

(10)

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Exam ②

1

$$R_f = 4.5 \text{ mm}$$

$$\Delta HR = 250 \text{ w/cm}$$

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$$a) K = 0.1 \text{ w/cm} \cdot K$$

$$E = 290 \text{ GPa}$$

$$\omega = 0.3$$

$$\alpha = 8.2 \times 10^{-6} \text{ 1/K}$$

$$\alpha_{max} = ?$$

assuming that the max stress is the hoop stress: ✓

$$\alpha_o(\eta) = -\alpha^* (1 - 3\eta^2)$$

$$\text{where } \eta = r/R_f \quad \text{and } \alpha^* = \frac{\alpha E (T_0 - T_s)}{4(1-\nu)} \quad \checkmark$$

To calculate α^* we need to calculate $(T_0 - T_s)$

$$T_0 - T_s = \frac{\Delta HR}{\pi R_f} = \frac{250}{\pi \times 0.1} = 198.94 \text{ K} \quad \checkmark$$

$$\therefore \alpha^* = \frac{8.2 \times 10^{-6} \times 290 \times 10^3 \times 198.94}{4(1-0.3)} = 168.95 \text{ MPa} \quad \checkmark$$

we know that the max hoop stress is at $\eta = 1$ (p67 pg. 28)

where $r = R_f$

$$\therefore \alpha_o(\eta=1) = -168.95 (1 - 3(1)^2) = 337.91 \text{ MPa}$$

$$\therefore \alpha_{max} = 337.91 \text{ MPa.} \quad \checkmark$$

b) $\sigma_f = 120 \text{ MPa}$, crack extension?

By solving for η :

$$\sigma_\theta = \sigma_f = -\sigma^* (1 - 3\eta^2) \Rightarrow -\frac{\sigma_f}{\sigma^*} = 1 - 3\eta^2$$

$$\therefore \frac{1}{3} \left(\frac{\sigma_f}{\sigma^*} - 1 \right) = \eta^2 \Rightarrow \eta = \sqrt{\frac{1}{3} \left(1 + \frac{\sigma_f}{\sigma^*} \right)}$$

$$\therefore \eta = \sqrt{\frac{1}{3} \left(1 + \frac{120}{168.95} \right)} = 0.755$$

$$\therefore r = \eta \cdot R_f = 0.755 \cdot 4.5 = 0.57 \text{ mm}$$

$$\boxed{2} \quad P = 50 \text{ MPa}$$

$$\bar{R} = 5.4 \text{ mm}$$

$$t_c = 1.2 \text{ mm}$$

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a)

$$\alpha_\theta = \frac{P\bar{R}}{8} = \frac{50 \times 5.4}{1.2} = 225 \text{ MPa}$$

$$\alpha_z = \frac{\alpha_\theta}{2} = \frac{225}{2} = 112.5 \text{ MPa}$$

$$\alpha_r = \frac{-P}{2} = \frac{-50}{2} = -25 \text{ MPa.}$$

$$b) \quad R_o = \bar{R} + \frac{t_c}{2} = 5.4 + 0.6 = 6 \text{ mm}$$

$$R_i = \bar{R} - \frac{t_c}{2} = 4.8 \text{ mm}$$

for ($r = 5.6 \text{ mm}$):

12.9

$$\alpha_r = -P \frac{\left(\frac{R_o}{r}\right)^2 - 1}{\left(\frac{R_o}{R_i}\right)^2 - 1} = -50 \frac{\left(\frac{6}{5.6}\right)^2 - 1}{\left(\frac{6}{4.8}\right)^2 - 1} = 13.15 \text{ MPa}$$

- small calculator error?

$$\alpha_z = \frac{P}{\left(\frac{R_o}{R_i}\right)^2 - 1} = \frac{50}{\left(\frac{6}{4.8}\right)^2 - 1} = 88.8 \text{ MPa}$$

$$\alpha_\theta = P \frac{\left(\frac{R_o}{r}\right)^2 + 1}{\left(\frac{R_o}{R_i}\right)^2 - 1} = 50 \times \frac{\left(\frac{6}{5.6}\right)^2 + 1}{\left(\frac{6}{4.8}\right)^2 - 1} = 190.92 \text{ MPa}$$

c) Assuming that the max strain will be in the θ -dire.

$$\epsilon_\theta = \frac{1}{E} (\alpha_\theta - \nu(\alpha_r + \alpha_z)) = \frac{1}{180 \times 10^3} (190.92 - 0.28(13.15 + 88.8))$$

$$= 9.09 \times 10^{-4} = 0.09 \%$$

(b) / b

[3]

$$R_f = 0.52 \text{ cm}, t_{gap} = 0.005 \text{ cm}, t_{clad} = 0.08 \text{ cm}$$

$$k_f = 0.05 \text{ W/cm.K}, k_{gap} = 0.003 \text{ W/cm.K}, T_{co} = 550 \text{ K}$$

$$\alpha_f = 15 \times 10^{-6} \text{ 1/K}$$

$$k_{clad} = 0.15 \text{ W/cm.K}$$

$$\alpha_c = 4.5 \times 10^{-6} \text{ 1/K}$$

$$\Delta HR = 225 \text{ W/cm}$$

$$T_{ref} (\text{fuel, clad}) = 300 \text{ K}$$

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

for clad:

$$\bar{R}_c = R_f + R_{gap} + \frac{t_{clad}}{2} = 0.52 + 0.005 + \frac{0.08}{2} = 0.565 \text{ cm}$$

