Manufacturing Process

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FUNDAMENTALS OF METAL FORMING

1. Material Behavior in Metal Forming
2. Overview of Metal Forming
3. Temperature in Metal Forming
4. Strain Rate Sensitivity
5. Friction and Lubrication in Metal Forming

Metal Forming

Large group of manufacturing processes in which plastic deformation is used to change the shape of metal workpieces

- The tool, usually called a ***die***, applies stresses that exceed the yield strength of the metal
- The metal takes a shape determined by the geometry of the die

Stresses in Metal Forming

- Stresses to plastically deform the metal are usually compressive
  - Examples: rolling, forging, extrusion
- However, some forming processes
  - Stretch the metal (tensile stresses)
  - Others bend the metal (tensile and compressive)
  - Still others apply shear stresses (shear spinning)

Material Properties in Metal Forming

- Desirable material properties:
  - **Low yield strength**
  - **High ductility**
- These properties are affected by **temperature**:
  - Ductility increases and yield strength decreases when work temperature is raised
- Other factors:
  - Strain rate and friction

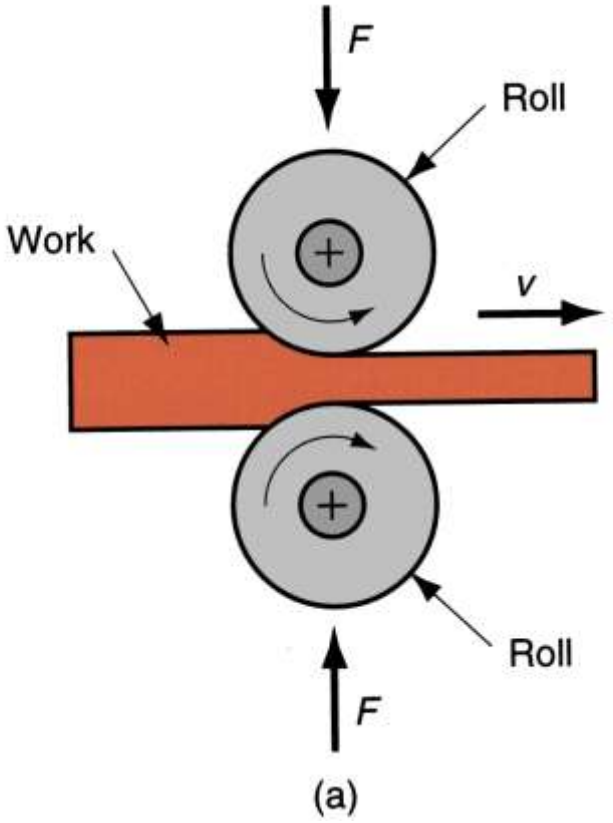
Basic Types of Deformation Processes

1. Bulk deformation **(stock has high V/A)**
   - Rolling
   - Forging
   - Extrusion
   - Wire and bar drawing
2. Sheet metalworking **(stock has low V/A)**
   - Bending
   - Deep drawing
   - Cutting

