Metal Forming Processes —— ME5807

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Outlines

Temperature in Metal Forming

Strain Rate

Lecture No. 2

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Tensile Test / Properties - True Stress-Strain

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

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

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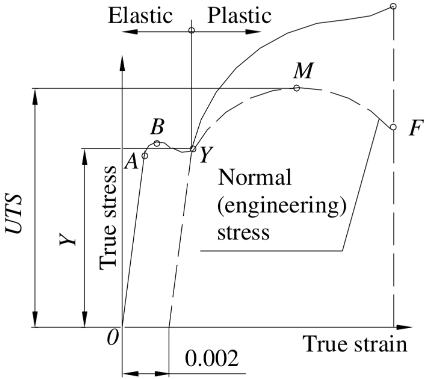

Figure: True Stress Strain

Tensile Test / Properties - True Stress-Strain

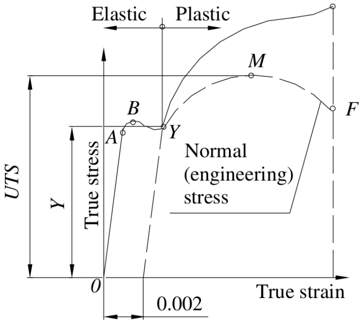

Figure: True Stress Strain

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

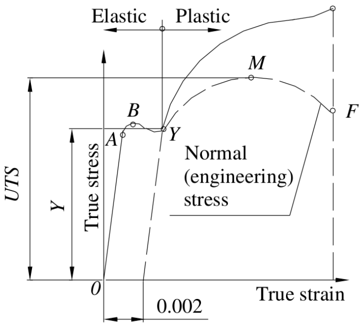

Figure: True Stress Strain

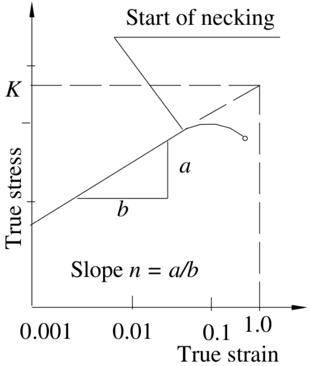

Figure: True Stress Strain - Logarithmic

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.

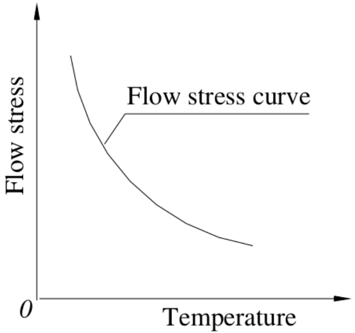

Figure: Effect of temperature on flow stress

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,

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

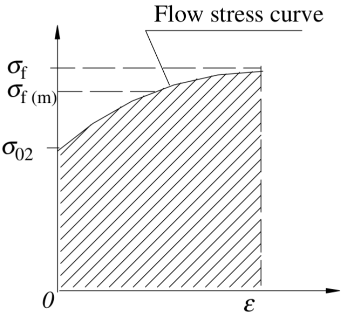

Figure: Flow curve during cold-forming

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)