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Ans: 1 (a)

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

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

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$T_0 - T_s = \dfrac{LHR}{4\pi k}$

$= \dfrac{250 \text{ W/cm}}{4 \times 3.1416 \times 0.1 \text{ W/cm-K}}$

$= \dfrac{250 \text{ W/cm}}{1.2567 \text{ W/cm-K}}$

$= 198.934 \text{ K}$.

From (ii) $\Rightarrow$ $\sigma^* = \dfrac{(8.2\times10^{-6}) \text{ 1/K} \times 29\times10^4 \times 198.934 \text{ K}}{4(1-0.3)}$.

$= \dfrac{461.52\cancel{88}688}{2.8}$ MPa

$= 164.831$ MPa

$\therefore$ Maximum stress, $\sigma_\theta = -\sigma^*(1-3\eta^2)$.

$= -164.831 (1-3 \cancel{(0.5)}^2 (1)^2)$

$= -164.831 \cancel{(1-0.6075)} (1-3)$ [$\because \eta = 1$ when max]

$= \cancel{-647}$ 329.662 MPa

Ans: 329.662 MPa.

Ans: 1(b)

$\sigma_{frac} = 120\,MPa$.

we get, $\sigma^* = 164.831\,MPa$

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

$$\eta^* = \sqrt{\frac{(1+\sigma_{frac})/\sigma^*}{3}}$$

Slight error $\eta = \sqrt{\frac{\frac{\sigma_{fr}}{\sigma^*}+1}{3}}$

$$= \sqrt{\frac{\frac{1+120\,MPa}{164.831\,MPa}}{3}}$$

$$= \sqrt{\frac{0.7341}{3}}$$

$$= \sqrt{0.2447}$$

$$= 0.4947.$$

Ans: 0.4947.

Ans: TO THE Q. NO. 2.

$p = 50\,MPa$.

$\bar{R} = R = 5.4\,mm$

$\delta = 1.2\,mm$.

(a) Three components of stress in thin-walled cylinders,

(a) Hoop's stress, $\underline{\sigma_\theta} = \frac{pR}{\delta}$

$= \frac{50 MPa \times 5.4 mm}{1.2 mm}$

$= 225 MPa$ **Ans:** ✓

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Radial stress, $\underline{\sigma_r} = -\frac{p}{2}$

$= -\frac{50 MPa}{2}$

$= -25 MPa$ **Ans:** ✓

Axial stress, $\underline{\sigma_z} = \frac{pR}{2\delta}$

$= \frac{50 MPa \times 5.4 mm}{2 \times 1.2 mm}$

$= 112.5 MPa.$ ✓

/Ans.

Given: $r = 5.6 mm$

(b) Three components of stress for thick-walled cylinder are ⟶

$\bar{R} = \frac{R_i + R_o}{2}$

$\bar{R} = 5.4$

$5.4 mm = \frac{5.6 mm + R_o}{2}$ $[\because r = R_i]$.

$R_i = 4.8$

$R_o = 6.0$

or, $10.8 mm - 5.6 mm = R_o$

or, $R_o = 5.2 mm$

$$\sigma_{rr} = \frac{-p\left[\left(\frac{R_o}{r}\right)^2 - 1\right]}{\left(\frac{R_o}{R_i}\right)^2 - 1}$$

$$= -p \frac{\cancel{\left(\frac{R_o}{r}\right)^2 - 1}}{\cancel{\left(\frac{R_o}{r}\right)^2 - 1}} \quad [\because r = R_i]$$

$$\frac{R_o}{r} \neq \frac{R_o}{R_i}$$

$$= -p$$

$$= -50 MPa$$

Ans:—

$$\sigma_{\theta\theta} = p \frac{(R_o/r)^2 + 1}{(R_o/R_i)^2 - 1} \checkmark$$

$$\frac{R_o}{R_i} > 1 \quad \text{always}$$

$$= 50 MPa \times \frac{\left(\frac{5.2 mm}{5.6 mm}\right)^2 + 1}{\left(\frac{5.2 mm}{5.6 mm}\right)^2 - 1}$$

$$= 50 MPa \times \frac{0.862 + 1}{0.862 - 1}$$

$$= 50 MPa \times \left(\frac{1.862}{-0.138}\right)$$

$$= -674.637 \ MPa$$

Ans —

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

$$= 50\,MPa \frac{1}{(5.2mm/5.6mm)^2 - 1}$$

$$= 50\,MPa \frac{1}{-0.138}$$

$$= -362.32\,MPa.$$

/Ans:—

(d)

