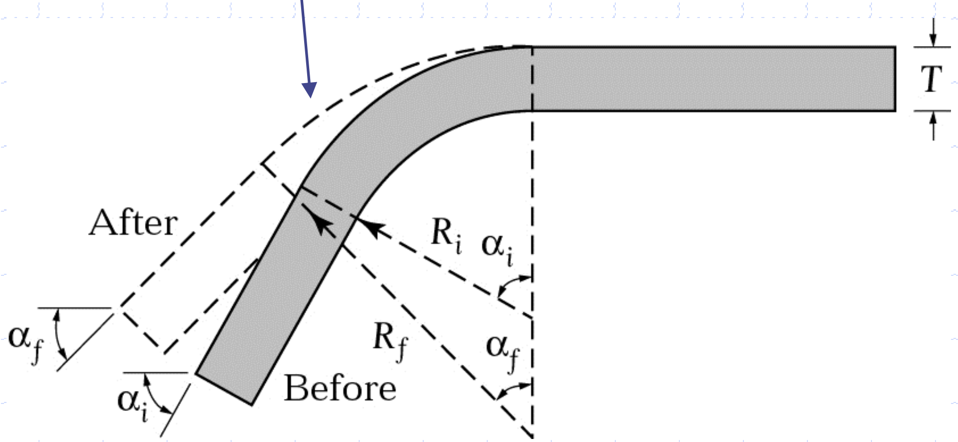
Better

Sheet-Metal Bending

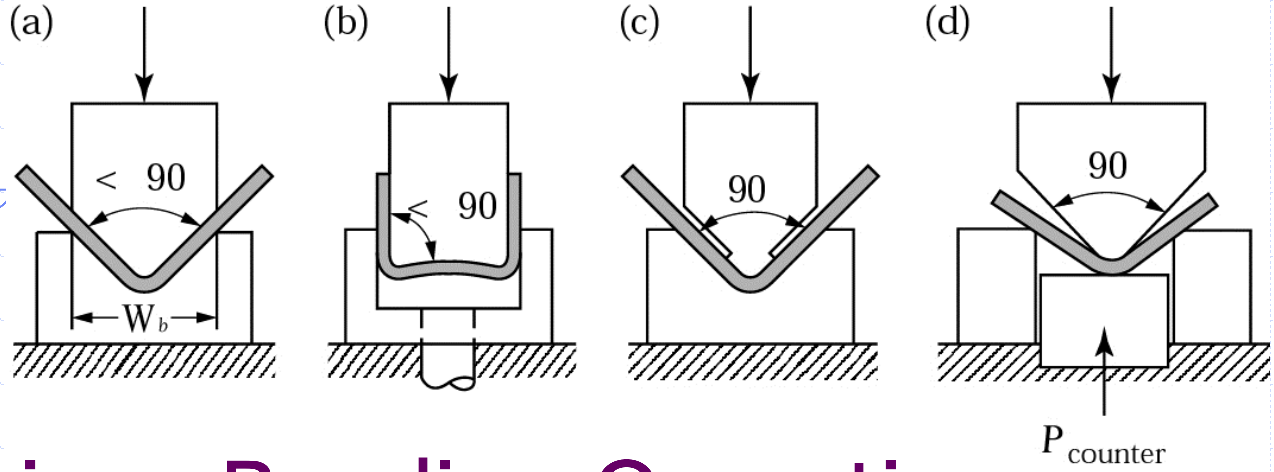
- Figure illustrates the the bending operation
- Cracks can develop as a result of bending
- Springback can occur due to the elastic portion of the sheet deformation



