ARIES-AT

MATERIALS DESIGN LIMITS AND ISSUES

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ARIES PROJECT MEETING

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(Updated on 7-3-00 to include discussion and follow-up items)

Resource Materials

- **SNOWMASS Materials Session, 7-99**
- **ICFRM-9, Colorado Springs, 10-99**
- **SiC Town Meeting, 1-00**
- **Fusion Materials Semiannual Progress Reports, up to 12/99**
- **SBIR Reviews, up to 6-00**
- **AMP SiC Task Group, up to 6-00**
- **Open Literature & Technical Reports**

ARIES-AT MATERIALS ISSUES

- **SiC/SiC Fabrication, Joining, Properties, Compatibility and Design Limits**

- **High-T (>700°C) Properties of Pb-Li**

- **Ferritic Steel Low-T Design Limits and LOCA/LOFA T_{max}**

- **W and W+TiC Impurities, Properties, Compatibility and Design Limits**

- **Special Topics**

  - **Joining W and SiC/SiC**
  - **Others**

SiC/SiC Fabrication, Joining, Properties, Compatibility and Design Limits

- **Fibers:**
  Hi-Nicalon-S, Sylramic-2, Tyranno-SA

- **Composites**

  - Chemical Vapor Infiltration (CVI)
  - PIP, CVR, mixed methods, etc.

- **Joining: Reaction Bonding, etc.**

- **High-T Thermal Conductivity of SiC_f/SiC**

  - MER (≈35 W/mK): may have excess C
  - Others (≈5-15 W/mK)
  - Effects of radiation uncertain at 1000°C
  - Recommend 20 W/mK for design

- **Potential T_{max} and Life-limiting Phenomena**

  - Compatibility of SiC/SiC with Pb-Li
  - Effects of He and H on swelling, thermal conductivity, mechanical integrity, etc.
  - Thermal and irradiation creep

SiC/SiC Fabrication, Joining, Properties, Compatibility and Design Limits (con't)

- **Recommended Design Limits**

  - $T \leq 1000°C$
    Based on possible void swelling threshold; poor database; little known about He effects on swelling

  - In-plane Stress Limits (unirradiated)
    Primary tensile $\sigma_t \approx 100$ MPa
    beginning of nonlinear behavior;
    Primary tensile $\sigma_t \approx 145$ MPa
    beginning of fiber/matrix debonding;
    Primary compressive $\sigma_c \approx 580$ MPa
    rupture limit for matrix

  - Recommendations for ARIES-AT
    (for thermoelastic, isotropic analysis using tensile part of von Mises stress)

    Primary membrane $\sigma_t \leq 100$ MPa
    Primary (membrane+bending) + secondary thermal $\sigma_t \leq 190$ MPa

High-T (>700°C) Properties of Pb-Li

- **References**

  - Billone (1992)
  - Flamant (1990)
  - KfK Report 4144 (1986)
  - Need to track down original references

- Suggestion made to examine RF report for higher T properties

- **Temperature Limits for Database**

  - Density: 350°C
  - Electrical resistivity: 660°C
  - Viscosity: 700°C
  - Specific heat: 525°C

- **Recommendations**

  - Re-verified correlations
  - Most extrapolations are linear
  - Recommended for high-T application

Ferritic Steel Low-T Design Limits

- **Database for Low-T Design Limits for FS**

  - Unirradiated FS
    Odette & Lucas (UCSB): 80-723K

  - Irradiated FS
    60-300°C, 0-34 dpa, 0-185 appm He
    Very little data at 60-90°C and 0-10 dpa
    Data implications are that ΔDBTT = 150-350°C

- **Odette & Lucas Modeling Results for Average Material Properties**

  - DBTT=-50°C, $K_{IC} \geq 40$ MPa•m$^{0.5}$, S_y=500 MPa

  - ΔDBTT

    $\Delta DBTT/\Delta S_y \approx 0.7 \pm 2$ K/MPa (empirical)

    ΔDBTT(dpa) ≈ 150°C
    ΔDBTT(He) ≈ uncertain (0-25°C)
    ΔDBTT(dynamic) = 50°C
    ΔDBTT(crack) = 0, thick wall with deep crack
    ΔDBTT(margin) = 40°C

    DBTT ≈150-250°C

<u>Ferritic Steel Low-T Design Limits</u> (cont'd)

- **Design Stress Limits at RT-100°C based on Current Technology**

  - Unirradiated material
    Primary membrane $\sigma \leq 193$ MPa
    Prim. (memb.+bend.) $\sigma \leq 290$MPa
    Prim. (memb.+bend.)+thermal $\sigma \leq 580$MPa

    Fracture toughness $K_{eff} \geq 250$ MPa•m$^{0.5}$
    (does not limit peak stress)

    Limits may apply to OD VV at 3-dpa/1-appm-He
    Fracture toughness may limit peak stress

  - Irradiated material
    (IB VV at 15-20 dpa, 10-15 appm He)

    Assume brittle conditions for end of life
    Design to $K_{jc} = 30$ MPa•m $^{0.5}$
    Limit based on global failure: $S_{fg} = K_{jc}/(9\pi a_u)^{0.5}$
    Limit based on local failure $\leq S_{fl} = 2K_{jc}/(9\pi a_u)^{0.5}$
    Peak+memb.+therm.≤180 MPa for $a_u = 1$ mm
    Peak+memb.+bend.+therm.≤360 MPa

  - Recommendations for IB VV
    Round corners of coolant channels to reduce
    Develop/select another FS with very low DBTT

W and W+TiC Impurities, Properties, Compatibility and Design Limits

- **Strength Properties of Tungsten at 1000°C**

  - **Heat treatments for powder met. W**
    Stress relieved: 1150°C for 5-10 min.
    Partially annealed: 1200°C for 1 h
    Annealed: 1400-1600°C for 1 h

  - **Properties**
    S_y = 480 MPa (stress-relieved)
    75 MPa (annealed)

    S_u = 550 MPa (stress-relieved)
    250 MPa (annealed)

- **W+TiC vs. W**

  - **Significant improvement in bending ductility (important for fabrication)**
  - **Effects of radiation yet to be determined**

- **Properties of Plasma-Sprayed W (TBD)**

Special Topics

- **Joining W and SiC_f/SiC in Divertor**

  - Plasma-facing divertor surface:
    3.5 mm W bonded to 0.5 mm SiC_f/SiC
    Bonding method: plasma-spray W

  - Issues
    0.5 mm SiC_f/SiC may be too thin
    Bond strength????
    Properties of plasma-sprayed W ????

  - Direct bonding of β-SiC to W (JPN)
    Preliminary results show excellent bond based on metallography; need to check with Hasegawa on bond strength

  - Direct bonding of SiC_f/SiC to W (JPN)
    Results at 1200-1400°C, 30 MPa, 1 hour
    Only partial bonding due to WC and W_2C formed at interface from excess C in composite matrix

  - Recommend bonding or coating 0.5 mm β-SiC onto W+TiC (carries all load)