To calculate the change in temp:

$$T_{ci} - T_{co} = \frac{\Delta HR}{2\pi R_f} \frac{t_c}{k_c} = \frac{225}{2\pi \cdot 0.52} \frac{0.08}{0.15} = 36.72 \text{ K}$$

$$\bar{T}_c = 550 + \frac{36.72}{2} = 568.36 \text{ K}$$

$$\Delta t_c = 0.565 \times 4.5 \times 10^{-6} + (568.36 - 300) = 6.813 \times 10^{-4} \text{ cm}$$

$$T_{ci} - T_{co} = \frac{\Delta HR}{2\pi R_f} \frac{t_c}{k_c} = \frac{225}{2\pi \cdot 0.52} \frac{0.08}{0.15} = 36.72 \text{ K}$$

$$T_{ci} = 550 + 36.72 = 586.72 \text{ K}$$

$$T_f - T_{ci} = \frac{225}{2\pi(0.52)} \frac{0.005}{0.003} = 114.77 \text{ K}$$

$$T_f = 586.72 + 114.77 = 701.49 \text{ K}$$

$$T_0 - T_F = \frac{225}{\text{uP} (0.05)} = 358.09 \text{ K}$$

✓

$$\therefore T_0 = 701.49 + 358.09 = 1059.58 \text{ K}$$

✓

$$\bar{T}_F = \frac{T_0 + T_F}{2} = \frac{701.49 + 1059.56}{2} = 880.535 \text{ K}$$

$$\therefore \Delta t_F = 0.52 \times 15 \times 10^{-6} \times (880.5 - 300) = 4.52 \times 10^{-3} \text{ cm}$$

$$\therefore \text{tg} = 0.005 + 6.813 \times 10^{-4} - 4.52 \times 10^{-3} \text{ cm} = 1.14 \times 10^{-3} \text{ cm}$$

✓

(4)

$$a = 8 \times 10^{-11} \text{ cm}$$

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$$\dot{F} = 2 \times 10^{13} \text{ fission/cm}^3 \text{ sec}$$

$$D = 2 \times 10^{-15} \text{ cm}^3/\text{yr}$$

of atoms/cm³; t = 2 years, y = 0.3017.

To determine which equation to be used:

$$\approx = D \times \frac{t}{a^2} = 2 \times 10^{-15} \times \frac{2 \times 365 \times 24 \times 60 \times 60}{(8 \times 10^{-11})^2} = 0.1971 \times \pi^{-2}$$

$$\therefore f = 1 - \frac{6}{\pi^2} e^{-\pi^2 \times 0.1971} = 0.9131$$

$$\text{total fission released} = f y \dot{F} t = 0.9131 \times 0.3017 \times 2 \times 10^{13} \times (2 \times 365 \times 24 \times 60 \times 60)$$

$$= 3.47 \times 10^{20} \text{ atom/cm}^3.$$

- in-pile release eqns needed, not annealing

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⑤

Strain hardening is the increase of the stress required to produce the same value of the strain (i.e. the slope of the stress-strain curve in the plastic region is positive).

Strain hardening occurs ~~not~~ mainly due to the increase of the dislocation density. So dislocation will start to interact with each other and impede the motion of each other which decreases the mobile dislocation density.

- ⑥
- ① melting temp. ✓
 - ② thermal conductivity ✓ 6%
 - ③ grain growth ✓
 - ④ fission gas release

⑦ \Rightarrow for fuel:

- ① calculate temp profile ✓ 6%
- ② ~ volumetric change

\Rightarrow for gap:

- ① calculate gap heat transport
- ② ~ the mechanical interaction between fuel and clad
- ③ ~ the gap pressure.

\Rightarrow for clad:

- ① calculate temp profile and stress.

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- 1) Diffusion of gas atoms to GBs. ✓ 9/9
- 2) Growth and interconnection of GB bubbles
- 3) Transport of gas atoms through interconnected bubble to a free surface.

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* Due to the change in the flux profile, we will have strong capture at the periphery of the fuel which will lead to Pu production and increase in the fissile density. Hence, the burnup also will increase - this helps cause HBS

* HBS will have a high porosity because of the large number of pores filled with FG, which will ~~degrade~~ improve the material conductivity, and reduce the mean grain size. K_{th}

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(10)

\Rightarrow 0-D defects \Rightarrow interstitials, substitutional, vacancies
3-D defects \Rightarrow Grain boundary, precipitates

(11) \Rightarrow for fuel densification \Rightarrow the driving force is the change in the free energy by decreasing the surface area of pores.

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\Rightarrow for grain growth \Rightarrow there are many but the most common is reducing the grain boundary energy.

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Valence state for U in UO_2 is U^{4+} . This ~~state~~ ✓

Can be change due to fission products to U^{5+} and U^{6+} .

also +3