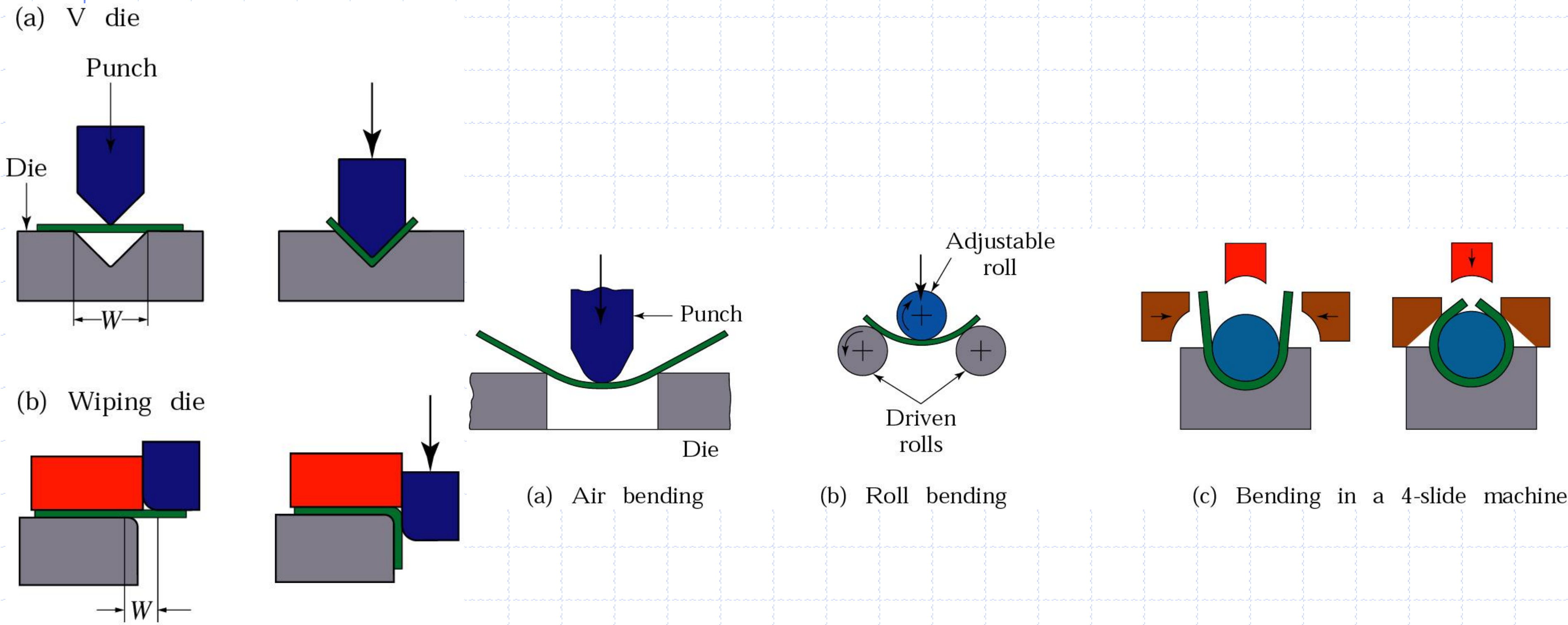




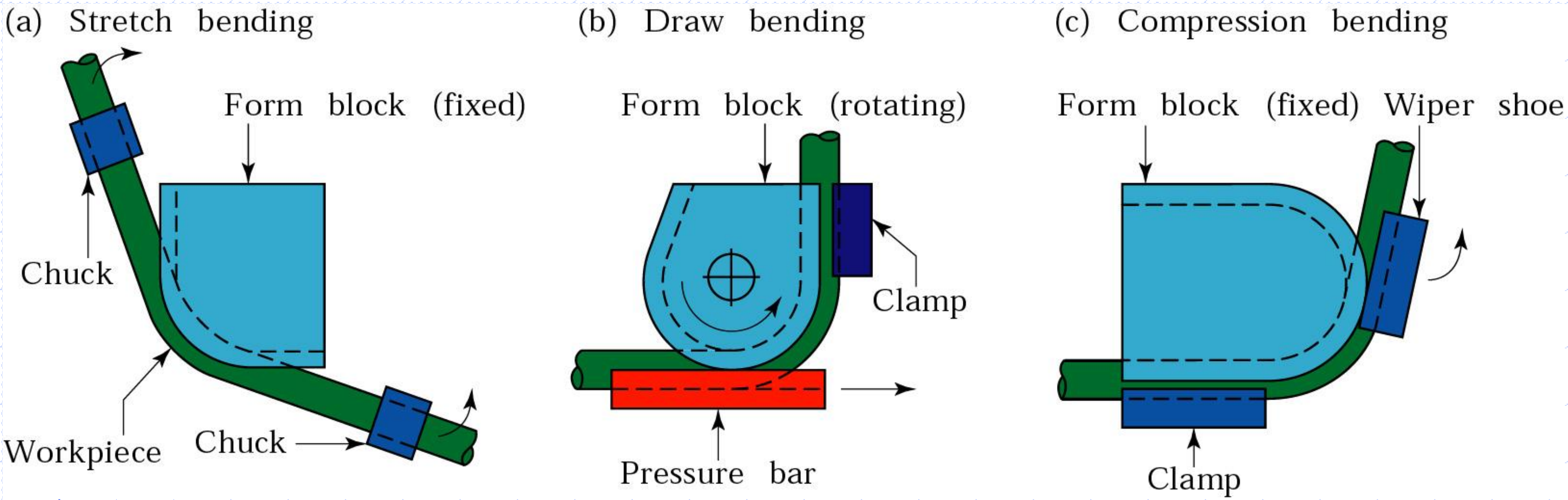
Eliminating Springback



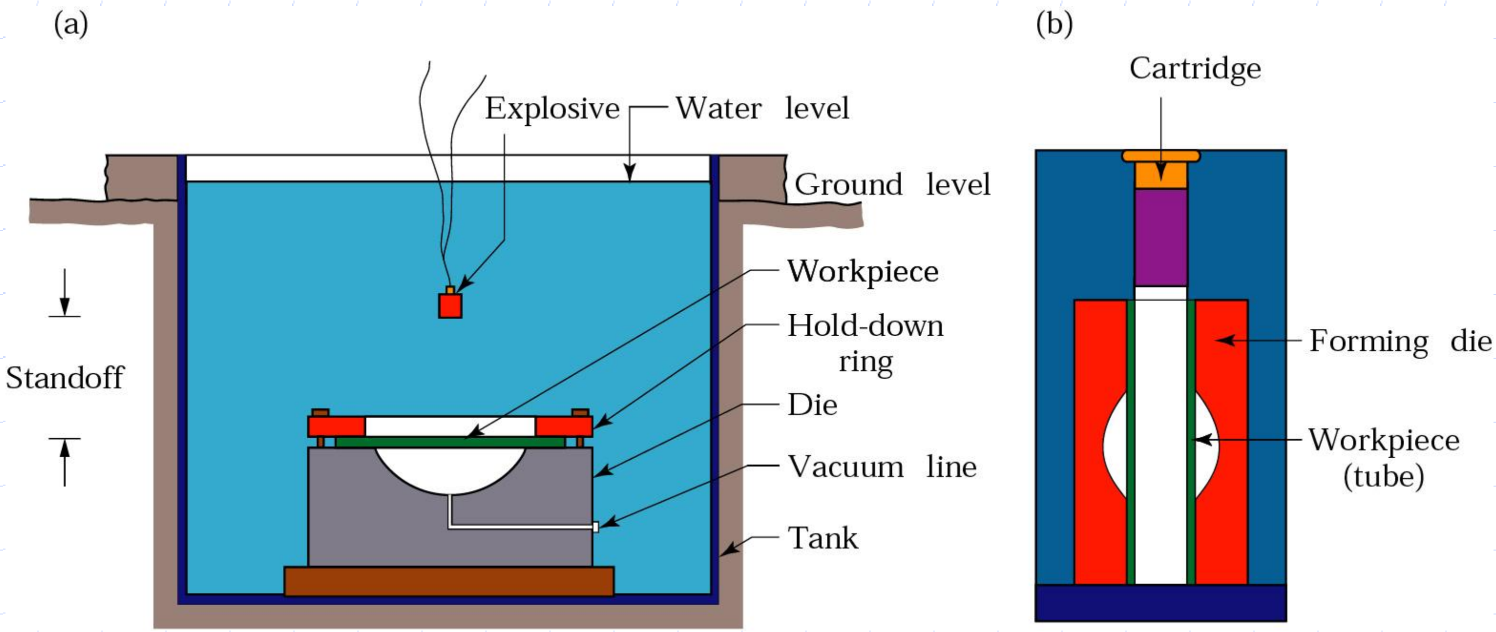
Various Bending Operations



Tube Bending



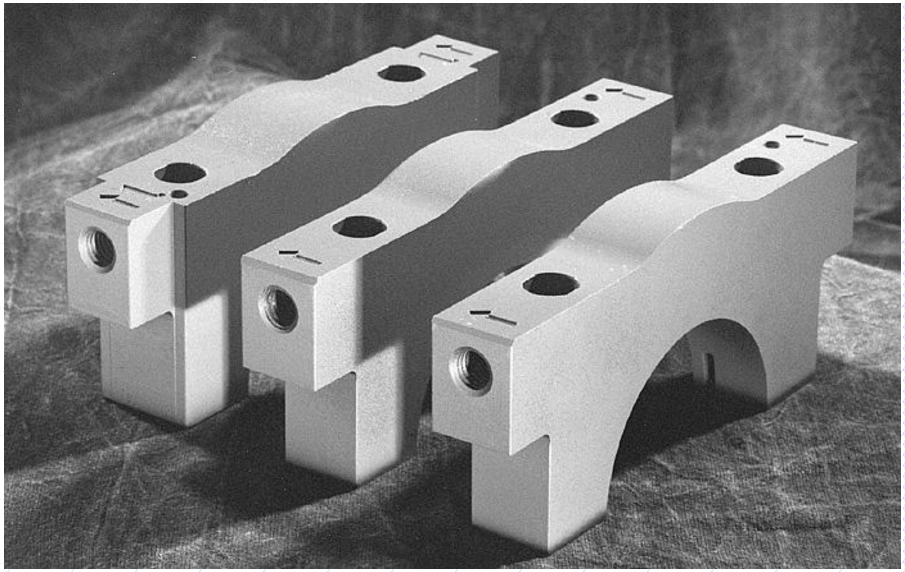
