NE591 exam 2 Fu-Yun Tsai

3\. 0-D defect : point defect

ex: Vacancies
self interstitial atom (SIA)
interstitial impurity atoms
substitutional impurity atoms

3-D defect :

voids (larger clusters of vacancies)
precipitates (clusters of impurity atoms)

4\. Stoichiometry affects
- melting temperature
- thermal conductivity
- chemical reactions at inner cladding surface

5\. Grain size affects
- fission gas release
- swelling
- thermal conductivity
- creep

7\. Fuel performance codes can predict:

① temperature profile in fuel and volumetric change of fuel.

② temperature profile and stress in cladding

③ gap heat transport, mechanical interaction between fuel and cladding and gap pressure.

8. The driving force for fuel densification is the change of free energy resulting from decreasing in surface area of pores and decreasing of the surface free energy.

9. Driving forces for grain growth:

① Temperature gradients

② Elastic energy gradients

③ Dislocation energy gradients

Grain boundary motion can be inhibited by pores, precipitates, solut atoms.

6. Strain hardening is a process that makes a metal harder and stronger by plastic deformation.

When a metal is strained beyond the yield stress, more and more stress is required to produce additional plastic deformation and the metal seems to have become more stronger and more difficult to deform.

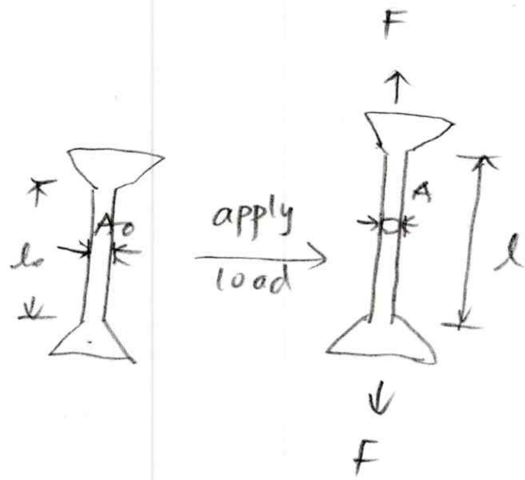
Dislocation motion causes plastic defomation, dislocation pile up causes hardening.

2. Elastic deformation is a reaction that the shape of a material change when the stress applies. The deformation is temporary and is recoverable once the stress is released. It's caused by stretching of the atom lattice.

Plastic deformation is the permanent distortion that occurs when a material is subjected to stress that exceed its yield strength and cause it to deform. It's caused by breaking bonds.

1.

	Engineering	True
stress (σ)	$\frac{F}{A_o}$	$\frac{F}{A}$
strain (ε)	$\frac{l-l_o}{l_o}$	$\int_{l_o}^{l} \frac{dl}{l} = \ln\left(\frac{l}{l_o}\right)$



where l_o is original length

l is the length when the load applies

A_o is the initial cross section area

A is the deformed cross section area

10.

a)

```
In[1]:= (*stress in thin-walled assumption*)
        p = 20 (*MPa*);
        δ = 0.8 (*mm*);
        Ra = 5.4 (*mm*);
        Print["σθ", "=", p * Ra / δ, " MPa"];
        Print["σz", "=", p * Ra / (2 δ), " MPa"];
        Print["σr", "=", -p / 2, " MPa"]

        σθ=135. MPa

        σz=67.5 MPa

        σr=-10 MPa
```

b)

```
In[2]:= (*stress @ midpoint in thick-walled assumption*)
        p = 20 (*MPa*);
        R0 = 5.8 (*mm*);
        Ri = 5.4(*mm*);
        Ra = 5.0 (*mm*);
        r = 5.4;
        Print["σr", "=", -p * ((R0 / r) ^2 - 1) / ((R0 / Ri) ^2 - 1),
         " MPa"];
        Print["σθ", "=", p * ((R0 / r) ^2 + 1) / ((R0 / Ri) ^2 - 1), " MPa"];
        Print["σz", "=", p / ((R0 / Ri) ^2 - 1), " MPa"]

        σr=-20. MPa

        σθ=280.357 MPa

        σz=130.179 MPa
```

c)