Bulk Deformation Processes

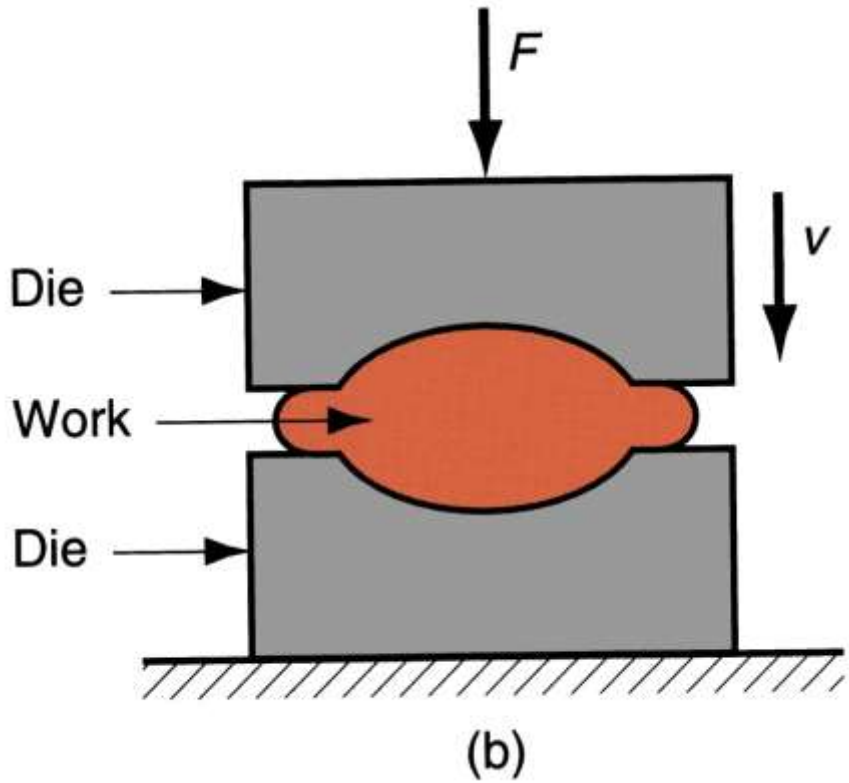
- Characterized by significant deformations and massive shape changes
- "Bulk" refers to workparts with relatively low surface area-to-volume ratios
- Starting work shapes include cylindrical billets and rectangular bars

Rolling



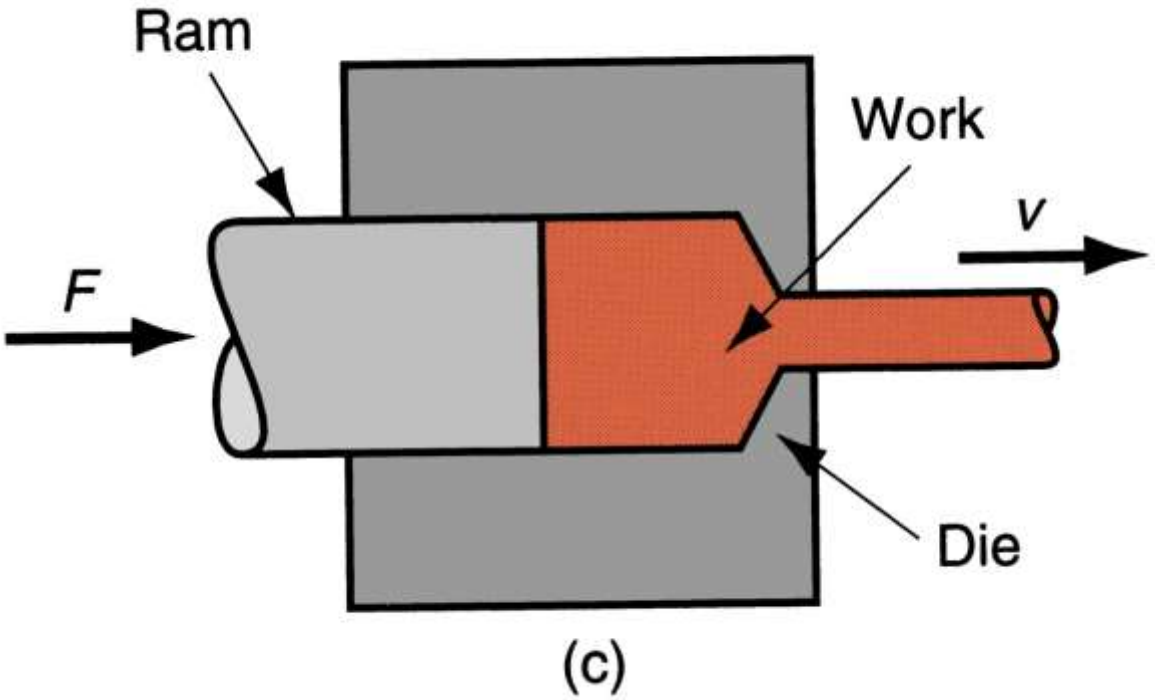
Basic bulk deformation processes: rolling

