Metal Forming Processes (ME5807)

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Introduction to Metal Forming

Metal Forming is the largest group of manufacturing processes in which plastic deformation is used to changed the shape of metal workpiece. In metal forming:–

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

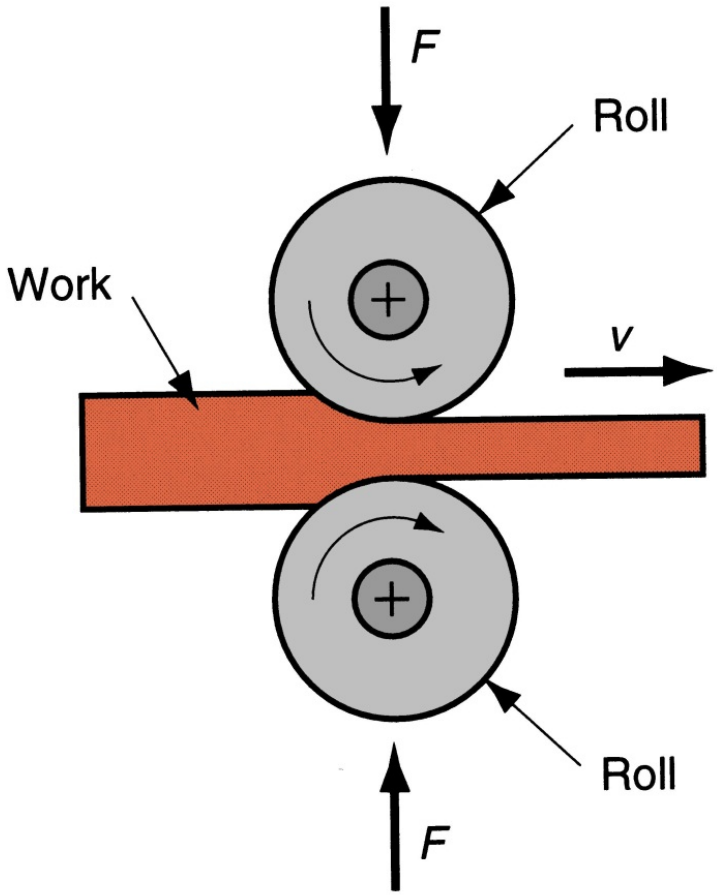
Classification of Metal Forming Processes

1. Bulk Forming (stock has high V/A)
   - Rolling
   - Forging
   - Extrusion
   - Wire and bar drawing
2. Sheet metal working (stock has low V/A)
   - Bending
   - Twisting
   - Deep drawing
   - Stretch Forming
   - Spinning