Explosive Forming



Processing of Metal Powders

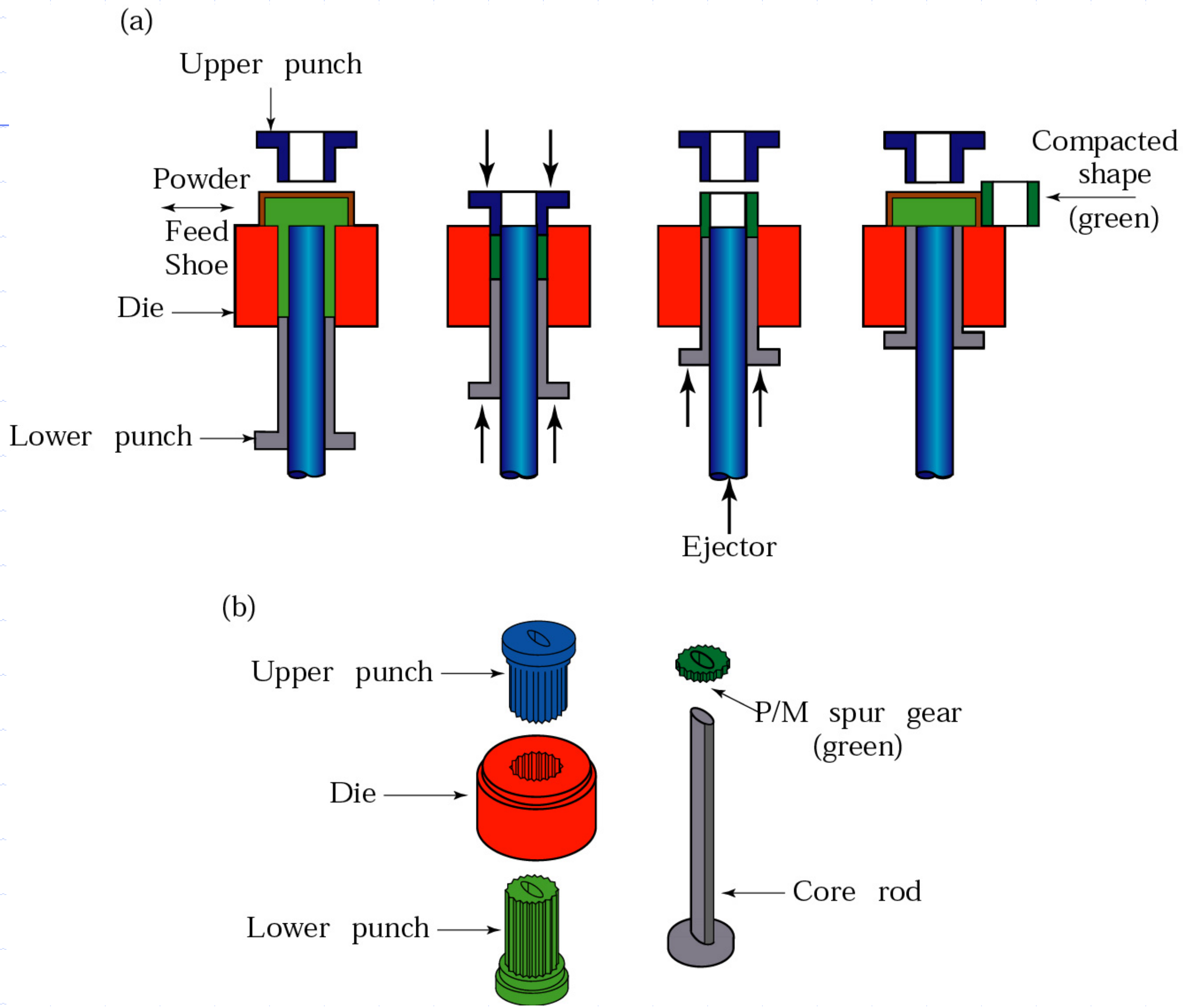
- P/M stands for Powder Metallurgy
- Parts are made by compacting metal powder into a die and sintering.
- Sintering means heating the compacted/pressed particle mix to 70%-90% of the melting temperature. This allows the particles to bond or fuse permanently together.
- <u>Main advantage</u> of P/M process is near net-shape forming
- Main disadvantage is porosity which reduces strength

