1) $R_f = 0.55$ m $LHR: 350$ W/cm

σ_{max} ? $k_f = 0.05$ W/cm·K $E = 200$ GPa $\nu = 0.35$

$\alpha_F = 10 \times 10^{-6}$ 1/K

$\eta = r/R_f$

fuel!

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

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

$\Delta T = T_0 - T_s = \dfrac{LHR}{4\pi k_f} = \dfrac{350}{4\pi(0.05)} = 557 K$

σ_θ = max @ $r = R_f$ → $\eta = 1$

$$\sigma^* = \frac{(10 \times 10^{-6})(200 \times 10^3)(557)}{4(1-0.35)} = 428.5 \text{ MPa}$$

$$\sigma_\theta = -428.5(1 - 3(1^2)) = \boxed{858 \text{ MPa}}$$

$\sigma_{fr} = 150$ MPa

$\sigma_\theta = \sigma_{fr}$ → $150 = -428.5(1 - 3\eta^2)$

$\eta^2 = 0.45$ $\eta = 0.67$

→ <u>33% into the fuel</u>

2) Cladding Stress State

$p = 55$ MPa $\qquad \bar{r}_c = 0.55$ cm $\qquad \delta_c = 0.05$ cm

$R_{ic} = 0.525$ cm $\qquad R_{oc} = 0.575$ cm

i) $\sigma_\theta = \dfrac{pR}{\delta} \qquad \sigma_r = \dfrac{-p}{2} \qquad \sigma_z = \dfrac{pR}{2\delta}$

$\sigma_\theta = \dfrac{55(0.55)}{0.05} = \underline{605 \text{ MPa}} \qquad \sigma_z = \dfrac{\sigma_\theta}{2} = \underline{302.5 \text{ MPa}}$

$\sigma_z = \dfrac{-55}{2} = \underline{-27.5 \text{ MPa}}$

ii) σ @ $r = R_{ic}$

$\sigma_r = -p\left[\dfrac{(R_o/r)^2 - 1}{(R_o/R_i)^2 - 1}\right] \qquad \sigma_\theta = p\left[\dfrac{(R_o/r)^2 + 1}{(R_o/R_i)^2 - 1}\right] \qquad \sigma_z = \dfrac{p}{(R_o/R_i)^2 - 1}$

$R_o/R_i = \dfrac{0.575}{0.525} = 1.095$

$\sigma_r = -55\left[\dfrac{1.095^2 - 1}{1.095^2 - 1}\right] = \underline{-55 \text{ MPa}}$

$\sigma_\theta = 55\left[\dfrac{1.095^2 + 1}{1.095^2 - 1}\right] = \underline{607.7 \text{ MPa}}$

$\sigma_z = \dfrac{55}{1.095^2 - 1} = \underline{276.3 \text{ MPa}}$

5) $\Delta t_g = \bar{R}_c \alpha_c (\bar{T}_c - T_c^{ref}) - R_p \alpha_p (\bar{T}_p - T_f^{ref})$

$R_f = 0.52$ cm $\quad t_g = 0.005$ cm $\quad T_{co} = 550$ K $\quad t_c = 0.08$ cm

$k_f = 0.04 \ W/cm\text{-}K \quad k_g = 0.003 \ W/cm\text{-}K \quad k_c = 0.15 \ W/cm\text{-}K$

$LHR = 175 \ W/cm \quad \alpha_c = 10 \times 10^{-6} \ 1/K \quad \alpha_p = 14 \times 10^{-6} \ 1/K \quad T_{ref} = 300$ K

$$T_{c1} - T_{co} = \frac{LHR}{2\pi R_f} \frac{t_c}{k_c} = \frac{175}{2\pi(0.52)} \frac{0.08}{0.15} = 28.6 \text{ K}$$

$$T_{c1} = 578.6 \text{ K} \qquad \bar{T}_c = \frac{550 + 578.6}{2} = 564.3 \text{ K}$$

$$T_s - T_{c1} = \frac{LHR}{2\pi R_f} \frac{t_g}{k_g} = \frac{175}{2\pi(0.52)} \frac{0.005}{0.003} = 89.3 \text{ K} \qquad T_s = 667.9 \text{ K}$$

$$T_o - T_s = \frac{LHR}{4\pi k_f} = \frac{175}{4\pi(0.04)} = 348.2 \text{ K} \qquad T_o = 1016 \text{ K}$$

$$\bar{T}_F = \frac{1016 + 667.9}{2} = 842 \text{ K}$$

$$\bar{R}_c = 0.52 + 0.005 + \frac{0.08}{2} = 0.565 \text{ cm}$$

$$\Delta t_g = 0.565(10 \times 10^{-6})(564.3 - 300) - 0.52(14 \times 10^{-6})(842 - 300)$$

$$= 0.00149 - 0.00395 = -0.00246 \text{ cm}$$

$$t_g' = 0.005 - 0.00246 = \boxed{0.0025 \text{ cm}}$$

4) cladding thermal exp. stress σ_θ & σ_r

$\Delta T = 50\ K$ $\quad \alpha_c = 15\times10^{-6}\ 1/K$ $\quad E = 100\ GPa$ $\quad \nu = 0.34$