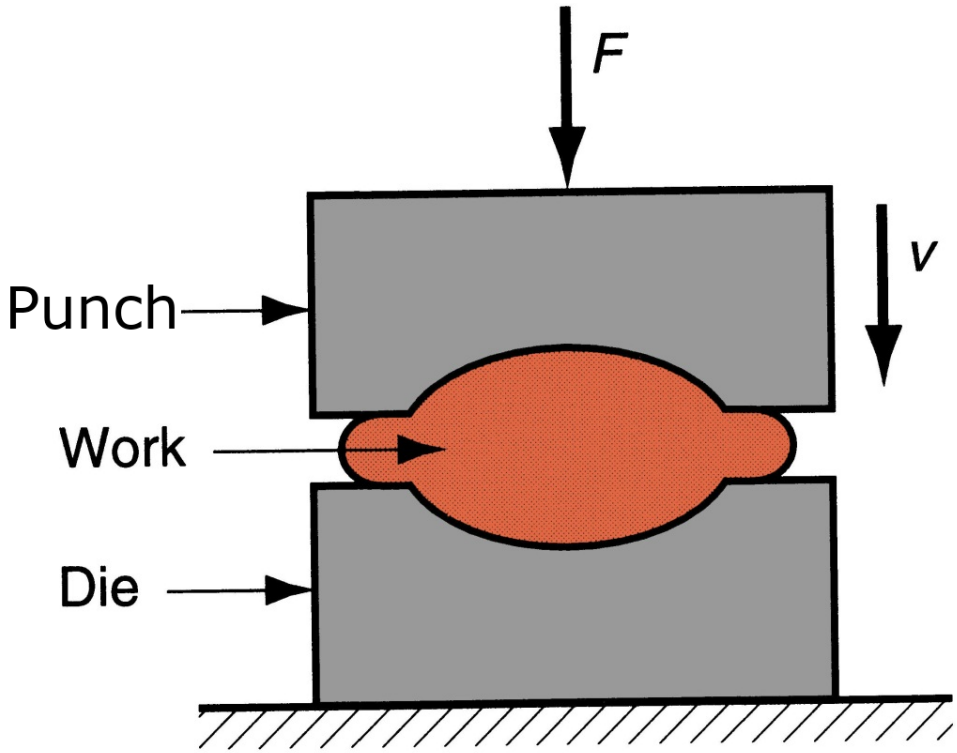
Bulk Forming Processes

- Characterised 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.

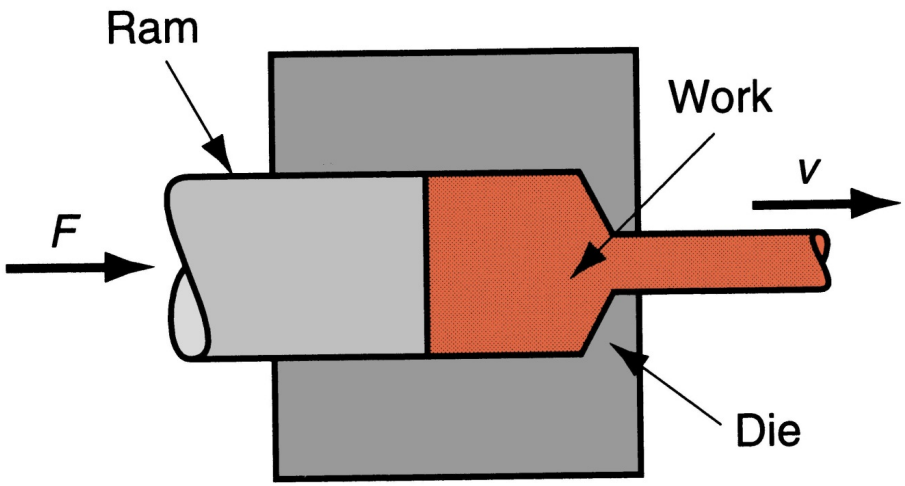
Rolling



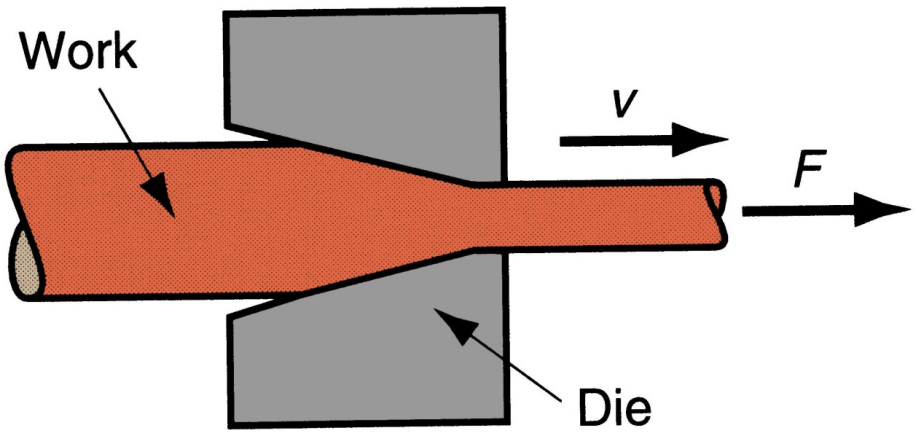
Forging



Extrusion



Wire and Bar Drawing



Sheet Metal Working

- 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

Material Behaviour in Metal Forming

Compressive stresses

- Ex.: rolling, forging, extrusion.

