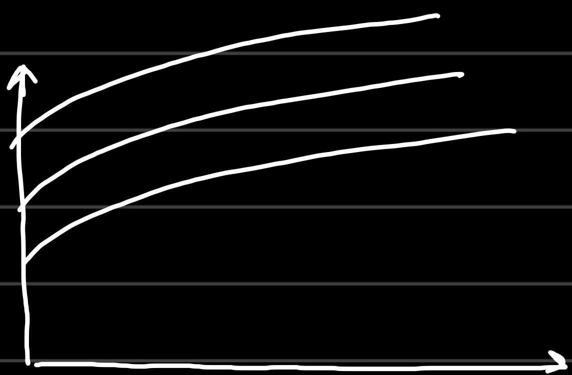
# Lecture 8

# Metal Working

Strain Hardening:

$$\sigma = K\varepsilon^{n}$$

strain hardening exponent.



Flow curves shifts upward with increasing $\dot{\varepsilon}$.

$$\sigma = C\,\dot{\varepsilon}^{m}$$

Flow stress. — constant — strain rate sensitivity

→ material becomes more sensitive at higher temperatures.

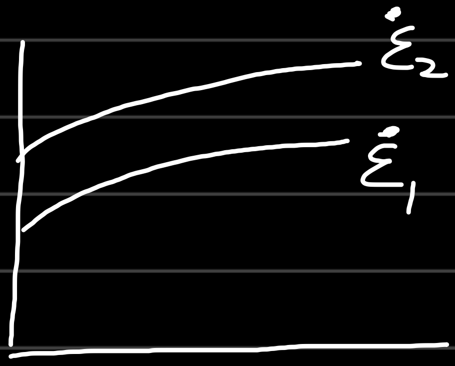
$m \sim 0.2 - 0.3$ {at high temperature}

$m \sim 0 - 0.03$ {at low temperature}

$m = f(T)$ {function of temperature}

# To determine m:

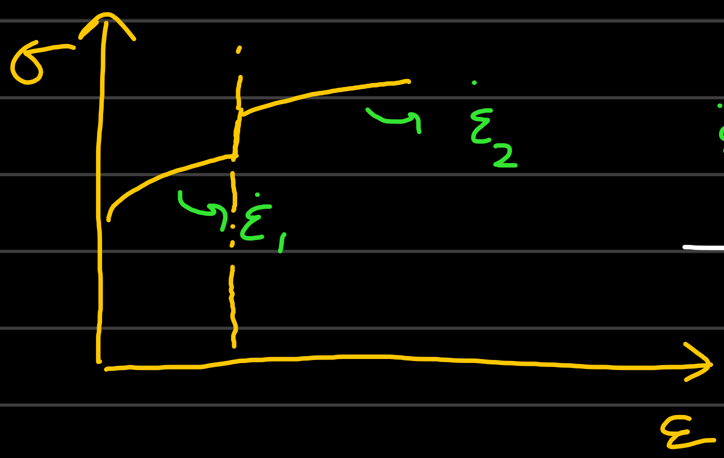
i) Tensile test: @ $\dot{\varepsilon}_1$
at a particular T.




$\dot{\varepsilon}_2 > \dot{\varepsilon}_1$

ii) Strain-rate jump test.

↳ Single test.

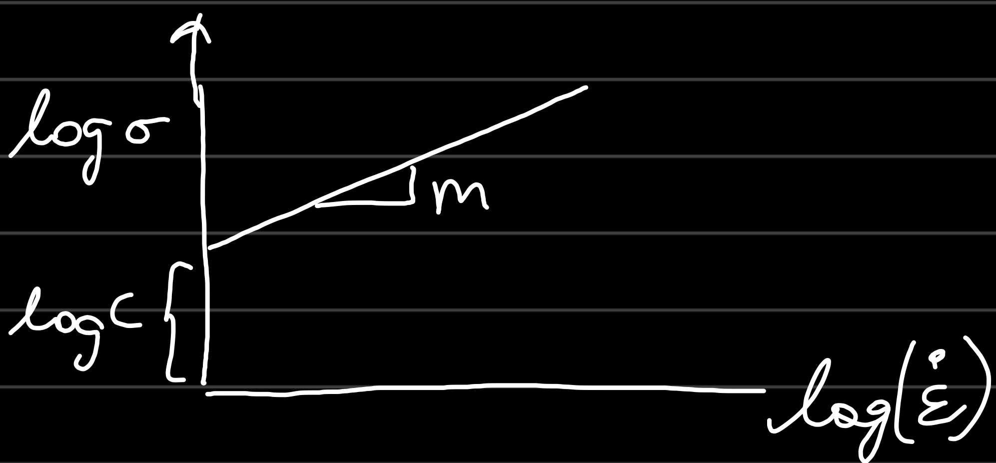



$\dot{\varepsilon}_2 > \dot{\varepsilon}_1$

→ determine value of m.

