(5) - Strain hardening is wherein plastic deformation from exposure to extrinsic load causes
Pement ~~de~~ strain, even after load is removed.

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- An increase in yield strain

- what is happening in the microstructure to cause this?

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(6) - Thermal Conductivity
- Behaviour of fission products
6/6
- Chemical reaction between products at inner cladding
- Melting temperature

(7) (a) Temperature profile and volume change of fuel
(b) Temperature profile of cladding; stress profile of cladding
6/6
(c) Gap pressure estimation, heat transport across gap, mechanical interraction betwen
fuel and cladding

(8) (1) Fission gas production and diffusion to grain boundary
(2) Grain boundary bubble nucleation and growth, and increased interconnectiveness
9/9
(3) Gas transport to free surfaces through interconnected bubbles.

(9) - Instability of crystalline structure secondary to accumulation of defects.
- Reduction in material conductivity due to increase porosity value.
- ↑ retention of fission gas bubbles causing reduced pressure on cladding due to
6/6
gas present in plenum.
- Increase in thermal conductivity of fuel
- Increase in fissile density of fuel due to increased ~~plutonium~~ Plutonium production.

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(10) (a) - Point defects are 0D defects; Example is vacancies; (b) 3D example = precipitate

(11) - 1° driving force for ~~grain~~ grain growth is (a) reduction of grain boundary energy.

Others ≤ (b) Temperature gradient

6/6 (c) elastic energy gradient

(d) Dislocation energy gradient.

- 1° force for fuel densification is reduction in available free energy secondary to reduction in surface area.

(12) - Valence state of U in UO_2 is +3 +4

3/4 - Possible valence states are +4, +5, and +6

(2)

(a) Thin walled

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$$\sigma_r = -P/2 = 50/2 = -25\ \text{MPa}$$

$$\sigma_\theta = \frac{PR}{\delta} = \frac{50 \times 5.4}{1.2} = 225\ \text{MPa}$$

$$\sigma_z = \frac{PR}{2\delta} = 225 \times \frac{1}{2} = 115.2\ \text{MPa}$$

(b) $$\sigma_r = -\frac{P\left[(R_o/r)^2 - 1\right]}{(R_o/R_i)^2 - 1}$$

$r = R_i$

$R_o = R_i +$ thickness

$\bar{R} = 5.4$

$R_i = 4.8$ $R_o = 6.0$

$$= -50\,\frac{(6.8/5.6)^2 - 1}{(6.8/5.6)^2 - 1}$$

$$= -50\ \text{MPa}$$

$$\sigma_\theta = \frac{P\left[(R_o/r)^2 + 1\right]}{(R_o/R_i)^2 - 1}$$

$$= 50\,\frac{(6.8/5.6)^2 + 1}{(6.8/5.6)^2 - 1} = \frac{50 \times 2.47}{0.47}$$

$$= 263\ \text{MPa}$$

$$\sigma_z = \frac{P}{(R_o/R_i)^2 - 1}$$

since fuel is enclosed in Zr cladding.

1 ~~Maximum stress is~~

$$\frac{50}{\left(6.8/5.6\right)^2 - 1} = \frac{50}{0.47} = 106.38\ MPa$$

(c) Maximum strain = $\varepsilon_\theta = \frac{1}{E}\left(\sigma_\theta - \nu\left(\sigma_r + \sigma_z\right)\right)$ ✓

$$= \varepsilon_\theta = \frac{1}{180}\left(263 - 0.28\left(106.38 - 50\right)\right)$$

right formula, incorrect stresses

$$\Rightarrow \varepsilon_\theta = 1.37$$

(3) Δ gap thickness = Δ Radius of cladding − Δ Radius of fuel. ✓

$$= 0.52 + 0.005\ cm + \frac{0.08}{2} \Rightarrow 0.565 \Rightarrow \bar{R}_{cladding}.$$

Δ Radius of cladding $\Rightarrow 0.565 \times 4.5 \times 10^{-6} \times$ ~~(550 − 300)~~ (550 +

~~$\Rightarrow 6.356 \times 10^{-4}$~~ cm

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$\bar{R}_{fuel}$ ~~$\bar{R}_{fuel} \Rightarrow 0.52 \times 15 \times 10^{-6} \times \left(\frac{T_0 + T_s}{2} - 300\right)$~~

=

(1) (a) $T_0 - T_s = \frac{\Delta H R}{4\pi K} = \frac{250}{4\pi\, 0.1} = 198.94$

and $\sigma^* = \frac{\alpha E (T_0 - T_s)}{4(1-\nu)}$ ✓

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$\therefore \Rightarrow \frac{8.2\times10^{-6} \times (198.94)}{4 - 4(0.3)}$ E

should just be 4×0.3

$\Rightarrow 5.826\times10^{-4}$

$\therefore \sigma_\theta = -\sigma^*(1-3\eta^2)$ where at max stress $\eta = 1$.

$= -5.826\times10^{-4}(1-3(1)^2)$

$\Rightarrow -5.826\times10^{-4}(-2)$

$\Rightarrow 1.1652\times10^{-3}$ //.

→ does this make sense?

(4)

$$\tau = \frac{D \times t}{a^2}$$

9/12

$$= \frac{2\times10^{-15} \times 6.308\times10^{7}}{(8\times10^{-4})^2}$$

$\tau = 0.19 > \pi^{-2}$

$\tau = 1.577\times10^{-4}$ $\underline{a}$ is $< \pi^{-2}$

correct in-pile, but wrong τ

So :

$$f = 4\sqrt{\frac{2\times10^{-15}}{\pi \times (8\times10^{-4})^2}} - \frac{3}{2}\times(2\times10^{-15}) \times \frac{6.308\times10^{7}}{(8\times10^{-4})^2}$$

$\Rightarrow 3.9788\times10^{-9} - 0.2956875$

$\Rightarrow -.295687$ //.

$\Rightarrow 29.5\%$.

→ the negative should have indicated something was wrong...

$\therefore F = 2\times10^{13} \times 0.3017 \times 6.308\times10^{7}$ ✓

So amount released $\Rightarrow (2\times10^{13}\times0.3017\times6.308\times10^{7}) \times 0.2956875$

$\Rightarrow 1.125\times10^{20}$ //.

(1) (b)

here is 1b

$1.1652\times10^{-3} = -120\,(1-3(x)^2)$

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

$$-\frac{1.1652\times10^{-3}}{120} - 1 = -3x^2$$

$$\Rightarrow x = \sqrt{\left(\frac{1.1652\times10^{-3}}{120}+1\right)\times \frac{1}{3}} \Rightarrow 0.57735 //.$$