(c)

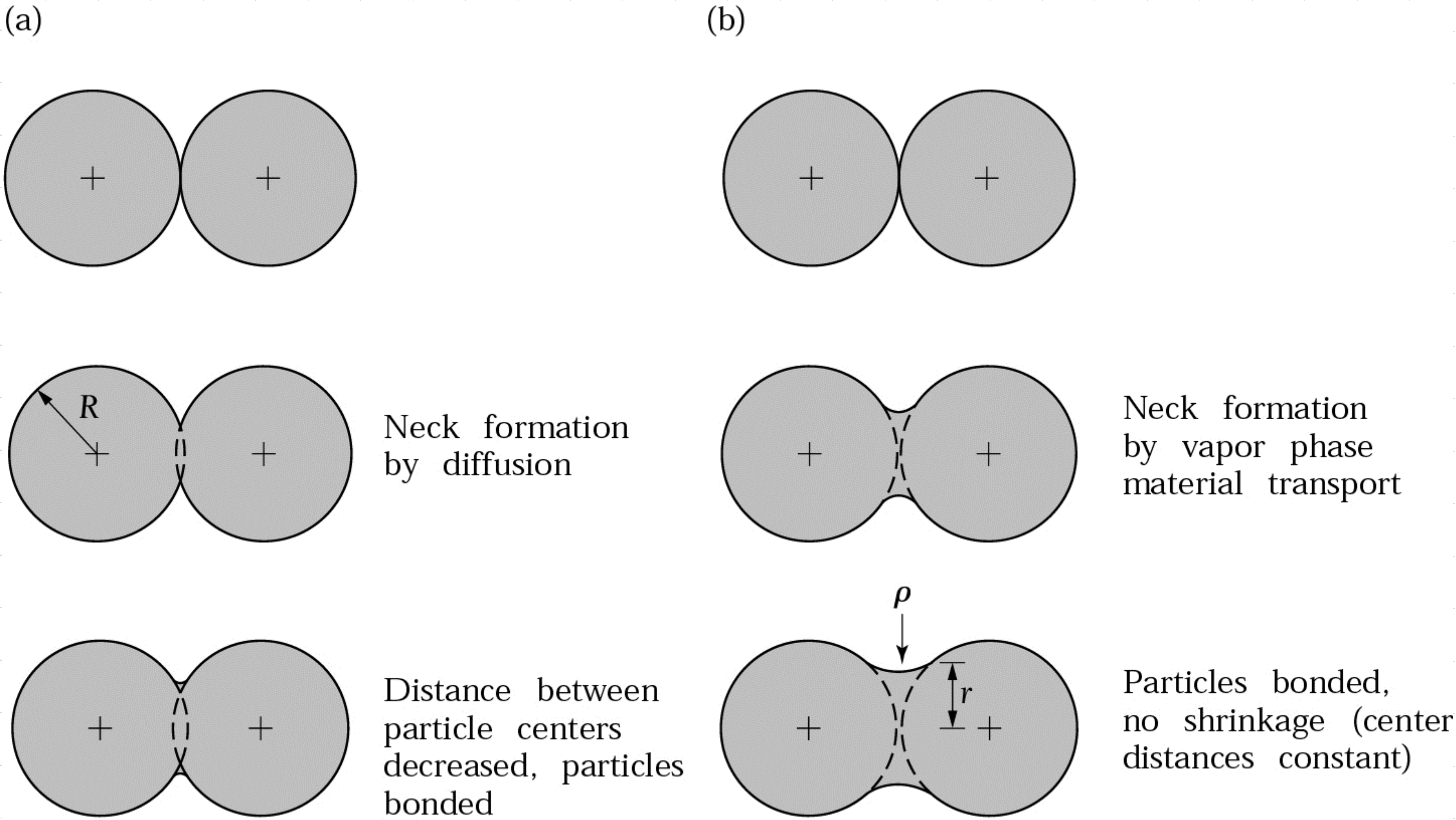


Example of parts made with a P/M process

Example of Compaction



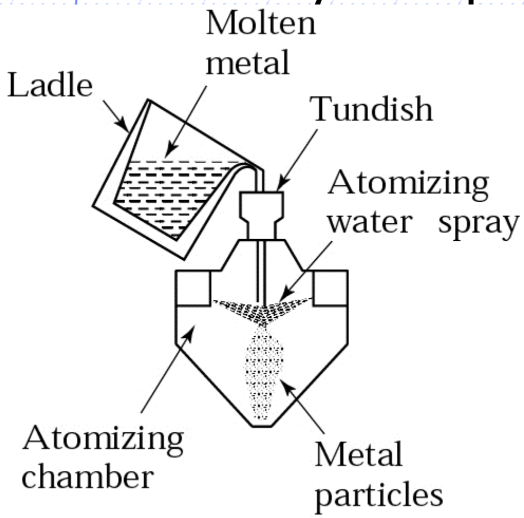
Effect of Sintering

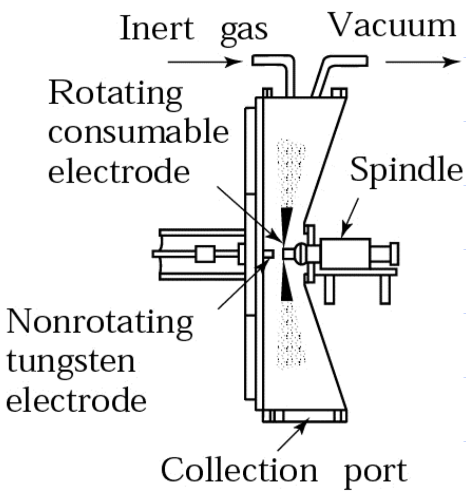