Tensile and Compressive

- Ex.: Bending.

Tensile stresses

- Ex.: Stretching.

Shear stresses

- Ex.: Punching.

Material Properties in Metal Forming

The following material properties which decides that how the behave under loading..

- Strength
- Hardness
- Toughness
- Elasticity
- Plasticity
- Malleability

Tensile Test / Properties - Nominal Stress-Strain

The tensile test is used to determine:

- Modulus of Elasticity
- Elastic Limit
- Elongation
- Proportional limit
- Reduction in Area
- Tensile Strength
- Yield point
- Yield strength

Tensile Test / Properties - Nominal Stress-Strain

The Stress (σ) ans strain (ϵ) can be plotted as:

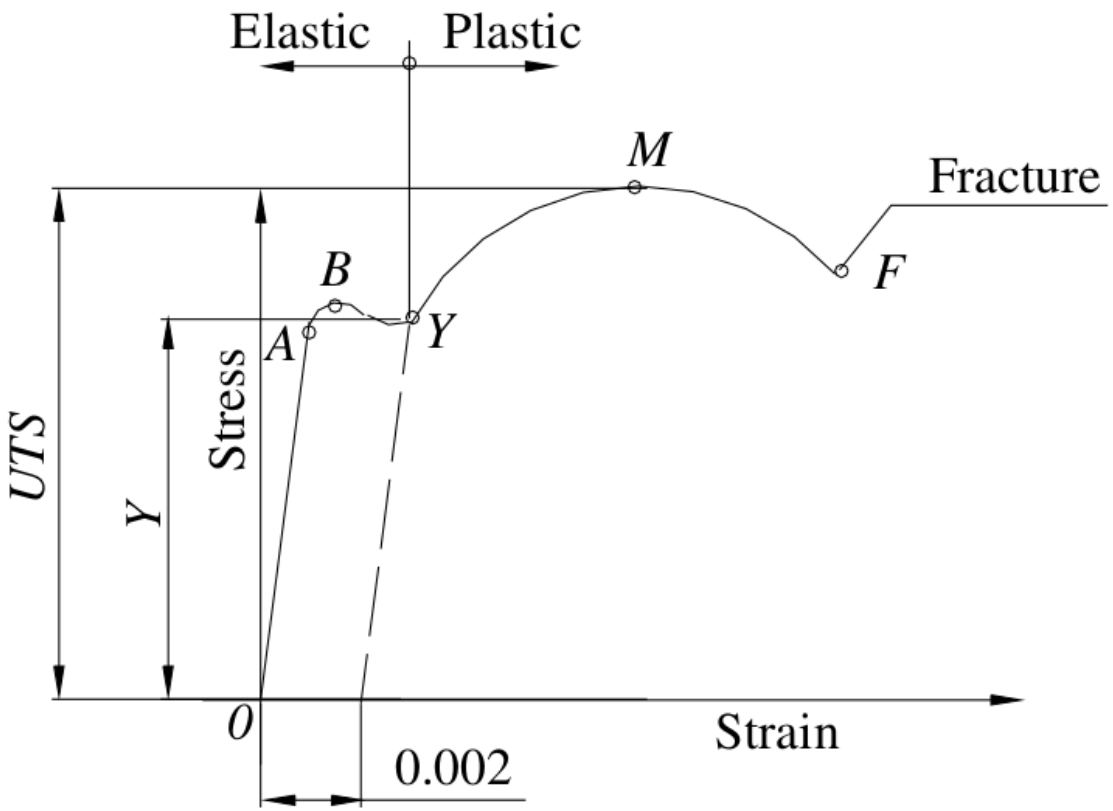
- Nominal / Engineering Stress-Strain, or
- True Stress-Strain

Tensile Test / Properties - Nominal Stress-Strain

Nominal (Engineering) Stress, $\sigma_n = \frac{F}{A_o}$

Nominal (Engineering) Strain $\epsilon_n = \frac{l - l_o}{l_o} = \frac{\Delta l}{l_o}$