$t_c = 0.06\ cm$ $\quad R_i = 0.55\ cm$ $\quad r = R_i = 0.55\ cm$

$$\sigma_r = \frac{\Delta T}{2}\frac{\alpha E}{1-\nu}\left(\frac{r}{R_i}-1\right)\left(1-\frac{R_i}{\delta}\left(\frac{r}{R_i}-1\right)\right)$$

$$\sigma_\theta = \frac{\Delta T}{2}\frac{\alpha E}{1-\nu}\left(1-2\frac{R_i}{\delta}\left(\frac{r}{R_i}-1\right)\right)$$

$$\frac{\Delta T}{2}\frac{\alpha E}{1-\nu} = \frac{50}{2}\frac{(15\times10^{-6})(100\times10^{3})}{1-0.34} = 56.82\ MPa$$

$$\sigma_r = 56.82\left(\underbrace{\frac{0.55}{0.55}-1}_{0}\right)\left(1-\frac{0.55}{0.06}\left(\underbrace{\frac{0.55}{0.55}-1}_{0}\right)\right)$$

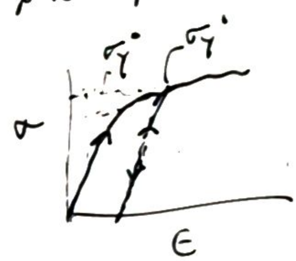
$\underline{\sigma_r = 0\ MPa}$ @ R_i

$$\sigma_\theta = 56.82\left(1-2\frac{0.55}{0.06}\left(\overbrace{\frac{0.55}{0.55}-1}^{0}\right)\right)$$

$\underline{\sigma_\theta = 56.82\ MPa}$

5) Elasticity is a reversible deformation due to the stretching of bonds. Plasticity is a permanent deformation due to bonds breaking. Elasticity is a fundamental property of the material which is insensitive to strain hardening. Plasticity is accomplished through grain twinning or dislocation motion. The stress for the transition from elastic to plastic deformation is the yield stress.

6) Strain hardening is an increase in the yield stress due to plastic deformation of the material. Plasticity applies a permanent deformation to the material which makes subsequent transitions to plastic deformation more difficult. This is due to an increasing number of dislocations which tend to pile up at barriers such as grain boundaries or precipitates.



7) Describe the temperature in the fuel and associated stresses

Describe temperature and stress in the cladding

Describe gap heat transfer, pressurization, and closure/contact

Bison, FRAPCON, OFFBeat, etc.

8) 0-D : vacancy, interstitial, substitutional

3-D : voids, precipitates, second phases

9) The original powder particles serve as the nuclei of grains. With applied pressure + temperature, the particles come into contact w/ arbitrary crystalline orientations w/ respect to one another. The diffusive processes remove void space, leaving a 2-D defect, grain boundary, between two neighbor particles with different orientations.

10) Mechanistic modeling takes fundamental physical processes occurring on the atomic or microstructural scale to inform properties or behaviors on the macroscale. The evolution of underlying features (grain boundaries, point defects, fission gas, dislocations, etc.) defines how the system as a whole will evolve over time. This allows for more flexible and accurate prediction of property or behavior evolution compared to experimentally fit empirical models.

11) Microstructure is what is seen @ ~35X mag. Grains, pores, precipitates, etc. Annealing is a post-fabrication processing step which heats a material at a given temperature for a period of time. This allows for diffusive processes to take place, allowing grain growth and recombination of defects. Typically reduces yield strength and increases ductility.

12) HBS is the rim structure of UO_2 which forms at high levels of burnup. HBS forms due to the self-shielding effect of the fuel, leading to higher powers and higher Pu content in the rim region. This higher fission rate, coupled with lower temperature on the outer fuel, means that thermal recombination of defects is insufficient, leading to higher defect concentrations and a subsequent polygonization of the UO_2 microstructure. HBS is characterized by small size grains and a large population of intergranular bubbles. HBS tends to increase the thermal conductivity of UO_2 through the 'defect-cleaning' process in the formation of new grains. HBS also serves to retain fission gases, minimizing cladding strain.