iii)
$$\sigma = C\dot{\varepsilon}^m$$

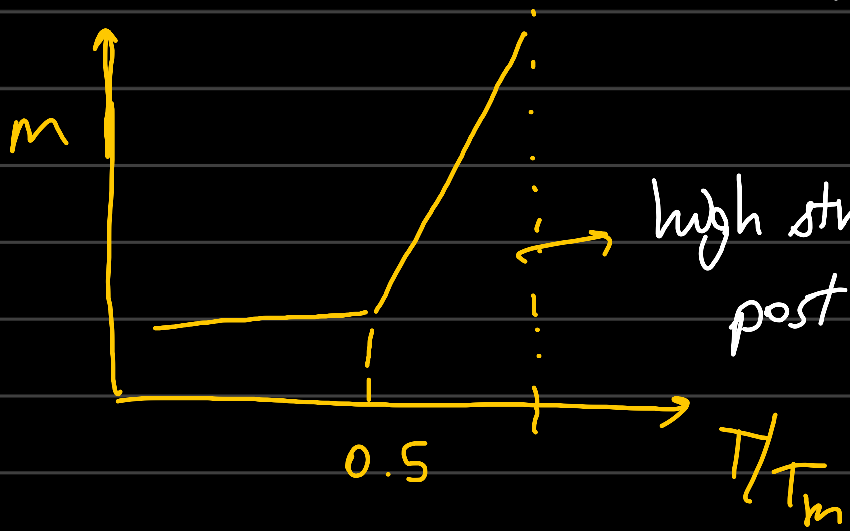
$$\log\sigma = m\log(\dot{\varepsilon}) + \log C$$



→ at room temperature : $m \approx 0$.

↳ flow stress remains more or similar for both rolling & uniaxial tensile tests.

→ high strain-rate processes needs to be taken care while dealing with elevated temp.




→ high strain rate sensitivity post recrystallization/ hot working zone.

# Super-plastic forming:

Superplasticity: strain % > 1000 %

↳ material behaving like rubber-band.

↳ permanent strain of >1000%

→ In typical ductile metals, upper limit of plastic strain: 100%

→ Superplasticity achieved under special conditions.

Eg: Bi-Sn alloy wire: stretched to 1950% {superplasticity}

Deformation

- routine plastic deformation
- severe plastic deformation
  - ↳ ECAP
  - ↳ high pressure Torsion (HPT)
  - ↳ ARB ( Roll Bonding)

→ microstructure grain refinement achieved.

Conditions:

→ An extremely fine grain size (< 1 μm) with equiaxed grain structure.

→ High temperature (T > 0.5 $T_m$)

→ low strain rates.

* Huge amt of strain can accomodated by sliding of GB : Creep phenomenon.

→ at high temp, GB can slide easily.

→ at high temp, grain growth possible also low strain rate.

↳ to compensate for this grain growth, and provide stability in microstructure, small grain size is desirable.

## Zener-Holloman :

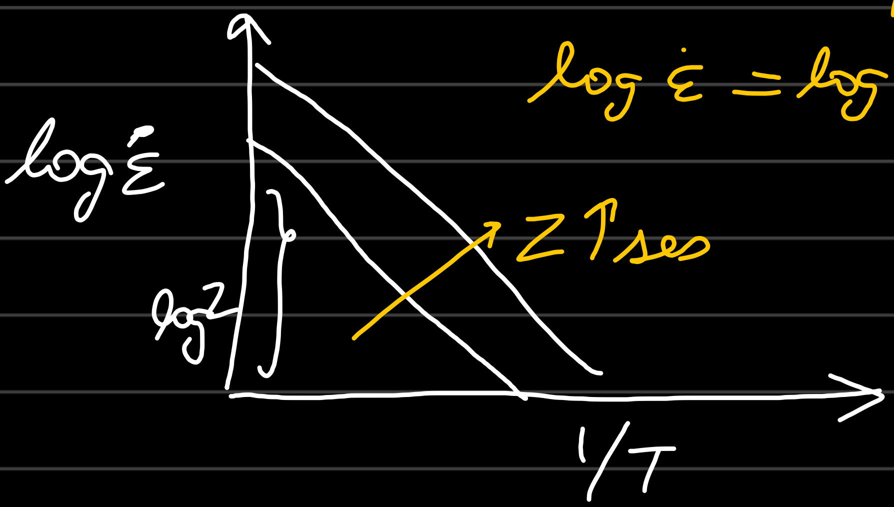
$$\underbrace{Z}_{\text{Zener-Holloman parameter}} = \underbrace{\dot{\varepsilon}}_{\text{strain rate}} \exp\left(\frac{Q}{RT}\right)$$

$Q$ → activation energy for deformation process

$T$ → in K

$$\log Z = \log \dot{\varepsilon} + \frac{Q}{R}\left(\frac{1}{T}\right)$$

$$\log \dot{\varepsilon} = \log Z - \frac{Q}{R}\left(\frac{1}{T}\right)$$



☆ $$\dot{\varepsilon} = A[\sinh(\alpha\sigma)]^n \exp\left(\frac{-Q}{RT}\right)$$

$$Z = A[\sinh(\alpha\sigma)]^n$$ hyperbolic sine fnc.

→ higher $Z$ ⇒ higher $\sigma$.

☆ Effect of Z on microstructure:

high Z:
- ↳ high $\dot{\varepsilon}$ ↳ more hardening
- ↳ high $\sigma_{flow}$
- ↳ less time for dislocation movement
- ↳ low T, low recovery

☆ elongated grain structure and potential cracking

low Z:
- ↳ low $\dot{\varepsilon}$
- ↳ low $\sigma_{flow}$
- ↳ easy flow of dislocations.

☆ recrystallized & refined grain microstructure
↳ delayed failure {early failure overcome}

* The Z parameter is used to determine, the optimal strain rate during hot metal working processes.