Tensile Test / Properties - Nominal Stress-Strain



Tensile Test / Properties - Ductility

in terms of elongation, $\delta = (\frac{l_f - l_o}{l_o})x100$

in term of reduction in cross-sectional area, $\psi = (\frac{A_o - A_f}{A_o})x100$

Material Properties in Metal Forming

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

Tensile Test / Properties - True Stress-Strain

True Stress, $\sigma = \frac{F}{A}$

True Strain, $\epsilon = ln\frac{l}{l_o}$

Tensile Test / Properties - True Stress-Strain

True Stress, $\sigma = \frac{F}{A}$

True Strain, $\epsilon = ln\frac{l}{l_o}$

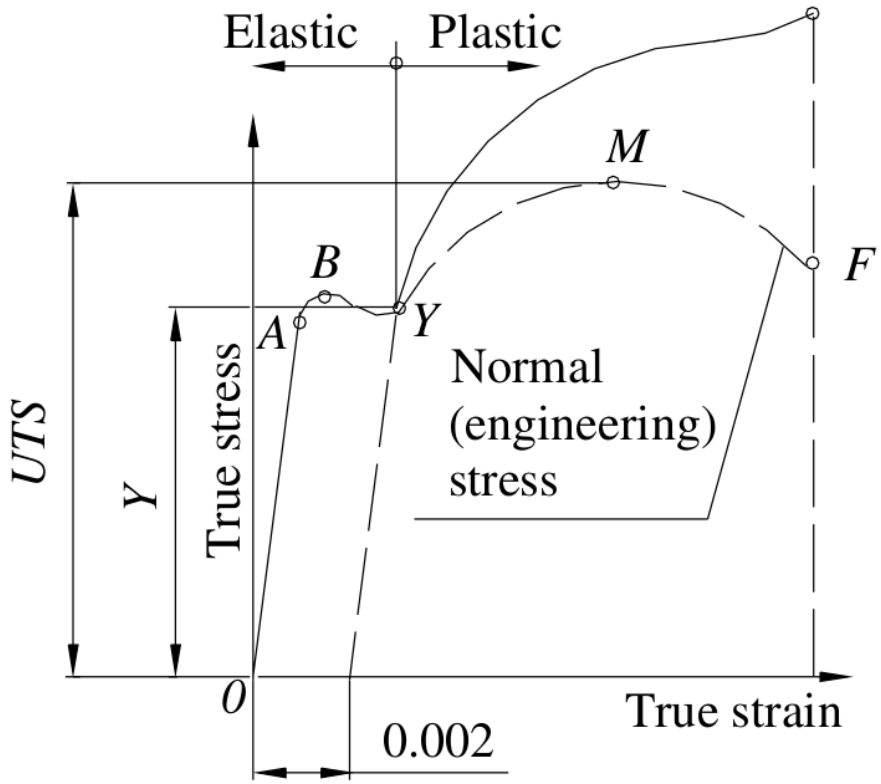


Figure: True Stress Strain

Tensile Test / Properties - True Stress-Strain

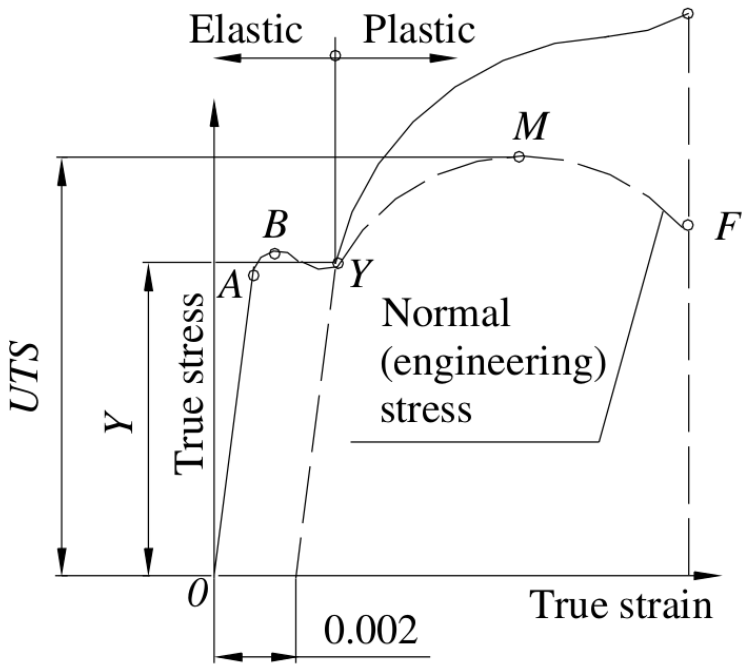


Figure: True Stress Strain

