Simulation of Fission-induced Creep of U-Mo Fuel

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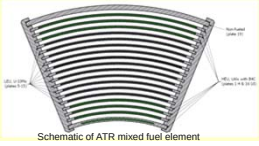
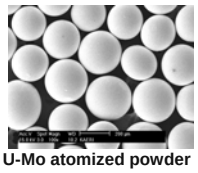
U-Mo alloy fuel

- The US GTRI-CONVERT Program (also known as RERTR) has been developing U-Mo dispersion (Mo=6-10wt%) in Al matrix or U-10wt%Mo foil for conversion of high-power research and test reactors from HEU fuel to LEU fuel.
- U-Mo alloy, denser than currently qualified high-density U_3Si_2, can provide enough U-mass to compensate lowered enrichment.
- U-Mo fuel undergoes fission-induced creep both in monolithic (foil) and particle-dispersion forms.
- Fission-induced creep is an effective mechanism to avoid bucking in a thin plate geometry by relieving stresses.

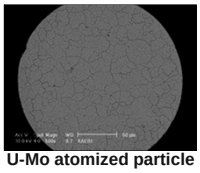


Schematic of ATR mixed fuel element

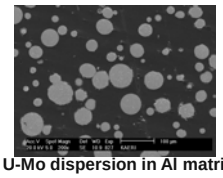
U-Mo alloy fuel irradiation tests



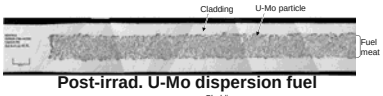
U-Mo atomized powder



U-Mo atomized particle

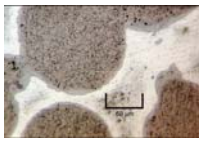


U-Mo dispersion in Al matrix

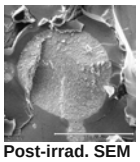


Post-irrad. U-Mo dispersion fuel

Post-irrad. U-Mo foil fuel



Post-irradiation OM



Post-irrad. SEM (Fracture surface)

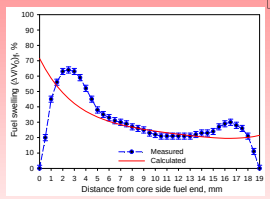
U-Mo fuel has been extensively tested in the ATR.

Objectives of the study

- To examine the observed phenomenon is realistic by ABAQUS FES together with known materials properties and fiss.-product-induced fuel swelling.
- **To obtain the creep-rate constant for measure U-Mo alloy fuel showing fission-induced creep.**

U-Mo alloy fuel recrystallization measurement

Simulation for monolithic U-Mo fuel (ABAQUS FEA)



Measured and calculated fuel swelling across width of L1P04A (C6) from RERTR-9; average FD = 5.39E21

Data for ABAQUS simulation

Al 6061 cladding property data

1.E = 66 GPa
2.Poison's ratio = 0.34
3.Cladding yield strength = 280 MPa
4.Strain hardening exponent = 0.13

U-Mo

1.E = 85 GPa, Poison's ratio = 0.34
2.Fuel swelling:

$$\left(\frac{\Delta V}{V_0}\right)_f = 5.0F, \quad F \le 3\times10^{20}\ f/cm^3$$

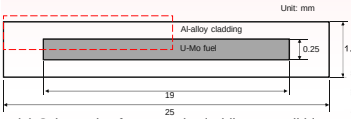
Kim et al., JNM, 2011

$$\left(\frac{\Delta V}{V_0}\right)_f = 15 + 6.3(F-3) + 0.33(F-3)^2, \quad 3\times10^{20}\ f/cm^3 < F$$

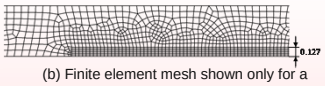
$$\varepsilon_{eq,true} = \ln\left[1+\left(\frac{\Delta V}{V_0}\right)_f\right]$$

3.Fuel swelling to true strain conversion:
4.Creep: $\dot{\varepsilon}_f(s^{-1}) = A\,\sigma\,\dot{f}$

A: to be obtained by ABAQUS simulation

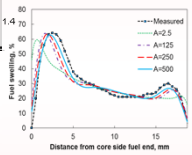


(a) Schematic of symmetric cladding monolithic fuel plate

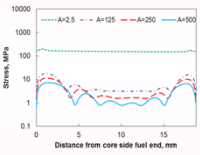


(b) Finite element mesh shown only for a quadrant:
Generalized plane strain condition

FE modeling for L1P04A



(a) Fuel swelling



(b) Von Mises stress

Parametric study for creep rate constant at EOL of L1P04A

→ Best fit is obtained with creep rate constant (A)
A = 500x10^{-25} cm^3 MPa^{-1} $\dot{\varepsilon}_f(s^{-1}) = A\,\sigma\,\dot{f}$

Comparison of fission enhanced creep rate constants for various uranium fuels

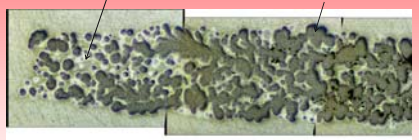
$$\dot{\varepsilon}_f(s^{-1}) = A\sigma\dot{f}$$

where the creep rate constant A is in cm^3 MPa^{-1}.

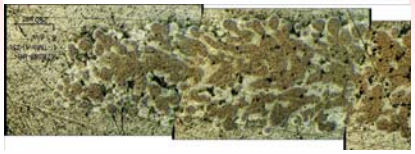
Fuel	A (10^{-25})	~T/T_m	Reference
U	800	0.3	Hesketh ('67); Zaimovski ('59)
U-10wt%Mo	500	0.3	Present study
	56	0.25	White('99)
MOX	7	0.25	Dienst JNM ('77), Clough, Solomon
UO_2	3	0.3	Zeisser JNM ('77), Druckluger ('77)
UN	1	0.3	Clough JNM ('77)
UC			

U-Mo alloy fuel recrystallization and FGB swelling modeling

Observation for U-Mo/Al dispersion fuel

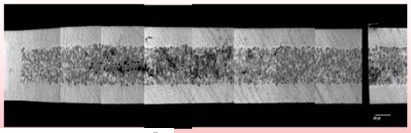


R6R018(B7)-RERTR9
Average FD = 7.1E21 f/cc

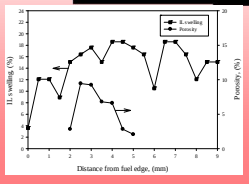


R2R088(B6)-RERTR9
Average FD = 7.0E21 f/cc

Fuel relocation during irradiation by creep of IL, UMo



V6022M RERTR-4
Average FD = 5.6x10^{21} f/cc



Simulation procedure

- Time-dependent IL volume will be obtained in the mesh.
- Using the same A from the monolithic case, estimate As for IL and Al.

Conclusions and future work

- ABAQUS finite element simulation confirms that the fuel mass transfer is indeed caused by the creep mechanism.
- ABAQUS simulation produced the best-fit creep rate constant for U-10Mo alloy fuel 500x10-25 cm3/MPa, which lies between pure uranium and MOX, and greater than other ceramic uranium fuels.
- Extension to U-Mo/Al dispersion fuels is planned to obtain the creep rate constants (A values) for interaction layers and Al matrix.

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