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.

Improved Creep Measurements for Ultra-High Temperature Materials

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Motivation

- Increasing need for high-temperature materials
- Higher operating temperatures leads to greater performance and efficiency
- Creep of metals is important at high temperatures ($T \geq 0.4$-$0.5\ T_{melt}$)
- High-temperature materials ($T_{melt} \geq 2500$ ºC) are being developed and ready to use
  - i.e. ultra-high temperature ceramics and platinum group metals
- Conventional methods limited to ~1700 ºC
- Non-contact method demonstrated up to 2350 ºC

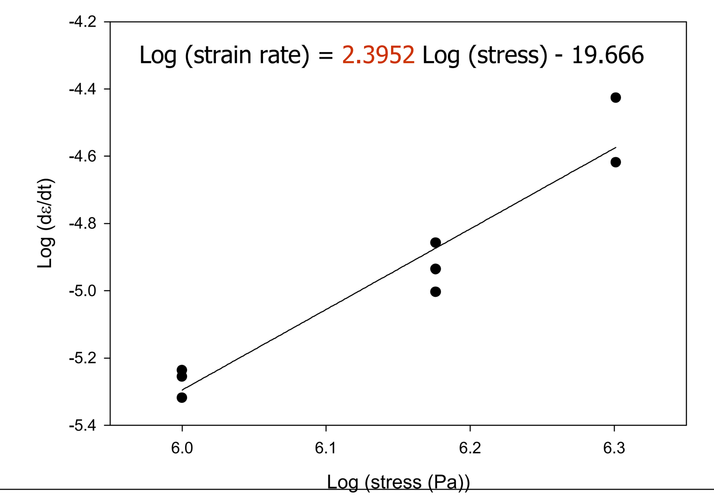
Applications

- Next Generation turbine blades
  - >1250 ºC for more than 4000 hours
- Rocket Nozzle
  - Up to 3000 ºC, high stress
- Hypersonic Flight
  - Leading edge materials
  - ≥ 2700 ºC

Conventional Creep Tests

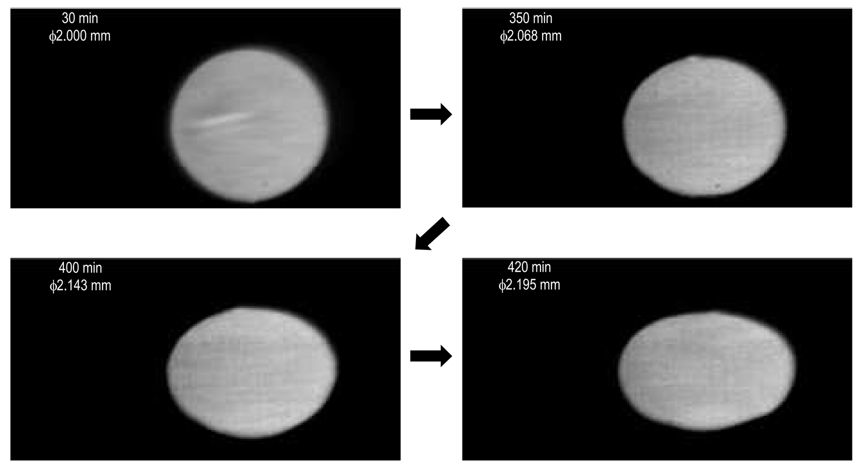
- Specimen in contact with test equipment
- Materials become reactive at high temperatures and incompatible with the containers or equipment