The stress-strain curve can be represented as,

$$\sigma = K\epsilon^n \qquad (1)$$

K = is the strength coefficient,
n = strain hardening / work hardening exponent.

Tensile Test / Properties - True Stress-Strain

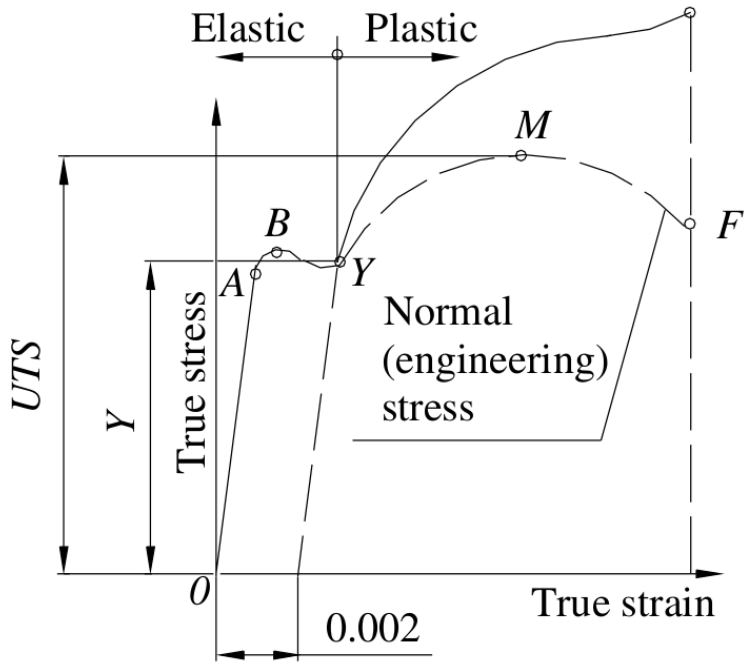


Figure: True Stress Strain

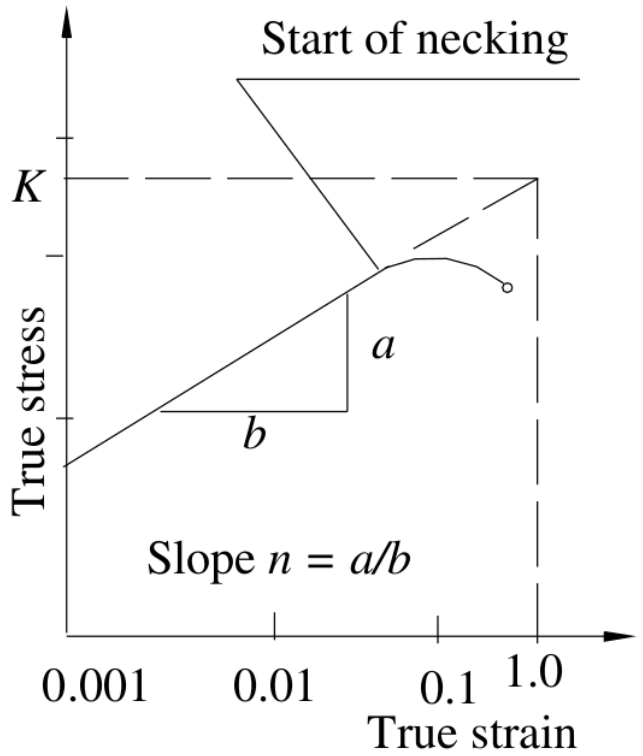


Figure: True Stress Strain - Logarithmic

Tensile Test / Properties - True Stress-Strain

- Equation 1 is called as the flow curve.
- Behaviour of metals in plastic zone.
- capacity for cold strain hardening.
- the logarithmic plot of flow curve is straight line.
- the slope of straigth line is equal to the exponent n.
- $n = 0$ for perfectly plastic solid, and $n = 1$ for perfectly elastic solid.
- for most of the metals, n has values between 0.10 and 0.50.