Forging



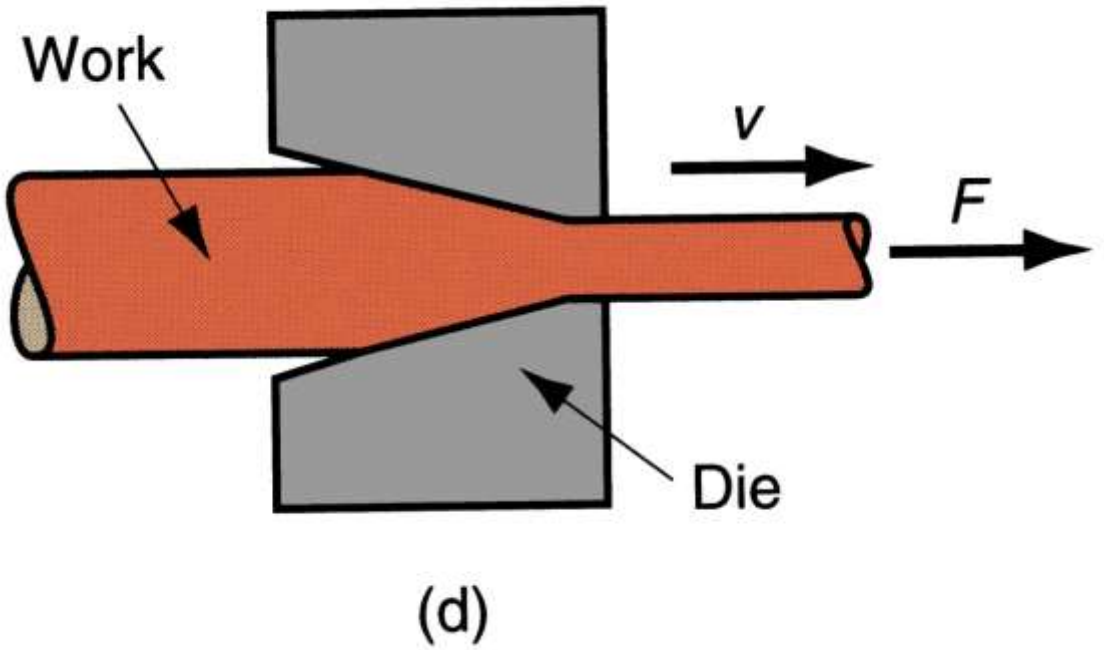
Basic bulk deformation processes: forging