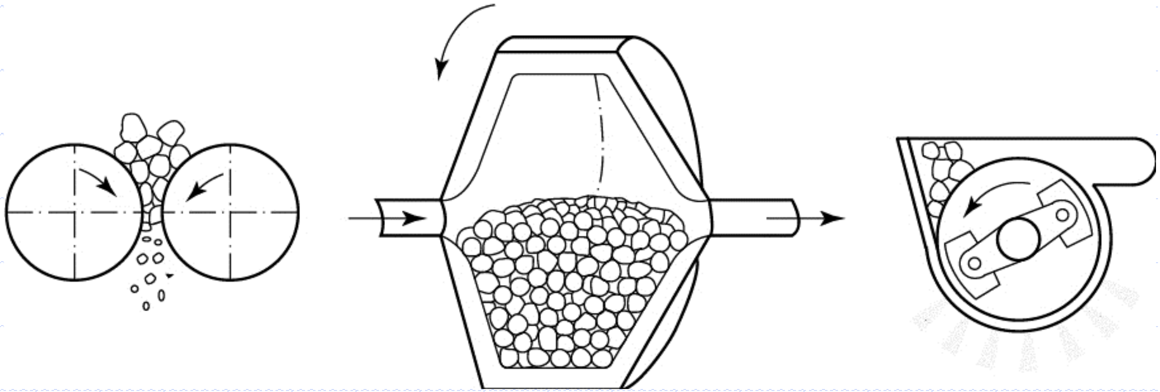
Methods of Metal-Powder Production

- Atomization
- Mechanical Comminution (pulverization)
- Fine metal chips by machining
- Electrolytic deposition

