ABSTRACT FOR 2010 NSMMS

Improved Creep Measurements for Ultra-High Temperature Materials

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Our team has developed a novel approach to measuring creep at extremely high temperatures using electrostatic levitation (ESL). This method has been demonstrated on niobium up to 2300°C, while ESL has melted tungsten (3400°C). The method has been extended to lower temperatures and higher stresses and applied to new materials, including a niobium-based superalloy, MASC.

High-precision machined spheres of the sample are levitated in the NASA MSFC ESL, a national user facility, and heated with a laser. The samples are rotated with an induction motor at up to 30,000 revolutions per second. The rapid rotation loads the sample through centripetal acceleration, producing a shear stress of about 60 MPa at the center, causing the sample to deform. The deformation of the sample is captured on high-speed video, which is analyzed by machine-vision software from the University of Massachusetts. The deformations are compared to finite element models to determine the constitutive constants in the creep relation. Furthermore, the non-contact method exploits stress gradients within the sample to determine the stress exponent in a single test.
**Motivation**
- Increasing need for high-temperature materials
- Higher operating temperatures lead to greater performance and efficiency
- Creep of metals is important at high temperatures (T > 0.4-0.5 T_Crit)
- High-temperature materials (T_Crit ≥ 2500 °C) are being developed and ready to use
  - i.e. ultra-high-temperature ceramics and platinum group metals
- Conventional methods limited to ~1700 °C
- Non-contact method demonstrated up to 2350 °C

**Applications**
- Next Generation turbine blades
- >1250 °C for more than 4000 hours
- Rocket Nozzle
  - Up to 3000 °C, high stress
- Hypersonic Flight
  - Leading edge materials
  - ≥ 2700 °C
- Nasa Marshall Space Flight Center

**Non-Contact Creep Tests**
- 2-3 mm diameter high-precision spheres
- Load by centripetal acceleration,
- Rotation rates up to 30,000 rev/sec
- Loads up to 100 MPa, Temperature to 2300°C

**Induction Motor Design**
- Decay/temperature and stress
- Increased acceleration ⇒ greater maximum stress
- Enables experiments below 2000°C
- Torque depends on electrical conductivity

**Status: Modeling and Analysis**
- FEA Model running with parameters extrapolated from Talmy, et al.
- Pure ZrB2: Model predicts 100 hours to 10% strain at 2000°C and 100 MPa (rotation rate 32,500 Hz). 2.8GPa / 150,000 Hz needed for 2 hour experiment.
- ZrB2 + 25 vol% SiC: Model predicts 1.5 hours to get 10% equatorial strain at 1900°C and 100 MPa (rotation rate 32,500 Hz).
- ZrB2 + 25 vol% SiC: Model predicts 1.5 hours to get 10% equatorial strain at 1900°C and 100 MPa.
- Total strain ~2%, 2X less than extrapolation.

**Conventional Creep Tests**
- Specimen in contact with test equipment
- Materials become reactive at high temperatures and incompatible with the containers or equipment.

**Current Work**
- Non-contact measurement of creep in ZrB2 and ZrB2-SiC composites.
- Material from NSWCCD
  - ZrB2: 6 mm grains
  - SiC: 2 mm grains
- Spheres machined ITI
- Tests at NASA MSFC
- Analysis with UMass

**Non-Contact Creep Test Analysis**
- Deformed shape depends on stress exponent
- The ratio of the polar to equatorial strains (Strain Ratio) from a single ESL test determines the stress exponent
- FEA model used to generate a stress exponent versus strain ratio plot

**ZrB2 and ZrB2 + 25 vol% SiC**
- ZrB2 + 25 vol% SiC at 1800°C
- Samples accelerated by ESL induction motor:
  - 22,200 Hz (35 million RPMs)
  - 232 minutes at load, temperature
  - 22,400 Hz (15 million RPMs)
  - 219 minutes at load, temperature
  - Total strain ~2%, 2X less than extrapolation.

**Non-Contact Creep Test Analysis**
- Clearance: unobstructed view of levitated sample.
- Vacuum compatibility:
  - Materials, cooling.
- Integration with MSFC ESL
  - Performance:
    - up to 30,000 rev/sec, 10x better
    - up to -5 x 10-10 N-m, 10x better
- Lower temperature materials
- Higher speed = higher stress.

**On-Going Work**
- Continue work with UHTC's, Ni- and Nb-based superalloys, other materials.
- Improved treatment of evaporation
- Further analysis of non-contact creep method
  - Multiple creep mechanisms
  - Higher stresses
    - Photon pressure: ~3,000 rev/sec => ~1 MPa max.
    - Present induction motor and measurement: ~30,000 rev/sec => ~100 MPa max.
    - NASA developing new rotation measurement: even higher speeds, stresses.
- Higher torque to reduce experiment duration.
- More automation of analysis.

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