Extrusion



Basic bulk deformation processes: (c) extrusion

Wire and Bar Drawing

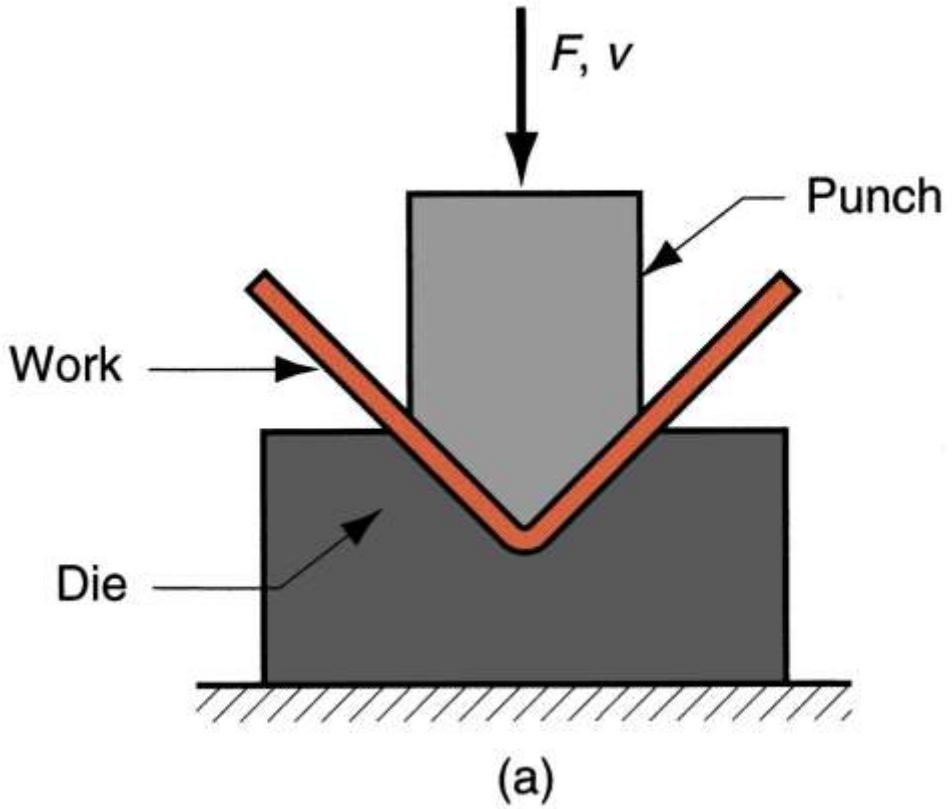


Basic bulk deformation processes: (d) drawing

Sheet Metalworking

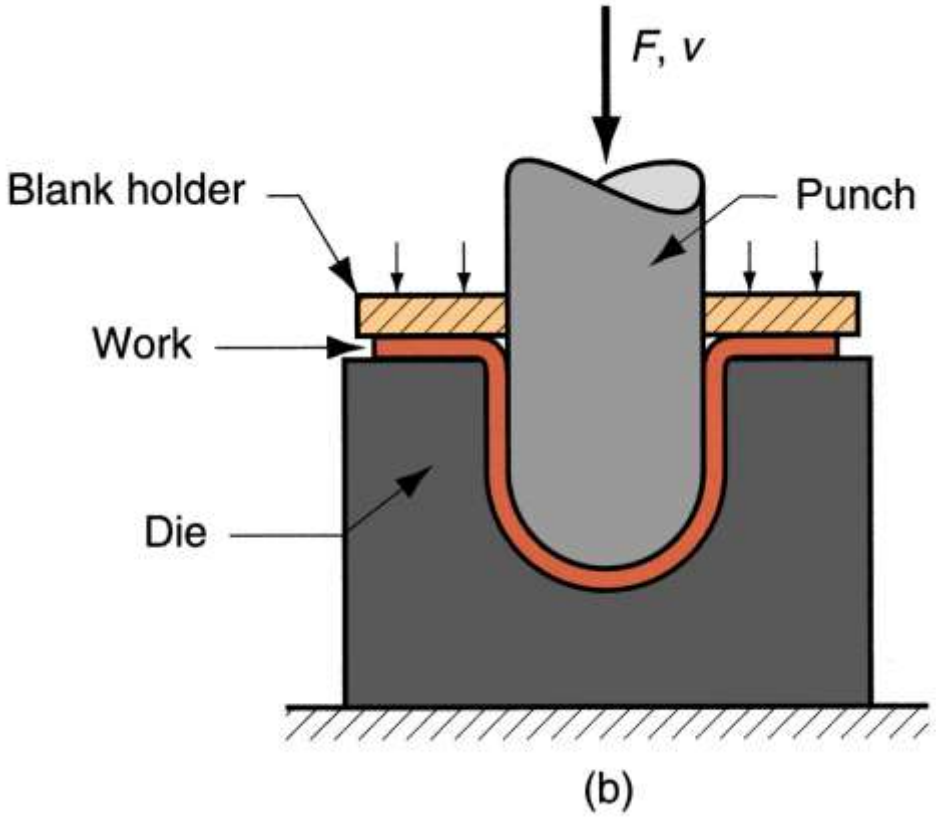
- Forming and related operations performed on metal sheets, strips, and coils
- High surface area-to-volume ratio of starting metal, which distinguishes these from bulk deformation
- Often called *pressworking* because presses perform these operations
  - Parts are called *stampings*
  - Usual tooling: *punch* and *die*

