# 1. (15 points) Steady-State Diffusion

- In order to solve this problem, we must first compute the value of $D_0$ from the data given at 727 °C (1000 K); this requires the combining of both Equations 7.2 and 7.8 as

$$J = -D\frac{\Delta C}{\Delta x} = -D_0\frac{\Delta C}{\Delta x}\exp\left(-\frac{Q_d}{RT}\right)$$

- Solving for $D_0$ from the above expression gives

$$D_0 = -\frac{J}{\frac{\Delta C}{\Delta x}}\exp\left(\frac{Q_d}{RT}\right) = -\frac{5.0\times10^{-10}\left[\frac{\mathrm{kg}}{\mathrm{m^2\cdot s}}\right]}{-500\left[\frac{\mathrm{kg}}{\mathrm{m^4}}\right]}\exp\left[\frac{83100\left[\frac{\mathrm{J}}{\mathrm{mol}}\right]}{8.31\left[\frac{\mathrm{J}}{\mathrm{mol\cdot K}}\right]\times1000\,[\mathrm{K}]}\right]$$

$$= 10^{-12}\times e^{10}\left[\frac{\mathrm{m^2}}{\mathrm{s}}\right]$$

- The value of the diffusion flux at 1300 K may be computed using these same two equations as follows:

$$J = -D_0\frac{\Delta C}{\Delta x}\exp\left(-\frac{Q_d}{RT}\right) = -10^{-12}\times e^{10}\left[\frac{\mathrm{m^2}}{\mathrm{s}}\right]\times\left(-500\left[\frac{\mathrm{kg}}{\mathrm{m^4}}\right]\right)\exp\left[-\frac{83100\left[\frac{\mathrm{J}}{\mathrm{mol}}\right]}{8.31\left[\frac{\mathrm{J}}{\mathrm{mol\cdot K}}\right]\times1300\,[\mathrm{K}]}\right]$$

$$\therefore J = 5\times10^{-10}\times\exp\left[\frac{30}{13}\right]\left[\frac{\mathrm{kg}}{\mathrm{m^2\cdot s}}\right]$$



# 2. (20 points) Stress-Strain Curve

- **(10 points) Typical Stress-Strain Curve of Mild Steel**
  - Region OB: linear elastic region
  - Region BC: yielding (항복), the material deforms without an increase in the applied load

  ➔ The material becomes perfectly plastic (The elongation is typically 10 to 15 times larger than that of region OA)
  - Region CD: strain hardening (변형경화) or work hardening (가공경화)

  ➔ The resistance of the material to further deformation increases due to the change of its crystal structures
  - Stress at the point B ($B_Y$): yield stress (항복응력) or yield strength (항복강도)
  - Stress at the point D ($D_Y$): ultimate stress (극한응력) or ultimate strength (극한강도)

- **(10 points) True Stress & Strain**
  - Region CE': True stress-true strain curve ➔ True stress keeps increasing
  - At point D, necking occurs, and thus, further stretching is accompanied by a reduction in the load, and the reduction of area becomes clearly visible
  - Sample area changes when sample stretched.
  - Definition of true stress: $\sigma_T = F/A_i$
  - Definition of true strain: $\varepsilon_T = \ln(\ell_i/\ell_o)$
  - Relationship between true stress and nominal stress: $\sigma_T = \sigma(1+\varepsilon)$
  - Relationship between true stress and nominal stress: $\varepsilon_T = \ln(1+\varepsilon)$

## 3. & 4.

- 3. **(15 points)**: Please refer to the lecture notes.
- 4. **(20 points)**: Please refer to the lecture notes.



## 5. (a) (7 points) Creep Behavior

- **The Larson–Miller parameter is a means of predicting the lifetime of material vs. time and temperature using a correlative approach based on the Arrhenius rate equation.**
- **Larsen Miller parameter $P_{LM}$ is used to represent creep-stress rupture data.**

$$\dot{\varepsilon}_s = K_2 \sigma^n \exp\left(-\frac{Q_c}{RT}\right)$$

$$\frac{\Delta l}{\Delta t} = A' \exp\left(-\frac{Q_c}{RT}\right)$$

$$\ln\left(\frac{\Delta l}{\Delta t}\right) = \ln(A') - \frac{Q_c}{RT}$$

$$\frac{Q_c}{R} = T\left[B + \ln(\Delta t)\right] \quad \text{where } \mathrm{B} = \ln\left(\frac{A'}{\Delta l}\right)$$

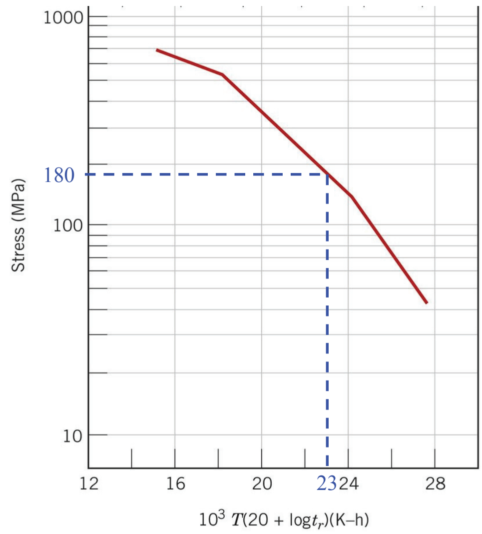
$$\therefore\ P_{LM} = T\left[C + \log(t_r)\right]$$

- T = temperature(K),
- $t_r$ = stress-rupture time (h)
- C = Constant (order of 20)

# 5. (b) (8 points) Creep Behavior

- We are asked in this problem to calculate the temperature at which the rupture lifetime is 1000 h when an S-590 iron component is subjected to a stress of 180 MPa. From the curve shown in the figure, at 200 MPa, the value of the Larson-Miller parameter is about $23\times10^3$ (K-h). Thus,

$$P_{LM} = T\left[C + \log(t_r)\right]$$
$$23\times10^3\,[\text{K-h}] = T\left[20 + \log(1000\text{ h})\right][\text{K-h}]$$
$$\therefore T = \frac{23\times10^3}{23} = 1000\,[\text{K}]$$






# 6. (15 points) Fracture of Pressure Vessel

1. The stress intensity factor for a given geometry is given as, $K_I = Y\sigma\sqrt{\pi a}$ where Y is a shape factor.
2. The leak-before-break criterion is just met when one-half the internal crack length, *a*, is equal to the thickness of the pressure vessel, *t*-that is, when *a*=*t*.
3. Fracture criterion for linear elastic materials: $K_I = K_{IC}$

- By combining above three equations, we can obtain $K_{IC} = Y\sigma\sqrt{\pi t}$
- For this spherical pressure vessel, the circumferential wall stress, σ, is a function of the pressure, *p*, in the vessel, the radius, *r*, and wall thickness, *t*, according to $\sigma = pr/2t$, and thus, $t = pr/2\sigma$. The stress, σ, is replaced by the yield strength because the tank should be designed to contain the pressure without yielding.

$$K_{IC} = Y\sigma_Y\sqrt{\pi\frac{pr}{2\sigma_Y}} \rightarrow \therefore p = \frac{2}{Y^2\pi r}\left(\frac{K_{IC}^2}{\sigma_Y}\right)$$