Lecture 8: Principles of deformation processing
Bulk Deformation Processes

- (a) Rolling and (b) forging
Bulk Deformation Processes

• (c) Extrusion and (d) wire and bar 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 these operations are performed on presses
  - Parts are called *stampings*
  - Usual tooling: *punch* and *die*
Sheet Metalworking

• (a) Bending and (b) deep drawing
Sheet Metalworking

- (c) Shearing: (1) punch first contacting sheet and (2) after cutting
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 curve:

\[ \sigma = K \varepsilon^n \]

where \( K \) = strength coefficient; and \( n \) = strain hardening exponent
Average Flow Stress

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

\[ \sigma_f = \frac{K \varepsilon^n}{1 + n} \]

where \( \varepsilon_m \) = maximum strain during deformation process
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

• Three temperature ranges in metal forming:
  – Cold working
  – Warm working
  – Hot working

Quiz: why forming are usually performed at high T?
Cold Working

- Performed at room temperature or slightly above (< 0.3 T<sub>m</sub>)

Advantages:
- Better accuracy, closer tolerances, near net shape
- Better surface finish
- Strain hardening increases strength and hardness
- Grain flow during deformation can cause desirable directional properties in product
- No heating of work required
Disadvantages of Cold Forming

- Higher forces and power required for deformation
- Surfaces of starting work must be clean
- Ductility and strain hardening limit the amount of forming that can be done
  - In some cases, metal must be annealed before further deformation can be accomplished
  - In other cases, metal is simply not ductile enough to be cold worked
Warm Working

- Performed at temperatures above room temperature but below recrystallization temperature
- \[ 0.3T_m < T_{\text{warm working}} < T_{\text{recrystallization}} \] where \( T_m \) = melting point (absolute temperature) for metal

Quiz: What is recrystallization?
Advantages and Disadvantages of Warm Working

- **Advantages**
  - Lower forces and power than in cold working
  - More intricate work geometries possible
  - Need for annealing may be reduced or eliminated

- **Disadvantage**
  - Workpiece must be heated
Hot Working

• Deformation at temperatures above the \textit{recrystallization temperature}
  – Recrystallization temperature = about one-half of melting point on absolute scale
  • In practice, hot working usually performed somewhat above 0.5\(T_m\)
  • Metal continues to soften as temperature increases above 0.5\(T_m\), enhancing advantage of hot working above this level
Why Hot Working?

Capability for substantial plastic deformation - far more than is possible with cold working or warm working

• Why?
  – Low Strength
  – Low Strain hardening
  – 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 strengthening of part occurs from work hardening
  - Advantageous in cases when part is to be subsequently processed by cold forming
Disadvantages of Hot Working

- Lower dimensional accuracy
- Higher total energy required, which is the sum of
  - The thermal energy needed to heat the workpiece
  - Energy to deform the metal
- Work surface oxidation (scale)
  - Thus, poorer surface finish
- Shorter tool life
  - Dies and rolls in bulk deformation
Friction in Metal Forming

• In most metal forming processes, friction is undesirable:
  – Metal flow is reduced
  – Forces and power are increased
  – Tools wear faster

• Friction and tool wear are more severe in hot working
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Lubrication in Metal Forming

• Metalworking lubricants are applied to tool-work interface in many forming operations to reduce harmful effects of friction

• Benefits:
  – Reduced sticking, forces, power, tool wear
  – Better surface finish
  – Removes heat from the tooling
HW assignment

- Reading assignment: Chapters 13
- Review Questions: 12.2, 12.4, 12.5, 12.6, 12.7, 12.9,
- Problems: 12.1, 12.2, 12.3, 12.5, 12.6, 12.8,