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NE 591 - EXAM #2

① Engineering: $\sigma = F/A_0$, $\epsilon = (l - l_0)/l$ → calculated with representative length (initial area)

True: $\sigma = F/A$; $\epsilon = \int_{l_0}^{l} \frac{dl}{l} \ln\left(\frac{l}{l_0}\right)$ → calculated with actual area (varying with time)

② Elastic deformation is the bond stretching and is not permanent. Plastic deformation is permanent (non-reversible) and caused by deformation in the crystal lattice (slip, twinning)

③ 0D defect. point defect: vacancies, interstitial atoms
3D defect: cluster of point defects: precipitates (cluster of impurity atoms).

④ - Melting temperature
- Thermal conductivity
- Chemical reactions at inner cladding surface

⑤ - Fission gas release: grain size changes space available within fuel for fission gas
- swelling (same)
- Thermal conductivity (depending on

⑥ strain hardening is the increase in the yield strain caused by permanent strain in plastic deformation (cause)

⑦ ① Fuel centerline temperature, ② stress in the cladding, ③ consider gap pressure, closure and heat transfer in some way

(8) The change in free energy from decrease in surface area of pores and lowering of the surface energy.

(9) Reduction of grain boundary energy is the most driving force to grain growth, but also T gradients among others. Grain growth is inhibited by pores, precipitations, solute atoms, etc. (impurities

(10) $p = 20\ MPa$ $\quad \bar{R} = 5.4mm$ $\quad t_c = 0.8mm$

$= 0.54cm$ $\quad = 0.08cm$

$\bar{R} = R_i + t_c/2 \Rightarrow R_i = 0.54 - 0.04 = 0.5cm$

$R_0 = R_i + t_c = 0.58\ cm$

a) $\sigma_\theta = \dfrac{p\bar{R}}{\delta} = \dfrac{20(0.54)}{0.08} = 142.5\ MPa$

$\sigma_z = \dfrac{p\bar{R}}{2\delta} = \dfrac{\sigma_\theta}{2} = 71.25\ MPa$

$\sigma_r = -\frac{1}{2}p = -10\ MPa$

b) at mid point, $r = \bar{R} = 0.54cm$ $\longrightarrow$ $\dfrac{R_0}{\bar{R}} = 1.07,$ $\quad \dfrac{R_0}{R_i} = 1.16$

$\sigma_\theta(r) = p\dfrac{(R_0/r)^2+1}{(R_0/R_i)^2-1} \Rightarrow \sigma_\theta(\bar{R}) = 20\dfrac{(1.07)^2+1}{(1.16)^2-1} = 124.13\ MPa$

$\sigma_z(r) = \dfrac{p}{(R_0/R_i)^2-1} \Rightarrow \sigma_z(\bar{R}) = \dfrac{20}{(1.16)^2-1} = 57.87\ MPa$

$\sigma_r(r) = -p\dfrac{(R_0/r)^2-1}{(R_0/R_i)^2-1} \Rightarrow \sigma_r(\bar{R}) = -20\dfrac{(1.07)^2-1}{(1.16)^2-1} = -8.69\ MPa$

c) The stress in the inside of the wall is $-p$ and on the outside is zero

(11) $R_f = 4.5\,mm$ $\quad LHR = 250\,W/cm$ $\quad K_f = 0.1\,W/cmK$ $\quad E = 290\,GPa$ $\quad \nu = 0.3$

$\alpha = 8.2\times10^{-6}\,1/K$

$$T_0 - T_s = \frac{LHR}{4\pi K_f} = \frac{250}{4\pi(0.1)} = 198.94\,K$$

maximum is σ_θ @ $r = R_f$; $\eta = 1$

$$\sigma^* = \frac{\alpha E (T_0 - T_s)}{4(1-\nu)} = \frac{(8.2\times10^{-6})(290\times10^3)(198.94)}{4(1-0.3)} = 168.96\,MPa$$

$$\sigma_\theta = -168.96(1 - 3(1)^2) = \boxed{337.92\,MPa}$$

(12) $T_{gap} = T_{CI} = 450K$ (assuming)

$$T_F = T_{gap} + \frac{LHR\, t_{gap}}{2\pi R_f K_{gap}} = 450 + \frac{(325)(0.02)}{2\pi(0.5)(0.04)} = 501.73\,K$$

$$T_0 = T_F + \frac{LHR}{4\pi K_f} = 501.73 + \frac{325}{4\pi(0.05)} = 1018.98K \text{ (before)}$$

$\bar{R}_c = 0.5 + 0.02 = 0.052\,cm$

$\bar{T}_c = 501.73\,K$

$\bar{T}_f = (1018.98 + 501.73)/2 = 760.36K$

$\Delta\delta_{gap} = (0.052)(4.5\times10^{-6})(501.73 - 300) - (0.5)(15\times10^{-6})(760.36 - 300)$

$\Delta\delta_{gap} = -0.0034\,cm$

$t_{g2} = 0.02 - 0.0034 = 0.0166\,cm$

$$T_{F_2} = 450 + \frac{(325)(0.0166)}{2\pi(0.5)(0.04)} = 492.93K$$

$$T_{0_2} = 492.93 + \frac{325}{4\pi(0.05)} = 1010.18K \text{ (after)}$$

(13)

$$\sigma^* = \frac{\alpha E(T_0 - T_S)}{4(1-\nu)} = \frac{(10.5\times10^{-6})(210\times10^{3})(1000/4\pi(0.05))}{4(1-0.25)} = 233.96 \text{ MPa}$$

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

$$-\frac{120}{233.96} = 1 - 3\eta^2 \Rightarrow \eta = 0.71 = \frac{r}{R_f}$$

$$\boxed{r = 0.39 \text{ cm}}$$