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Fuel Performance Midterm2

1) true strain accounts for shrinking of the section area and elongation on the further elongation

2) plastic deformation is permanent where elastic deformation will undo and return to normal once forces are released

3) Vacancies, self interstitials, and impurity atoms are 0-D since they are at a single point. Precipitate clusters of impurities or large vacant voids can be considered 3D.

4) Melting temperature, thermal conductivity, and processes such as grain growth, gas release, or creep depend on stoichiometry.

5) The grain size impacts fission gas release, swelling, thermal conductivity and creep - this is largely due to the fact that diffusion often occurs faster along grain boundaries

6)

Strain hardening is the result of plastic deformation leading to a permanent strain which may allow higher yield strains when reloaded

7)

1. numerically model temperature in the fuel
2. numerically model stress in cladding
3. consider gap pressure, closure, heat transfer

8) Fuel densification occurs as porosity is reduced in the reactor due to ~~irradiation~~ change in free energy from decreased surface area of pores. Therefore the system is driven toward the lower free energy state

9) Irradiation can accelerate grain growth - this is more significant for small grains at low temperature

Pores, precipitates, and solute atoms inhibit grain boundary growth by decreasing grain boundary mobility

10 a) $p = 20\,MPa$ $\bar{R} = 5.4\,mm$
$\delta = 0.8\,mm$

$\bar{\sigma}_r = -\frac{1}{2}p = -10\,MPa$

$\bar{\sigma}_\theta = \frac{pR}{\delta} = \frac{(20)(5.4)}{(0.8)} = 135\,MPa$ ~~[illegible]~~

$\bar{\sigma}_z = \frac{pR}{2\delta} = \frac{(20)(5.4)}{1.6} = 67.5\,MPa$

b) $r = \bar{R} = 5.4$, $R_o = 5.4 + 0.4 = 5.8$
$R_i = 5.4 - 0.4 = 5.0$
$R_o/r = 5.8/5.4 = 1.074$
$R_o/R_i = 1.16$

$\sigma_{rr} = -p\left(\frac{(R_o/r)^2 - 1}{(R_o/R_i)^2 - 1}\right) = -20\left(\frac{(1.074)^2 - 1}{(1.16)^2 - 1}\right) = -8.88\,MPa$

$\sigma_{\theta\theta} = p\frac{(R_o/r)^2 + 1}{(R_o/R_i)^2 - 1} = 20\left(\frac{1.074^2 + 1}{1.16^2 - 1}\right) = 124.62\,MPa$

$\sigma_{zz} = p\frac{1}{(R_o/R_i)^2 - 1} = 20\left(\frac{1}{1.16^2 - 1}\right) = -57.9\,MPa$

c) $\sigma_{\theta\theta}$ on the inner surface of thick wall would be the same

11)

$$T_o - T_s = \frac{LHR}{4\pi k} = \frac{250\,W/cm}{4\pi(0.1\,\frac{W}{cm\,K})} = 198.94\,K$$

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

$$= \frac{(8.2\times10^{-6}/K)(2.90\times10^{5}\,MPa)(198.94\,K)}{4(1-0.3)}$$

$$= 168.966\,MPa$$

$$\sigma_{\theta\theta}^{(\eta=1)} = -\sigma^*(1-3) = 2\sigma^* = 337.9\,MPa$$

12)

$$T_0 - T_s = \frac{LHR}{4\pi K}$$

$$\cancel{T_{gap} = T_{clad} + \frac{LHR\, t_{clad}}{2\pi R_{fuel}\, k_{clad}}}$$

$$\cancel{= 450 + (325)(0.02}$$

$$T_s = \underset{(\text{clad in})}{T_{gap}} + \frac{LHR}{2\pi R_f h_{gap}} \qquad h_{gap} = \frac{k_{gap}}{t_{gap}}$$

$$= 450 + \frac{(325)(0.02)}{2\pi(0.5)(0.04)}$$

$$T_s = 501.73\,K$$

$$T_0 = T_s + \frac{LHR}{4\pi K_f} = 501.73 + \frac{325}{4\pi(0.05)}$$

$$= 1018.98\ K \text{ initially}$$

$$\bar{R}_c = 0.5 + 0.02 = 0.52\ cm$$

$$\bar{R}_f = 0.25\ cm$$

$$\bar{T}_f = \frac{(1018.98 + 501.73)}{2} = 760.355\,K$$

12 continued

$$\Delta \delta_{gap} = R_c \alpha_c (T_c - T_{ref}) - R_f \alpha_f (T_f - T_{ref})$$

$$= 0.52(4.5\times10^{-6})(450-300) - 0.25(15\times10^{-6})(760.355-300)?$$

$$= -0.001375 \text{ cm}$$

(0.501726 is new R_f)

$$\delta'_{gap} = ~~[illegible]~~$$
$$0.018625 \text{ cm}$$

$$T_s' = T_{cl} + \frac{LHR}{2\pi R_f h_{gap}}$$

$$= 450 + \frac{(325)(0.018625)}{2\pi(0.501726)(0.04)}$$

$$= 498.0 \text{ K}$$

$$T_o' = T_s' + \frac{LHR}{4\pi k_f} = 498.0 + \frac{325}{4\pi(0.05)}$$

$$T_o' = 1015.25 \text{ K}$$ after one expansion

13)

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

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

$$T_0 - T_s = \frac{200}{4\pi(0.05)} = 318.310$$

$$\sigma^* = \frac{(10.5\times10^{-6}\ 1/K)(210\times10^3\ MPa)(318.310)}{4(1-0.25)}$$

$$= 233.957\ MPa$$

$$\eta = \sqrt{\frac{1}{3}\left(1 + \frac{120}{233.957}\right)}$$

$$= \sqrt{0.504305} = 0.710143$$

$$\eta = \frac{r}{R_f} \rightarrow r = \eta R_f$$

$$= (0.710143)(0.55\ cm)$$

$$= 0.3906\ cm$$