Flow Stress

Material Factors:

- Purity of the material,
- Cristal Structure,
- Grain Size,
- Heat Treatment of the materials.

Process Factors:

- Strain,
- Strain rate,
- Temperature.

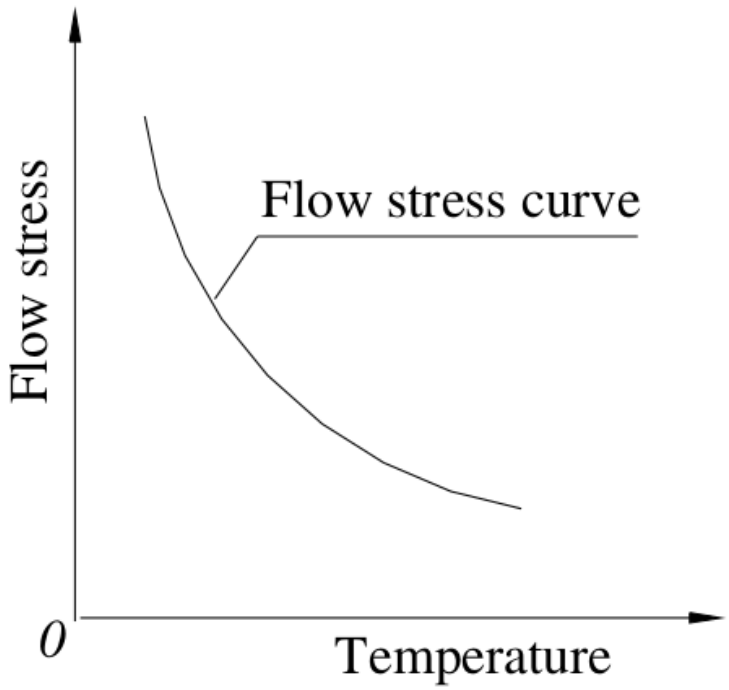


Figure: Effect of temperature on flow stress

Flow Stress Curve and Average Flow Stress

- Flow stress curve, $\sigma_f = K\epsilon^n$
- Flow stress curve based on true stress and true strain.
- Average Flow stress,

$$\sigma_m = \frac{K\epsilon_{max}^n}{1+n}$$

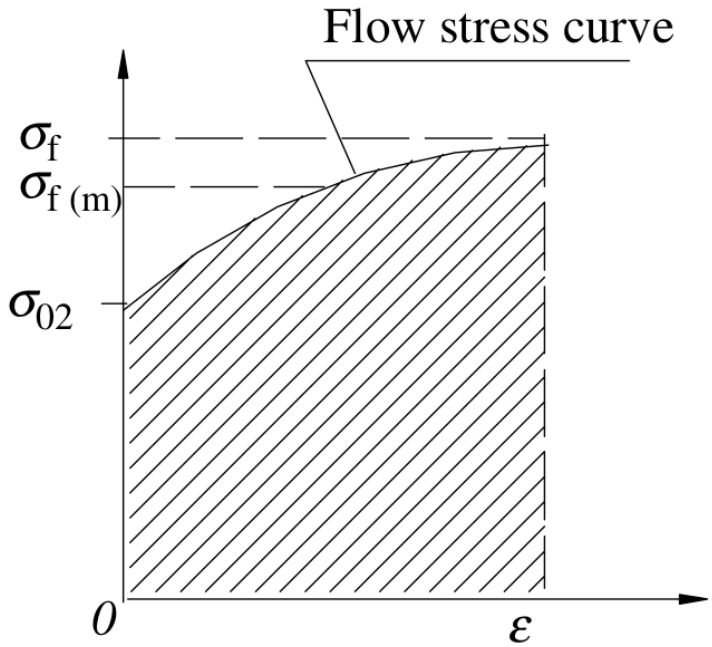


Figure: Flow curve during cold-forming

Temperature in Metal Forming

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

- Three temperature ranges in metal forming:
  1. Cold Working / Cold Forming,
  2. Warm Working / Warm Forming,
  3. Hot Working / Hot Forming.

