Daniel Falkenbach   Exam 2   91   1/6

1) 14/14

Given $r = 4.5\,mm$ $K = 0.1\ W/cm\text{-}K$

$LHR = 250\ W/cm$ $E = 290\ GPa$

$\nu = 0.3$

$\alpha = 8.2E\text{-}6/K$

Find a) $\sigma_{max} = ?$ Max is when $\eta = 1$

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

$$T_0 - T_s = \frac{LHR}{4\pi K} = \frac{250\ W/cm}{(4\pi)(0.1\ W/cm\text{-}K)}$$

$$= 198.94\ K \checkmark$$

$$= \frac{(8.2E\text{-}6/K)(290E3)(198.94\,K)}{4(1-0.3)}$$

$$= 168.96\ MPa \checkmark$$

$$\sigma_\theta = -\sigma^*(1 - 3\eta^2)$$

$$= -168.96\ MPa\,(1 - 3(1)^2)$$

$$\boxed{= 337.97\ MPa} \checkmark$$

b) Find crack depth?

using $\sigma^* = 168.96\ MPa$ ✓

Given $\sigma_{fr} = 120\ MPa$

$$\eta = \sqrt{\left(1 + \frac{120}{168.96}\right)\frac{1}{3}} = 0.755 = 1 - 0.755 \boxed{= 25\%}$$

② $P = 50\ MPa$; $\bar{R} = 5.4mm$; $t_c = 1.2mm$

a) Find thin-walled stresses:

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$$\sigma_\theta = \frac{pR}{t_c} = \frac{(50\ MPa)(0.0054\ m)}{0.0012\ m} \boxed{= 225\ MPa}$$ ✓

$$\sigma_r = -\tfrac{1}{2}P \boxed{= -25\ MPa}$$ ✓

$$\sigma_z = \frac{pR}{2t_c} = \frac{(50\ MPa)(0.0054\ m)}{2(0.0012)} \boxed{= 112.5\ MPa}$$ ✓

b) Find ~~thick~~-wall σ @ $r = 5.6mm = 0.56cm = 0.0056m$

$r_i = 4.8$

$r_o = 6$

$$\sigma_\theta = P\frac{\left(\frac{R_o}{r}\right)^2 + 1}{(R_o/R_i)^2 - 1} = 50\ MPa\frac{\left[(1.0)^2 + 1\right]}{(1.08)^2 - 1} \boxed{= 306.5\ MPa}$$

$\bar{R} = \frac{r_i + r_o}{2} = 5.4$

assuming $r = R_o = 5.6mm$

$r_i = 5.2$

$R_o/r = 1.0$

$R_o/R_i = 1.08$

$$\sigma_r = -P\frac{\left(\frac{R_o}{r}\right)^2 - 1}{(R_o/R_i)^2 - 1} \boxed{= 0\ MPa}$$

$$\sigma_z = P\frac{1}{(R_o/R_i)^2 - 1} = 50\ MPa\frac{1}{1.08^2 - 1} \boxed{= 300.5\ MPa}$$

$r \neq R_o$ here

- misunderstandings on geometry and eqns

c) Find ϵ_{max}? $E = 180\ GPa = 180E3\ MPa$

$\nu = 0.28$

Given $\sigma_\theta > \sigma_z$

$\epsilon_\theta > \epsilon_z$

$$\epsilon_{max} = \epsilon_{\theta\theta} = \frac{1}{E}\left(\sigma_\theta - \nu(\cancel{\sigma_r}^{\,0} + \sigma_z)\right) = \frac{1}{E}(\sigma_\theta - \nu\sigma_z) = \frac{1}{180E3}\begin{pmatrix}306.5 \\ -0.28 \cdot 30\end{pmatrix}$$

$$\boxed{= .00124}$$

✓

- right eqn, wrong values for stress

(3) Find $\Delta t_g = ?$

Given: $R_f = 0.52\,cm$; $t_g = 0.005\,cm$; $T_{co} = 550\,K$

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$k_{fuel} = 0.05\ W/cm\text{-}K$; $t_{clad} = 0.08\ cm$; $LHR = 225\ W/cm$

$k_{gap} = 0.003$ " " ; $k_{clad} = 0.15\ W/cm\text{-}K$

$\alpha_c = 4.5E\text{-}6/K$ $\quad \alpha_f = 15E\text{-}6/K$ $\quad T_{ref}(fuel=clad) = 300\,K$

$$\Delta_{gap} = \bar{R}_c \alpha_c \Delta T_c - \bar{R}_f \alpha_f \Delta T_f$$

$$\frac{\Delta R_f}{} = \alpha_f (T_f - T_{co})$$

$0.52\,cm = (15E\text{-}6/K)(T_f - 550\,K)$

$T_f = 550\,K =$

$\bar{R}_c = R_f + t_{gap} + \frac{t_c}{2} = 0.52 +$

$= 0.5255\,cm$

$\bar{R}_c : 0.565$

$$T_{c1} = T_{co} + \frac{LHR}{2\pi R_f}\frac{t_{clad}}{k_{clad}} = 550\,K + \frac{225\ W/cm}{2\pi(0.52\,cm)}\left(\frac{0.08\,cm}{0.15\ W/cm\text{-}K}\right) = 586.7\,K$$

