Irradiation Creep in Graphite
A Review

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Irradiation Creep in Graphite

- Due to fast neutron irradiation
- Significantly reduces stresses in nuclear graphite components
- The difference in dimensions between a stressed sample and a sample having the same properties as that sample when unstressed
Irradiated Unstressed Graphite Changes

- Dimensional
- Modulus
- Coefficient of Thermal Expansion - CTE
Irradiated Stressed Graphite Changes

- Dimensional
- Modulus
- Coefficient of Thermal Expansion - CTE
  - Additional changes to CTE
  - Additional changes to modulus
  - Modified dimensional change rate
Irradiation Creep Rate (UK)

- Proportional to stress
- Inversely proportional to creep modulus
  \( \gamma = \text{Irradiation dose} \)
- **CREEP RATE = PRIMARY + SECONDARY**

\[
\frac{d\varepsilon_{cr}}{d\gamma} = \alpha(T) \frac{\sigma}{E_c} \left[ \exp(-b\gamma) \right] + \beta(T) \frac{\sigma}{E_c}
\]
Coefficients

- Primary and secondary
  \[ \alpha(T), \ b \]
  \[ \beta(T) \]
- Secondary creep coefficient independent of temperature below 600°C
Low Dose Creep

- When expressed in elastic strain units

\[ esu = \frac{E_c \varepsilon_{cr}}{\sigma} \]

- Common law for tension and compression
- Common creep law for all graphite types
Creep Modulus $E_c$

- Unirradiated Young’s modulus
- Creep rate not changed by pinning
- However modified by:
  - *Structural changes*
  - *Radiolytic oxidation*
- UK theoretical pinning / unpinning model appears to back this up
USA and Russian low dose data

- Similar laws to the UK but has a different secondary creep temperature dependence
DRAGON Experience

• Flux dependent creep coefficient (Verginga and Blackstone)

\[
\text{cont} \frac{\exp\left(\frac{Q}{kT}\right)}{E \phi}
\]
High Dose Creep

- UK rule breaks down
- Tension and Compression different
- Kennedy, Cundy, Kliest

\[
\varepsilon_{crs} = K \left( \frac{\sigma}{E_o} \right)
\]

\[
K = K' \left[ 1 - \mu \frac{\Delta V/V_o}{(\Delta V/V_o)_m} \right]
\]
Dose $\times 10^{21}$ n.cm$^{-2}$ EDN

ESU

- ATR-2E @ 300 °C (in tension)
- ATR-2E @ 500 °C (in tension)
- ATR-2E @ 900 °C (in tension)
- ATR-2E @ 550 °C (in compression)
- 300°C with x3.3 multiplier (in tension)
- 500°C with x3 multiplier (in tension)
- 900°C with x7 multiplier (in tension)
Creep strain, CTE and Dimensional change

- By observation creep strain modifies CTE
- However, dimensional change appears to be a function of CTE
- Therefore creep strain should be expected to modify dimensional change
- Kelly, Burchell model 1994
Figure 13 (cont)
Change in CTE due to creep and elastic strain
(c) Comparison of elastic strain and irradiation creep experiments
Change in Modulus due to Creep Strain

• For IG-110 graphite a 35% change in modulus for 0.23% creep strain - Oku -1998
Main Conclusions

- Creep is important in the design of graphite components. However:
  - High dose creep is not well understood
  - Interaction between creep strain, modulus, CTE and dimensional change is not well understood
  - Poisson's ratio and other lateral effects have not been well quantified
  - Need for a well characterised irradiation creep experiment