

Nuclear Fuel Performance: Exam 2

- 1) In engineering stress, we use the initial surface area and for the stress it's the variation of the length divided by the initial length.
 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	$F/A \leftarrow$ new surface area
Strain	$\frac{l - l_0}{l_0}$	$\int \frac{d\ell}{l}$ that changes due to displacement

A_0 : initial surface area

l_0 : " length -

- 2) 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.

3) O-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 :

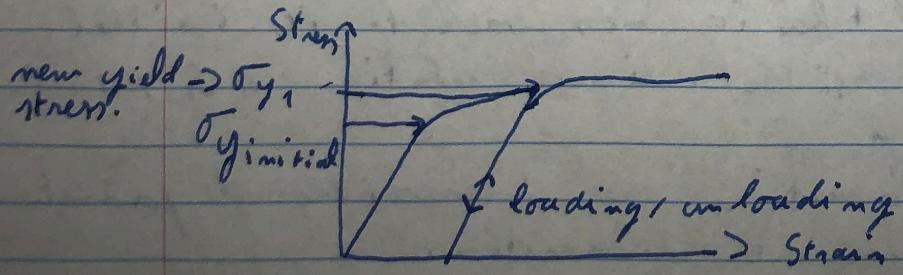
- Melting temperature
- Thermal conductivity
- Diffusion process such as creep, grain growth, fission gas release.

5) The grain size affect the mechanical properties through the quantity of grain boundary boundaries.

Grain boundaries inhibit the dislocations motions that control to create plastic deformation. Also diffusion and segregation happen at the grain boundaries.

The grain size also have an impact.

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



6) What causes strain hardening is the permanent strain due to a prior plastic deformation.

7) All fuel performance codes must be able to :

- 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.

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 \leftrightarrow surface energy is lower than pores surface area energy.

9) The grain growth can be accelerated 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, anything that inhibits the grain boundary motions.

$$10) a) \sigma_0 = \frac{\rho R}{\delta} ; \sigma_3 = \frac{\rho R}{2\delta} ; \sigma_n = -\frac{1}{2}\rho$$

$$\rho = 20 \text{ MPa}, R = 5.4 \text{ mm} \Rightarrow R_{\text{average}} ; \delta = 0.08 \text{ mm}$$

$$\sigma_0 = \frac{20 \times 5.4}{0.8} = 135 \text{ MPa} ; \sigma_3 = \frac{\sigma_0}{2} = 67.5 \text{ MPa} ; \sigma_n = -\frac{1}{2} \times 20 = -10 \text{ MPa}$$

$$b) \sigma_n = -P \frac{(R_o/n)^2 - 1}{(R_o/R_i)^2 - 1} ; \quad \sigma_o = P \frac{(R_o/n)^2 + 1}{(R_o/R_i)^2 - 1}$$

$$\sigma_g = P \frac{1}{(R_o/R_i)^2 - 1}$$

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

$$R_o/R_i : \frac{5.8}{5.0} = 1.16$$

$$n = R_{\text{average}} = 5.4 \text{ mm}$$

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

$$\sigma_o = 20 \times \frac{\left(\frac{5.8}{5.4}\right)^2 + 1}{1.16^2 - 1} = 124.6 \text{ MPa}$$

$$\sigma_g = 20 \times \frac{1}{1.16^2 - 1} = 57.9 \text{ MPa}$$

c) Thin wall thick wall ratio thin/thick

$$\sigma_n \quad -10 \quad -8.89 \text{ MPa} \quad 1.11$$

$$\sigma_o \quad 135 \text{ MPa} \quad 124.6 \text{ MPa} \quad 1.08$$

$$\sigma_g \quad 67.5 \text{ MPa} \quad 57.9 \text{ MPa} \quad 1.17$$

σ_o are the closer, but not exact identical.

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

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

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

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

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

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

$$d = 8.2 \text{ e}^{-6} \frac{1}{K}; \quad E = 290 \text{ GPa} \quad \nu = 0.3 \quad \text{gap} = 290000 \text{ MPa}$$

$$\nu = 0.3$$

~~We need to determine $T_0 - T_S$. However & we are not given enough information to determine it. We only know LTR but not R_{gap} , R_{cladd} , S_{cladd} , S_{gap} , R~~

$$T_0 - T_S = \frac{L + R}{4\pi R} = \frac{200 - 250}{4\pi \times 0.1} = 198.9 \text{ K}$$

$$\sigma_{\theta\theta \text{ max}} = 2 \times \frac{8.2 \times 10^{-6} \times 290 \times 10^3 \times 198.9}{4(1 - 0.3)} = 168.9 \text{ MPa.}$$

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

$$\alpha_{fuel} = 0.05 \text{ } ^\circ\text{C}/\text{K} ; \alpha_{gap} = 0.04 \text{ } ^\circ\text{C}/\text{K}$$

$$LHR = 325 \text{ W/cm}^2 ; \alpha_c = 8.5 \cdot 10^{-6} \frac{1}{\text{K}}$$

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

$$\Delta \delta_{gap} = \bar{\alpha}_c \alpha_c (\bar{T}_c - T_{gap}) - \bar{R}_f d_f (\bar{T}_f - T_{gap})$$

$$T_f - T_{CI} = \frac{LHR}{2\pi R_f \alpha_{gap}} = \frac{325}{2\pi \times 0.5 \times \frac{0.04}{0.02}} = 57.7 \text{ K}$$

$$T_o - T_f = \frac{LHR}{4\pi k} = \frac{325}{4\pi \times 0.05} = 514.3 \text{ K}$$

$$\bar{T}_f = T_f + \frac{T_o - T_f}{2} = \frac{T_f + T_o}{2}$$

$$T_f = T_{CI} + (T_f - T_{CI}) = 450 + 57.7 = 507.7 \text{ K}$$

$$T_o = 507.7 + 514.3 = 1022.0 \text{ K}$$

$$\bar{T}_f = \frac{507.7 + 1022.0}{2} = 760.35 \text{ K}$$

Before the thermal expansion, the fuel centraline temperature is 1022 K

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

$$13) R_f = 0.55 \text{ cm} \quad v = 0.25$$

$$E = 210 \text{ GPa}$$

$$LHR = 200 \text{ W/cm}$$

$$\alpha_{fuel} = 10.5 \times 10^{-6} \frac{1}{K}$$

$$\sigma_{fracture} = 170 \text{ MPa} \quad q_f = 0.05 \text{ W/cm}^2 \text{ K}$$

$$\tau_0 - \tau_s = \frac{LHR}{4\pi R} = \frac{200}{4\pi \times 0.05} = 318.3 \text{ MPa}$$

The cracks will appear because of the hoop stress

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

$$\gamma^2 = -\frac{\sigma_{fracture}}{\theta^*}$$

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

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

$$\theta^* = \frac{dE(\tau_0 - \tau_s)}{4(1-v)} = \frac{10.5 \times 10^{-6} \times 210 \times 10^3 \times 318.3}{(4(1-0.25))}$$

$$= 234.0 \text{ MPa}$$

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

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