Cold Working

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

Advantages of Cold Working

- Better accuracy, closer tolerances
- Better surface finish
- No heating of work required
- Strain hardening increases strength and hardness
- Grain flow during deformation can cause desirable directional properties in product

Disadvantages of Cold Working

- Higher forces and power required in the deformation operation
- Surfaces of starting workpiece must be free of scale and dirt
- 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

Warm Working

- Performed at temperatures above room temperature but below recrystallization temperature
- Dividing line between cold working and warm working often expressed in terms of melting point:

$$0.3T_m < T < 0.5T_m$$

Advantages of Warm Working

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

Hot Working

- Deformation at temperatures above the recrystallization temperature
- Recrystallization temperature = about one-half of melting point on absolute scale
  - In practice, hot working usually performed somewhat above $0.5T_m$
  - Metal continues to soften as temperature increases above $0.5T_m$, enhancing advantage of hot working above this level

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
- 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 (due to the thermal energy to heat the workpiece)
- Work surface oxidation (scale), poorer surface finish
  Shorter tool life

Strain Rate

- The strain rate is the rate at which the deformation occurs, i.e., deformation or strain per time unit.
- This is equivalent to the instantaneous strain (or change in strain) per time unit.

$$\dot{\epsilon} = \frac{\Delta \epsilon}{\Delta t}$$

Effect of Strain rate on Flow Stress

The effect of strain rate on the flow stress σ_f at a fixed strain and temperature,

$$\sigma_m = C\dot{\epsilon}^m$$

C = strength coefficient (similar but not equal to the strength coefficient K,
m = strain rate sensitivity exponent.

Flow stress as a function of strain and strain rate,

$$\sigma_m = A\epsilon^n\dot{\epsilon}^m$$

A = strength coefficient (combining the effect of the coefficients K and C)

Friction in Metal Forming

- Friction in metal forming arises because of the close contact between the tool and work surfaces and the high pressures that drive the surfaces together in these operations.
- In most metal forming processes, friction is undesirable for the following reasons:
  1. Metal flow in the work is retarded.
  2. The forces and power to perform the operation are increased.
  3. Rapid wear of the tool occurs.
- Friction and tool wear are more severe in hot working.
- If the coefficient of friction becomes large enough, a condition known as *sticking* occurs.

sticking in metal working is the tendency for the two surfaces in relative motion to adhere to each other rather than slide.

Lubrication in Metal Forming

- Metalworking lubricants are applied to tool-work interface in many forming operations to reduce harmful effects of friction.
- Benefits obtained from the application of lubricants are:
  1. Reduced sticking, forces, power, tool wear
  2. Better surface finish
  3. Removes heat from the tooling
- Consideration in choosing an appropriate metalworking lubricant include:
  1. Type of forming process (rolling, forging, drawing, etc.)
  2. Hot working or cold working
  3. Work material
  4. Chemical reactivity with tool and work metals
  5. Ease of application
  6. Cost

Numerical Problems – Problem No. 1

A metal is deformed in a tension test into its plastic region. The original specimen had $l_o = 50mm$ and $A_o = 322.6mm^2$.

At one point in the tensile test, the gage length $l_1 = 63.5mm$ and the corresponding engineering stress $\sigma_{n1} = 172.5MPa$; at another point, the tensile test prior to necking, the gage length $l_2 = 78.5mm$ and the corresponding engineering stress $\sigma_{n2} = 193MPa$.

Determine the strength coefficient K and strain- hardening exponent n.