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87

Nuclear Fuel Performance : Exam 2

1) 4/4 In engineering stress, ~~I~~ one use the initial surface area and for the stress it the variation of the lenght divided by the initial lenght.
In the true one, you compute the real value and don't use the initial value but the "updated value":

	Engineering	true
Stress	F/A_0	F/A_t new surface area that changes due to displacement
Strain	$\frac{l-l_0}{l_0}$	$\int_{l_0}^{l} \frac{dl}{l}$

A_0 : initial surface area
l_0 : " lenght

2) 8/8 Elastic deformations are deformations in the elastic range meaning that when the force is removed then it comes back to its initial shape (reversible). Linear relation stress/strain.
~~Elastic def~~
Plastic deformations are irreversible deformation. It is a permanent deformation.

4/4

3) 0-D defect: vacancy (an atom is missing)

3-D defect: voids (cluster of vacancies)

4) Properties that vary as a function of stoichiometry in UO_2: 6/6

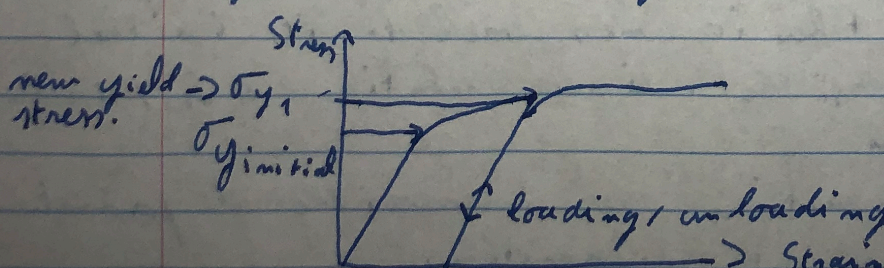
- Melting temperature
- Thermal conductivity
- Diffusion process such as creep, grain growth, fission gas ~~relea~~ release.

8/8

5) The grain size affect the mecanical ~~proper~~ propries through the quantity of grain ~~boundarie~~ boundaries. Grain boundaries inhibite the dislocations motions that ~~control~~ ~~as~~ create plastic deformation. Also diffusion and segregation happen at the grain boundaries.
~~The grain size also have an impact.~~

4/8

6) Strain hardening happens when the plastic region has been reach. When the force are removed, the ~~in~~ elastic strain recovery is smaller and the yield stress is higher now.



6) What causes strain hardening is the permanent strain due to a ~~plas~~ plastic deformation.
- dislocation pile up, etc.

7) All fuel performance codes must be able to :

6/6

- determine the fuel temperature profile and volumetric change
- determine the cladding temperature profile and stress
- determine the gap heat transport, mechanical interaction between fuel and cladding, and the gap pressure.

3/3

8) The driving force for fuel densification is the change in free energy from the decrease in surface area of pores ~~to~~ and lowering of the surface free energy. Grain boundaries ~~to~~ surface energy is lower than pores surface area energy.

4/6

9) - you just describe grain motion
The grain growth can be accelerated ~~by~~ by the movement of grain boundaries that can be due to curvature ~~as~~ driving force for example.
The grain growth can be inhibited by pores, precipitates, solute atoms, any thing that inhibits ~~ga~~ grain boundary motions.

13/16

10) a) $\sigma_\theta = \frac{pR}{\delta}$; $\sigma_z = \frac{pR}{2\delta}$; $\sigma_r = -\frac{1}{2}p$

4/4

$p = 20\ MPa$, $R = 5.4\ mm = R_{average}$; $\delta = \cancel{0.026}$ $0.8\ mm$

$\sigma_\theta = \frac{20 \times 5.4}{0.8} = 135\ MPa$; $\sigma_z = \frac{\sigma_\theta}{2} = 67.5\ MPa$, $\sigma_r = -\frac{1}{2} \times 20 = -10\ MPa$

b) $\sigma_r = -p \dfrac{(R_o/r)^2 - 1}{(R_o/R_i)^2 - 1}$; $\sigma_\theta = p \dfrac{(R_o/r)^2 + 1}{(R_o/R_i)^2 - 1}$

$\sigma_z = p \dfrac{1}{(R_o/R_i)^2 - 1}$ ✓

8/8

$p = 20$ MPa ; $R_o = 5.4 + \frac{0.8}{2} = 5.8$ mm
$R_i = 5.4 - \frac{0.8}{2} = 5.0$ mm.

$R_o/R_i = \frac{5.8}{5.0} = 1.16$ ✓

$r = $ ~~R~~ average $= 5.4$ mm

$\sigma_r = -20 \times \dfrac{\left(\frac{5.8}{5.4}\right)^2 - 1}{1.16^2 - 1} = -8.89$ MPa ✓

$\sigma_\theta = 20 \times \dfrac{\left(\frac{5.8}{5.4}\right)^2 + 1}{1.16^2 - 1} = 124.6$ MPa ✓

$\sigma_z = 20 \times \dfrac{1}{1.16^2 - 1} = 57.9$ MPa ✓

– not if they are identical, but WHERE

c) 1/4

	Thin wall	thick wall	ratio thin / thick
σ_r	-10	-8.99 MPa	1.11
σ_θ	135 MPa	124.6 MPa	1.08
σ_z	67.5 MPa	57.9 MPa	~~1.167~~ 1.17

σ_θ are the closer but not ~~exact~~ identical.