Sheet Metal Bending



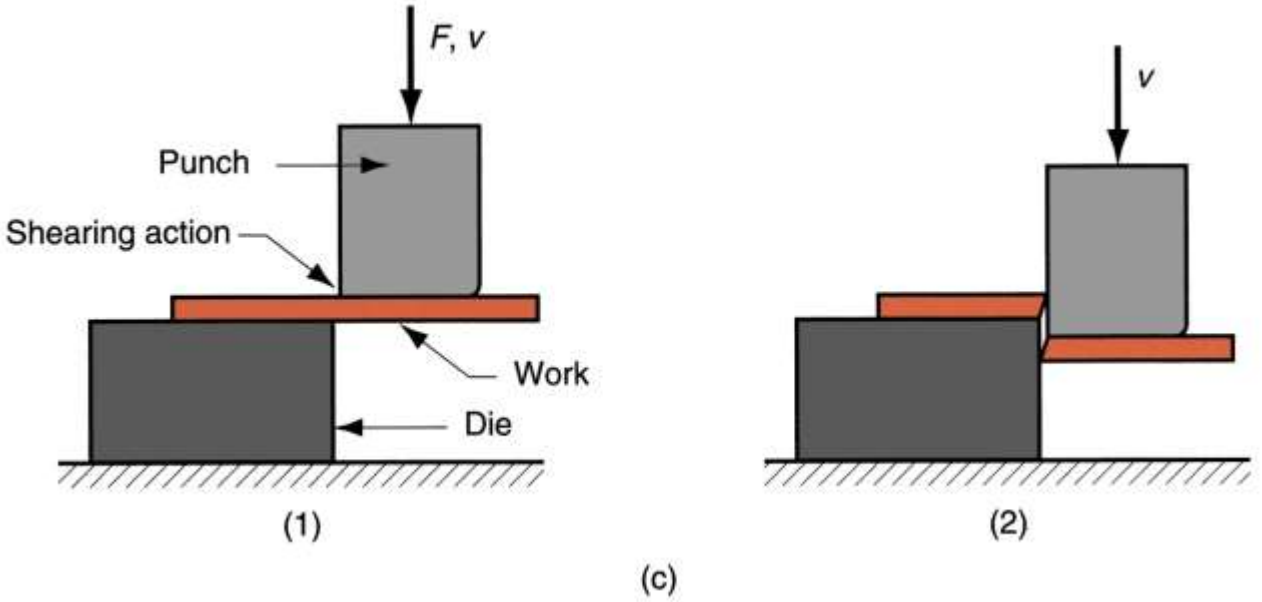
Basic sheet metalworking operations: bending