Particle size vary depending on the method



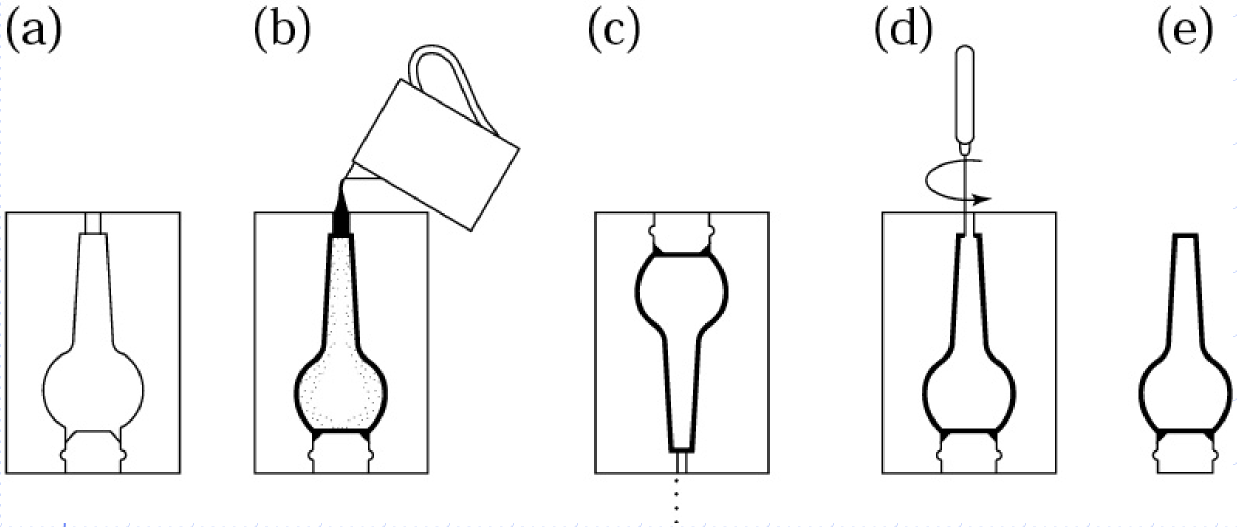




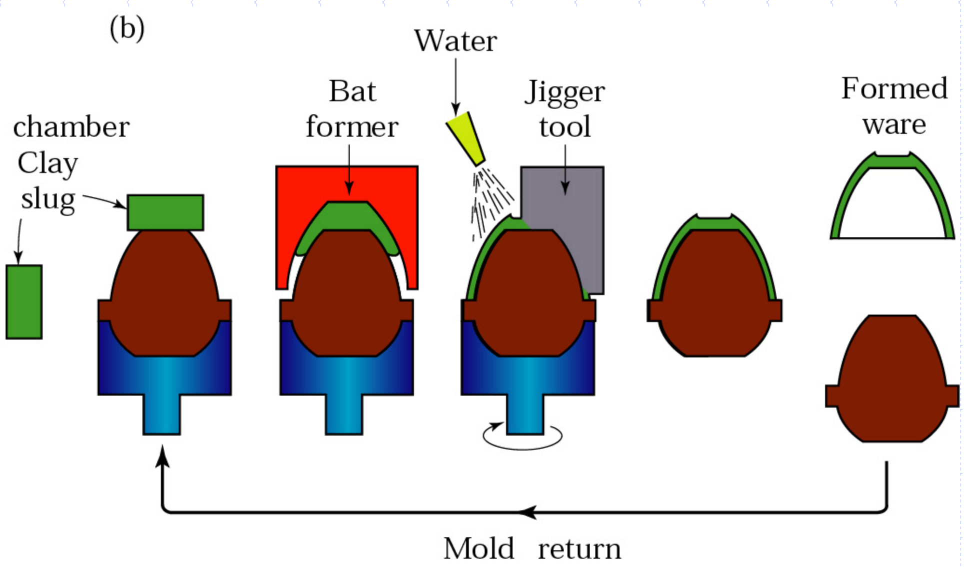
Processing of Ceramics and Glass

- Crushed ceramics are mixed with a binder, e.g. clay, and are thus able to be formed in different shapes. This green mixture is dried and fired to achieve final hard touch. Finishing operations follow.
- Glass is made from raw material by mixing and heating in an oven to achieve a viscous fluid that can be shaped in different ways and then let to cool and harden.