$$\sigma\theta\ (\text{thick}) = 2.07\ \sigma\theta\ (\text{thin})$$

$$\sigma z(\text{thick}) = 0.52\ \sigma z(\text{thin})$$

$$\sigma r\ (\text{thick}) = 2\ \sigma r(\text{thin})$$

11.

```
In[6]:= (*Max stress in a fuel pellet due to thermal expansion*)
Rf = 0.45 (*cm*);
LHR = 250 (*W/cm*);
k = 0.1 (*W/cm-K*);
Y = 290 * 10^3 (*MPa*);
α = 8.2 * 10^-6 (*1/K*);
v = 0.3;
deltaT = LHR / (4 * Pi * k) (*K*);
σ = α * Y * deltaT / (4 * (1 - v));
r = Rf;
Print["Maximum stress", "=", -σ * (1 - 3 * (r / Rf) ^2),
 " MPa"]

Maximum stress=337.92 MPa
```

→ B hoop stress

12. Before:

$$T_0 - T_{fuel} = \frac{LHR}{4\pi k_f} = \frac{325\ W/cm}{4\pi \times 0.05\ W/cm\text{-}K} = 517.25\ K.$$

$$T_{fuel} - T_{gap} = \frac{LHR \times t_{gap}}{2\pi R_{fuel} k_{gap}} = \frac{325\ W/cm \times 0.02\ cm}{2\pi \times 0.5\ cm \times 0.04\ W/cm\text{-}K} = 51.73\ K$$

T_{gap}: 450 K

$\Rightarrow T_{fuel} = 501.73\ K$

center line temperature (before thermal expansion):

$$T_0 = 501.73 + 517.25 = 1018.98\ K$$

thermal expansion

$$\Delta t_{gap} = \bar{R}_c \alpha_c (\bar{T}_c - T_{ref}) - \bar{R}_f \alpha_f (\bar{T}_f - T_{ref})$$

$$\bar{R}_c = R_f + t_{gap} + \frac{t_c}{2}$$ unknown ? assume $\bar{R}_c = R_c = 0.5 + 0.02 = 0.52\ cm$

$$\bar{T}_c = \frac{T_{ci} + T_{co}}{2}$$ assume $\bar{T}_c = T_{ci} = 450\ K$

$$\bar{T}_f = \frac{T_0 + T_f}{2} \Rightarrow \bar{T}_f = T_0 - \frac{T_0 - T_{fuel}}{2} = 1018.98 - \frac{517.25}{2} = 760.355\ K$$

$$\bar{R}_f = R_f = 0.5\ cm$$

$$\Delta t_{gap} = 0.52 \times 4.5 \times 10^{-6}(450 - 300) - 0.5 \times 15 \times 10^{-6}(760.355 - 300) = -3.1017 \times 10^{-3}\ cm$$

$$\therefore t'_{gap} = 0.02\ cm - 3.1017 \times 10^{-3}\ cm = 0.0169\ cm$$

After expansion:

$$T_{fuel} - T_{gap} = \frac{LHR \times t'_{gap}}{2\pi R_{fuel} \times k_{gap}} = \frac{325\ W/cm \times 0.0169\ cm}{2\pi \times 0.5\ cm \times 0.04\ W/cm\text{-}K} = 43.708\ K$$

T_{gap}: 450 K

center line temperature (after thermal expansion):

$$T_0 = 517.25\ K + (450 + 43.708)\ K = 1010.96\ K$$

13.

$$\sigma^* = \frac{\alpha E(T_o - T_s)}{4(1-\nu)} \; ; \; \sigma_{\theta\theta}(\eta) = -\sigma^*(1-3\eta^2) \; ; \; \eta = \frac{r}{R_F}$$

$$-\frac{\sigma_{fr}}{\sigma^*} = 1 - 3\eta^2$$

$$T_o - T_s = \frac{LHR}{4\pi k_f} = \frac{200 \text{ W/cm}}{4\pi \times 0.05 \text{ W/cm}\cdot\text{K}}$$

$\sigma_{fr} = 120$ MPa.

$$\sigma^* = \frac{10.5\times10^{-6}(1/\text{K}) \times 210\times10^3 \text{ MPa} \times \left(\frac{200}{4\pi\times0.05}\right)}{4(1-0.25)}$$

$$\doteq 233.96 \text{ MPa}$$

$$\eta = \sqrt{\frac{\left(1+\frac{120}{233.96}\right)}{3}} = 0.710$$

$$r = \eta R_F = 0.710 \times 0.55 = 0.3906 \text{ cm}$$