Deep Drawing



Basic sheet metalworking operations: drawing

Shearing of Sheet Metal



Basic sheet metalworking operations: shearing

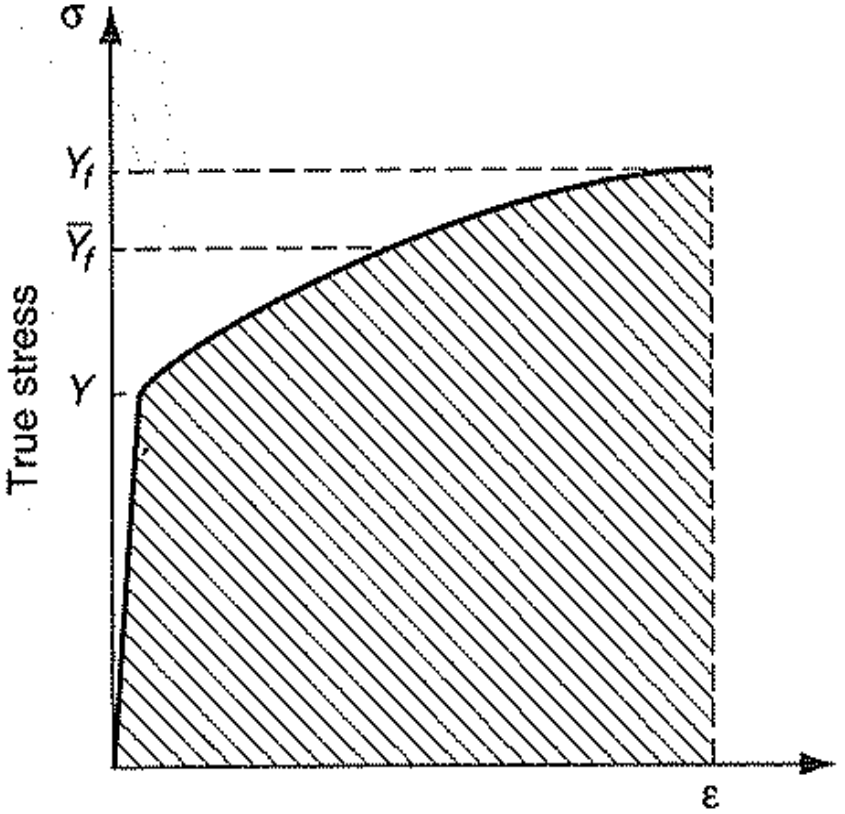
Material Behavior in Metal Forming

- Plastic region of stress-strain curve is primary interest because material is plastically deformed
- In plastic region, metal's behavior is expressed by the flow

$$Y_f = K\varepsilon^n$$

where K = strength coefficient;
and n = strain hardening exponent

- Flow curve based on true stress and true strain



Flow Stress

- For most metals at room temperature, strength increases when deformed due to strain hardening
- ***Flow stress*** = instantaneous value of stress required to continue deforming the material

$$Y_f = K\varepsilon^n$$

where Y_f = flow stress, i.e., the yield strength as a function of strain

Average Flow Stress

- Determined by integrating the flow curve equation between zero and the final strain value defining the range of interest

$$\bar{Y}_f = \frac{K\varepsilon^n}{1+n}$$

where $\bar{Y}_f$ = average flow stress; and $\boldsymbol{\varepsilon}$ = maximum strain during deformation process.
n = strain hardening exponent

Temperature in Metal Forming

- For any metal, ***K*** and ***n*** in the flow curve depend on temperature
  - Both strength (***K***) and strain hardening (***n***) are reduced at higher temperatures
  - In addition, ductility is increased at higher temperatures

Temperature in Metal Forming

- Any deformation operation can be accomplished with lower forces and power at elevated temperature
- Three temperature ranges in metal forming:
  - Cold working
  - Warm working
  - Hot working

1. Cold Working

- Performed at room temperature or slightly above
- Many cold forming processes are important mass production operations
- Minimum or no machining usually required

Advantages of Cold Forming

- Better accuracy, closer tolerances
- Better surface finish
- Strain hardening increases strength and hardness
- No heating of work required

Disadvantages of Cold Forming

- Higher forces and power required in the deformation operation
- Ductility and strain hardening limit the amount of forming that can be done
  - In some cases, metal must be annealed to allow further deformation
  - In other cases, metal is simply not ductile enough to be cold worked

Why Hot Working?

Capability for substantial plastic deformation of the metal - far more than possible with cold working or warm working

- Why?
  - Strength coefficient (***K***) is substantially less than at room temperature
  - Strain hardening exponent (*n*) is zero (theoretically)
  - Ductility is significantly increased

Advantages of Hot Working

- Workpart shape can be significantly altered
- Lower forces and power required
- Metals that usually fracture in cold working can be hot formed
- Strength properties of product are generally isotropic
- No work hardening occurs during forming

Disadvantages of Hot Working

- Lower dimensional accuracy in case of bulk forming
- Higher total energy required (due to the thermal energy to heat the workpiece)
- Work surface oxidation (scale), poorer surface finish
- Shorter tool life