Different Ceramic Shaping

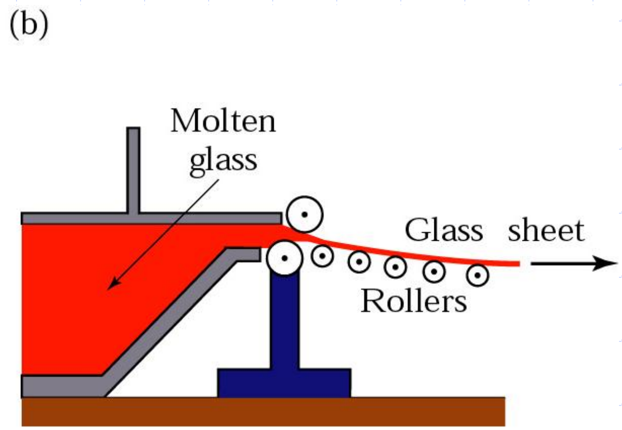


Slip-casting a ceramic part

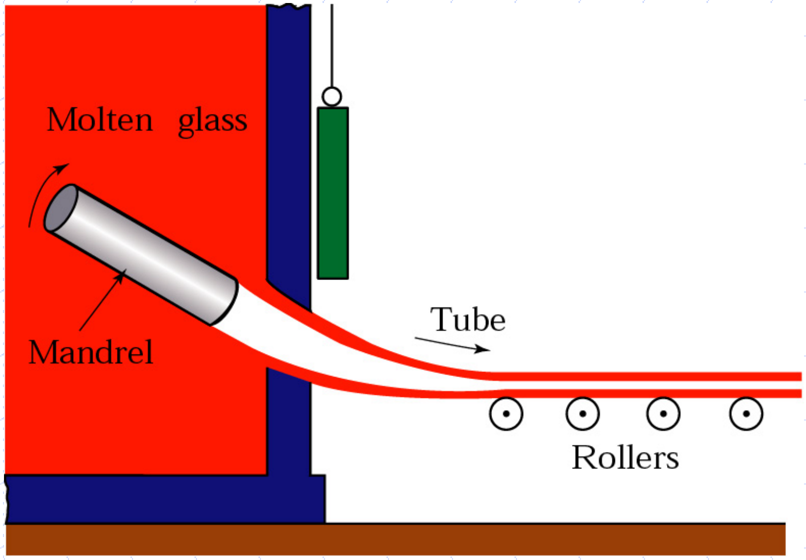


Jiggering operation

Glass Forming/Shaping

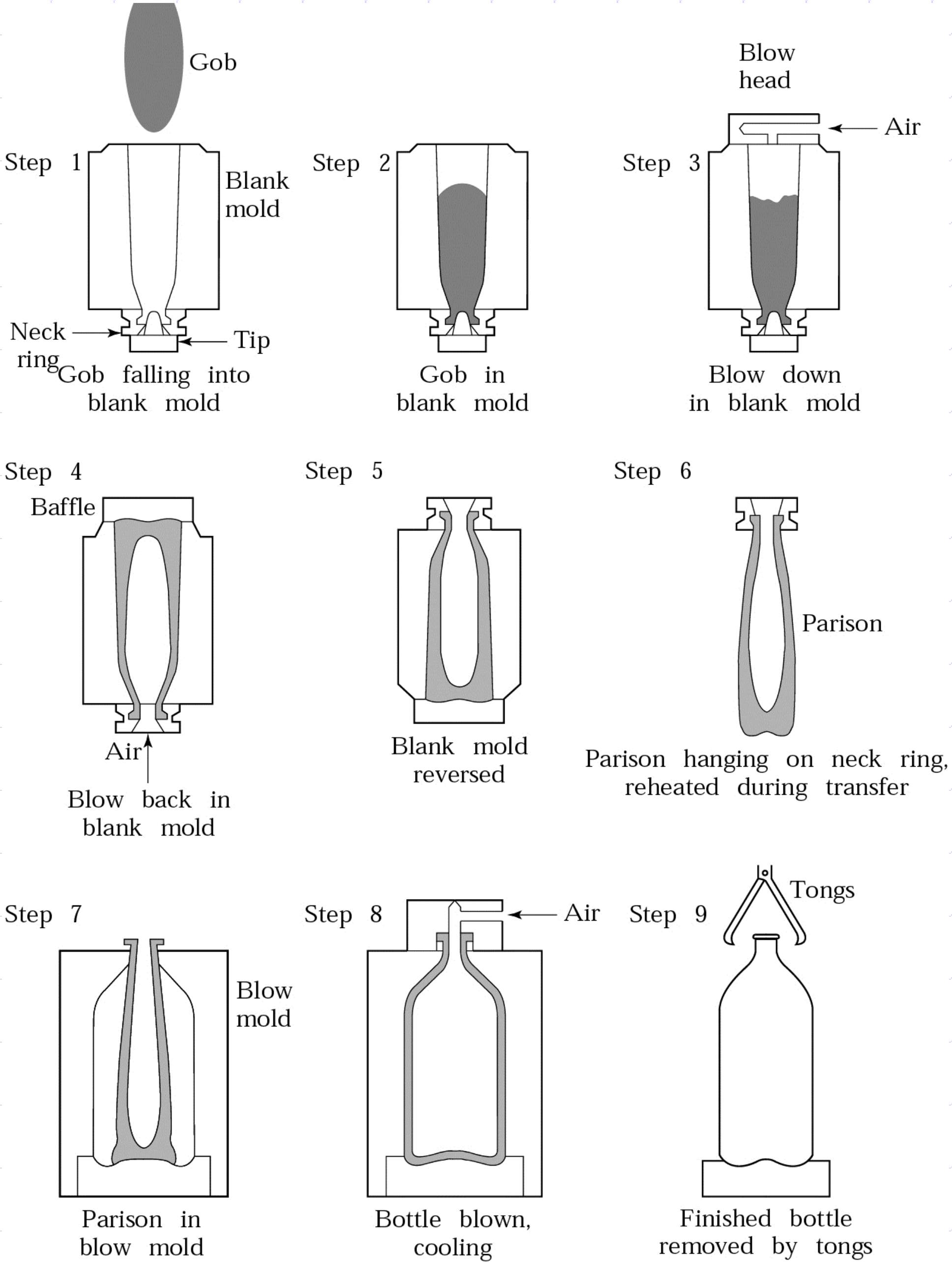


Making sheet glass



Making glass tube

Glass Forming/Shaping



Glass blowing