$$T_F = T_{c1} + \frac{LHR}{2\pi R_f}\frac{t_g}{k_g} = 586.7\,K + \frac{225}{2\pi(0.52\,cm)}\left(\frac{0.005}{0.003}\right) = 701.4\,K$$

$$T_0 = T_f + \frac{LHR}{4\pi k_f} = 701 + \frac{225}{4\pi(0.05)} = 1054.1\,K$$

$\Delta T_c = T_{c1} - T_{co} = 86.7\,K$ $\qquad \Delta T_c : \bar{T}_c - T_0$

$\Delta T_f = T_0 - T_f = 357.7\,K$ $\qquad \Delta T_f : \bar{T}_f - T_0$

$$\Delta t_{gap} = R_c \alpha_c \Delta T_c - R_f \alpha_f \Delta T_f$$

$$= R_c (4.5E\text{-}6/K)(86.7\,K) - (0.52\,cm)(15E\text{-}6/K)(357.7\,K)$$

$$= 0.5255\,cm\,(3.902\times10^{-4}) - 0.0028 = 0.0026\,cm$$

$$t_g = 0.005\,cm - 0.0026\,cm \;\boxed{= 0.0024\,cm}$$

- right sets of eqns, but various parameters incorrectly used

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(4) avg. grain size = 8 micron

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$\phi = 2.0E13$ fissions/cm^3-s

$D = 2E-15$ cm^2/s $\quad \sigma_f = 550b$

$y = 0.3017$

Find released # gas atoms @ $t = 2$ year $= 6.312E7$s

$$V(\text{assume spherical}) = \frac{\pi}{6} d^3 = \frac{\pi}{6}(8\mu m)^3 = 268.1\ mm^3$$
$$= 0.2681\ cm^3$$

$$\dot{F} = N_{U235}\,\phi\,\sigma_F V = (2.5E22\ \text{atoms/cm}^3)(2.0E13\ \text{f/cm}^3\text{s})(550E\text{-}24)(0.2681\ \text{c}$$

- I provided the fission rate

$$= 7.37E13\ \text{fiss/s}$$

$$gP_{tot} = y\dot{F}t = (0.3017)(7.37E13)(6.312E7)$$
$$= 1.404E21\ \text{gas atoms}$$

$$gr = gP_{tot} \cdot f_{gas}$$

Given $\tau > \pi^{-2}$ $\rightarrow$ $f_{gas} = 1 - \frac{0.0662}{Dt/a^2}\left(1 - 0.93 \cdot e^{-\pi^2 \cdot Dt/a^2}\right)$ ✓

how did you know $\tau > \pi^{-2}$?

$$\tau = Dt/a^2 = \frac{(2E-15)(6.312E7_s)}{0.2681\ cm^3} = 0.1973$$

$$f_{gas} = 1 - \frac{0.0662}{0.1973}\left(1 - 0.93\exp(-\pi^2 \cdot 0.1973)\right)$$
$$= 0.709 ✓$$

- wrong $\dot{F}$, thus wrong amount of gas

$$gr = gP_{tot} \cdot f_{gas} = (1.404E21)(0.709) = \boxed{9.954 \times 10^{20}\ \text{atoms released}}$$

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(5) Strain hardening — a mat. property with a value between 0 -> 1, ...

- why does this hardening occur?

0 = Mat. is fully plastically solid while 1 means mat. is fully elastic.

Caused by deformation beyond the mat. yield point, aka plastic deformation... the act hardens the mat.

(6) f(stoich) affects (1) Melting temp ✓

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(2) Thermal conductivity ✓

(3) creep/FGR/grain growth ✓ (dependant on diff)

(7) (1) Numerically model temp in fuel ✓

4/6 (2) " " stress in cladding ✓

(3) Consider gap pressure, closure, and HT effects ✓

(10) 0-D or point defects ⟶ Vacancies ✓

4/4 3-D ⟶ large clusters of vacancies or voids ✓

(8) FGR ⟶ Stage 1 ⟶ intragranular diff. to GB - gas generated

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Stage 2 ⟶ GB gas accumulation/saturation - along the grain boundaries

" "3 ⟶ once gas and connected, it's released

(9) HBS causes degradation of mat. conductivity due to change in crystal structure instability/changes

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-> due to ↑ porosity, but clean grains ↑ K_{th}

-> FG is retained

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(11) Densification is caused by continuation of sintering since fuel is not @ 100% TD... small pores close, pellets shrink and is driven by change in free E from decr. of surf. area of pores. (which decr. of free-E), Grain growth driven by P_d aka pressure... and reduction of GB-Energy. due to temp gradients Energy gradients & dislocation grads

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(12) Valence state of U in UO_2 = U^{4+}.

As U oxidizes it usually goes $U^{4+} \longrightarrow U^{5+} \longrightarrow U^{6+}$ to stay electrically neutral

U^{+3}

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