Maximum strain, $\epsilon_{\theta\theta} = \frac{1}{E}\{\sigma_{\theta\theta} - \nu(\sigma_{rr} + \sigma_{zz})\}$

$$= \frac{1}{180\times10^3\,MPa} \times \left[(-674.637\,MPa) - [0.28\{-50\,MPa + (-362.32\,MPa)\}]\right]$$

$$= \frac{1}{180\times10^3\,MPa}(-674.637\,MPa + 115.45\,MPa)$$

$$= \frac{-559.19\,MPa}{180\times10^3\,MPa}$$

- negative strain doesn't make sense here

$$= -0.003.$$

/Ans: →

ANS.TO.THE Q.NO.3

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We know, change in the thickness of our gap,

$$\Delta\delta g = \bar{R}_c \alpha_c \Delta T - \bar{R}_F \alpha_F \Delta T_F \quad -①.$$

$$~~Ar(R_c) = R_f + \delta gap + \frac{t_c}{2}~~.$$

$$~~= 0.52 cm +~~$$

$$\bar{R}_c = Ar(R_c) = R_f + t_{gap} + \frac{t_{clad}}{2}.$$

$$= 0.52\,cm + 0.005\,cm + \frac{0.08\,cm}{2}.$$

$$= 0.565\,cm$$

$\bar{T}_c = \frac{T_o - T_i}{2}$

$$\Delta T = T_c - T_{ref} = (550 - 300)\,K = 250\,K.$$

$$\Delta T_F = T_f - T_{ref} = 300K - 300K = 0.$$

$\therefore$ From ① $\Rightarrow$.

- need to solve for T_f given LHR + heat transport

$$\Delta\delta g = (0.565\,cm \times 4.5 \times 10^{-6}\,1/K \times 250\,K) - 0$$

$$= 6.5 \times 10^{-4}\,cm$$

Ans: 6.5×10^{-4} cm.

- halfway, but didn't obtain the temperature profile to determine $\bar{T}_c$ and $\bar{T}_f$

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(4)

$a = 8 \times 10^{-4}$

$D = 2\times 10^{-15}\ cm^2/s$.

$t = 2$ years.

$Y = 0.3017$.

$\dot{F} = 2\times 10^{13}$ fission/cm^3-s.

$\tau = \frac{Dt}{a^2}$.

$= \frac{1.26\times 10^{-7}}{6.4\times 10^{-7}}$

$= 0.196$

$\tau \cdot \pi^2$

gas production $= Y \dot{F} t$.

$= 0.3017 \times 2\times 10^{13} \times (63072000)$ s
fissi/cm^3-s.

$= 3.8\times 10^{10}$ atoms - Calculator error here...

gas released = gas production × time fraction

$$= (3.8\times 10^{10}) \times \left(1 - \frac{6}{\pi^2} e^{-\pi^2 \frac{Dt}{a^2}}\right)$$

$$= (3.8\times 10^{10}) \times \left\{1 - \left(0.608 \times e^{-1.934}\right)\right\}.$$

$$= (3.8\times 10^{10}) \times (1 - 0.089)$$ (Longer time fraction)

$= 3.46\times 10^{10}$ atoms

Ans.

- used equation for annealing instead of in-pile gas release

(5)

→ Strain hardening happens when a metal is strained beyond its ~~yi~~ yield point.

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Cause:

When a metal is strained, dislocations will happen in the metal. Gradually those dislocation will interact with each other as further strain is applied and they will become pinned or tangled together. At this point, strain hardening will happen. If the metal is strained furthere, it will reach to the necking point and eventually rapture.

(6)

Three points →

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① Lattice constant decrease with increase of stoichiometry.

② Vacancy formation energy also change with sto...

③ Solution energy of Xe, Cs and Sr in UO_2

depends on stoichiometry.

(7)

Fuel performance code:— 6/6

i) Need to have tom practice and measure volumetric change within the fuel.

ii) Must have tom practio and evaluates stress in cladding.

iii) ~~...~~ Need to able to handle heat transport, mechanical interaction betn fuel and cladding, and pressure in the gap.

(8)

Three stages fission gas release: 9/9

(1) Gas atoms are produced due to fission and are diffused toward the grain boundaries. Small intergranular bubbles within the greains. These gas atoms never get trapped within the intragranular bubbles migreate to the GB.

ii) Nucleation happens form bubbles on the ~~gates to~~ GB and grow and interconnect.

iii) Finally, the gas transports through interconnected bubbles ~~to~~ to a free surface.

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High burn up leads to instability in crystalline ~~or~~ structure and initiate a restructuring in the material. In UO_2 grain subdivide from 10 mm ~~to~~ (100 - 200) nm size and porous structure of porosity 20%. This increase of relative porosity degrades material conductivity and the mean grain size.

- fission gas is retained
- net thermal conductivity is increased

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Zero-D (0-D) defects: happens when there are lattice imperfections in one or two lattice sites.

Ex: In ZnS the smaller ion moves out

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its place and creates 0-D effect.

3-D defects: point defects cluster and formed 3-D defect.

Ex: Often void space appear inside the metal and create 3-D defects.

(11)

Cause:

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fuel densification → evacuation of leftover pores. → reducing free surface area

Grain Growth → ~~G.~~ GB migration caused by annealing/heat treating.

→ reduces GB length, reducing free energy

(12)

Valence state of ~~UO_2 is~~ U in UO_2 is U^{4+}. Other possible states are U^{3+}, U^{4+}, U^{5+}, ~~U^{6+}~~ U^{6+}.

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