11) $\sigma_{rr}(\eta) = -\sigma^*(1-\eta^2)$ $\qquad \eta = \frac{r}{R_f}$ $\qquad$ 11/12

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

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

$$\sigma_{zz}(\eta) = -2\sigma^*(1-2\eta^2)$$

✓

The maximum stress is the hoop stress $\sigma_{\theta\theta}$ for $r = R_f$.

$$\sigma_{\theta\theta\,max} = -\sigma^*(1-3\times1^2) = 2\sigma^*$$ ✓

$\alpha = 8.2e^{-6}\,\frac{1}{K}$; $E = 290\ GPa = 290\,000\ MPa$

$\nu = 0.3$ ✓

~~We need to determine $T_0 - T_s$. However we are not given enough information to determine it. We only know LHR but not k_{gap}, k_{cladd}, δ_{cladd}, δ_{gap}, k~~

$$T_0 - T_s = \frac{LHR}{4\pi k} = \frac{\cancel{200}\ 250}{4\times\pi\times0.1} = 198.9\ K$$ ✓

$$\sigma_{\theta\theta\,max} = 2\times\frac{8.2\times10^{-6}\times290\times10^3\times198.9}{4(1-0.3)} = 168.9\ MPa.$$

$\sigma_\theta = 2\sigma^*$ $\qquad$ σ^*

8/16

12) $R_f = 0.5\,cm$; $t_{gap} = 0.02\,cm$; $T_{CI} = 450\,K$;

$k_{fuel} = 0.05\ W/cm\,K$; $h_{gap} = 0.04\ W/cm\,K$

$LHR = 325\ W/cm$; $\alpha_c = 4.5\ 10^{-6}\ \frac{1}{K}$

$\alpha_f = 15 \times 10^{-6}\ \frac{1}{K}$; T_{ref} (fuel, clad) $= 300\,K$.

$$\Delta \delta_{gap} = \bar{R}_c\ \alpha_c\,(\bar{T}_c - T_{fab}) - \bar{R}_f\ \alpha_f\,(\bar{T}_f - T_{fab})$$

$$T_f - T_{CI} = \frac{LHR}{2\pi R_f\ h_{gap}} = \frac{325}{2\pi \times 0.5 \times \frac{0.04}{0.02}} = 51.7\,K$$

$$T_0 - T_f = \frac{LHR}{4\pi k} = \frac{325}{4\pi \times 0.05} = 517.3\,K$$

$$\bar{T}_f = \cancel{T_f + \frac{T_0 - T_f}{2}}\quad \frac{T_f + T_0}{2}\ ;$$

$$T_f = T_{CI} + (T_f - T_{CI}) = 450 + 51.7 = 501.7\,K$$

$$T_0 = 501.7 + 517.3\cancel{4} = 1019.0\,K$$

$$\bar{T}_f = \frac{501.7 + 1019}{2} = 760.35\,K$$

Before the thermal expansion, the fuel centerline temperature is 1019 K

I can not determine exactly ~~of~~ after thermal expansion because I am missing the thickness of the cladding.

13) $R_f = 0.55\ cm$ $\quad \nu = 0.25$

8/8

$E = 210\ GPa$

$LHR = 200\ W/cm$

$\alpha_{fuel} = 10.5e^{-6}\ \frac{1}{K}$

$\sigma_{fracture} = 120\ MPa \quad k_f = 0.05\ W/cm\text{-}K$

$$T_0 - T_s = \frac{LHR}{4\pi k} = \frac{200}{4\pi \times 0.05} = 318.3\ \cancel{MPa}\ K$$

The cracks will appear because of the hoop stress

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

$$1 - 3\eta^2 = -\frac{\sigma_{fracture}}{\theta^*}$$

$\cancel{\eta^2 =}$

$$\eta^2 = \left(1 + \frac{\sigma_{fracture}}{\theta^*}\right) \times \frac{1}{3}$$

$$\eta = \left(\frac{1 + \frac{\sigma_{fracture}}{\theta^*}}{3}\right)^{1/2} =$$

$$\sigma^* = \frac{\alpha E (T_0 - T_s)}{4(1-\nu)} = \frac{10.5 \times 10^{-6} \times 210 \times 10^3 \times 318.3}{(4(1-0.25))}$$

$$= 234.0\ MPa$$

$$\eta = \left(\frac{1 + \frac{120}{234}}{3}\right)^{1/2} = 0.71.$$

The cracks will extend to 29% into the fuel pellet from the outer surface, corresponding to a radius of 0.3905 cm.