$$\dot{\varepsilon} = A\sigma^n \cdot e^{\left(-Q/_{kT}\right)}$$

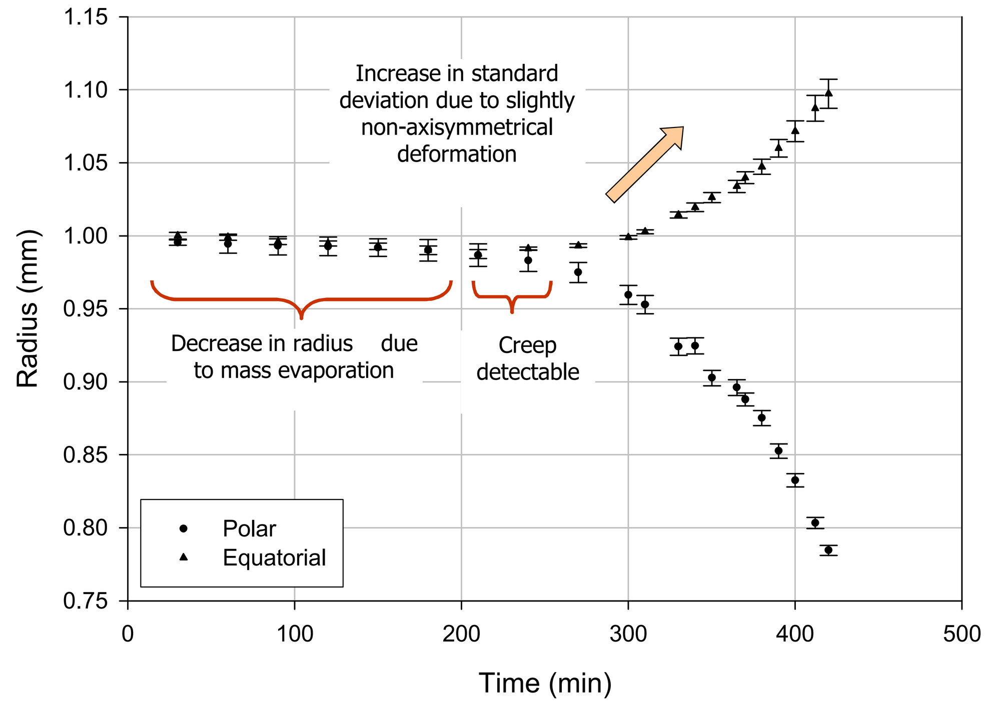


Non-Contact Creep Tests

- 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 2300ºC

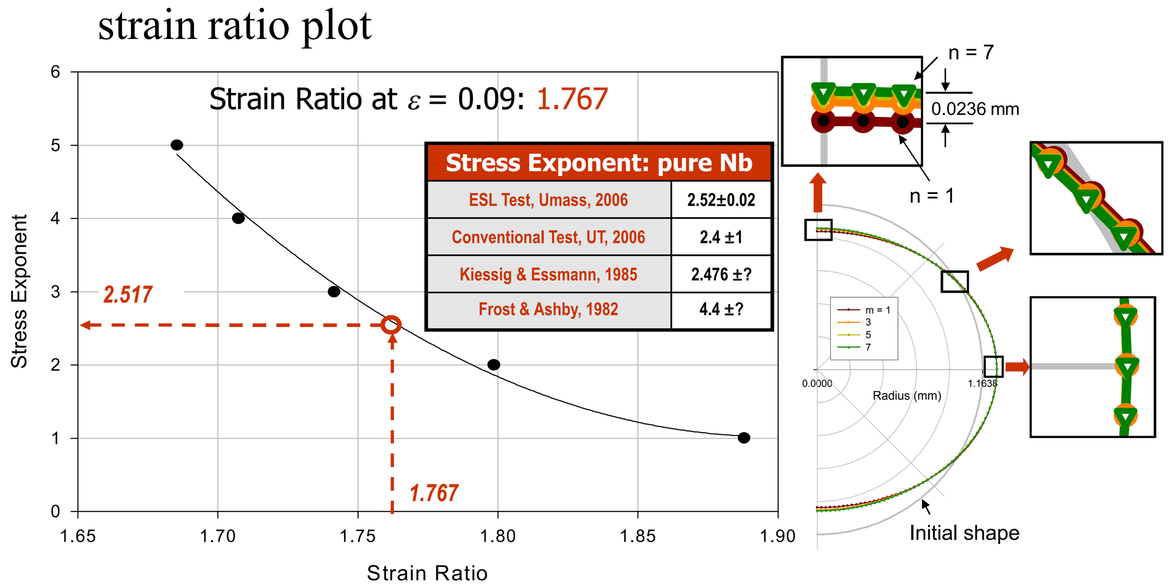


Non-Contact Creep Tests



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



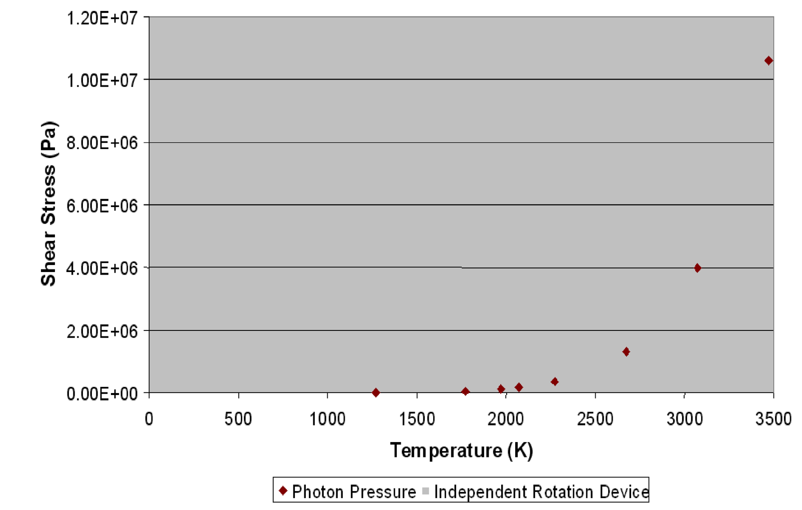
Induction Motor Design

- 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
- Sponsored by NASA IPP
- Completed July 2009

Rotation by Induction Motor

Decouple temperature and stress

- Increased acceleration => greater maximum stress
- Enables experiments below 2000°C
- Torque depends on electrical conductivity



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
- Comparison to flexural creep measurements

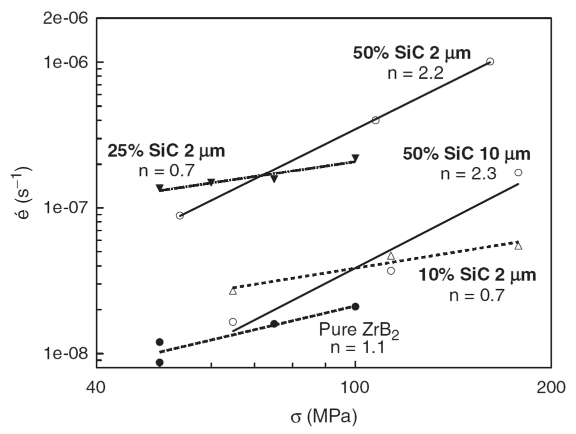
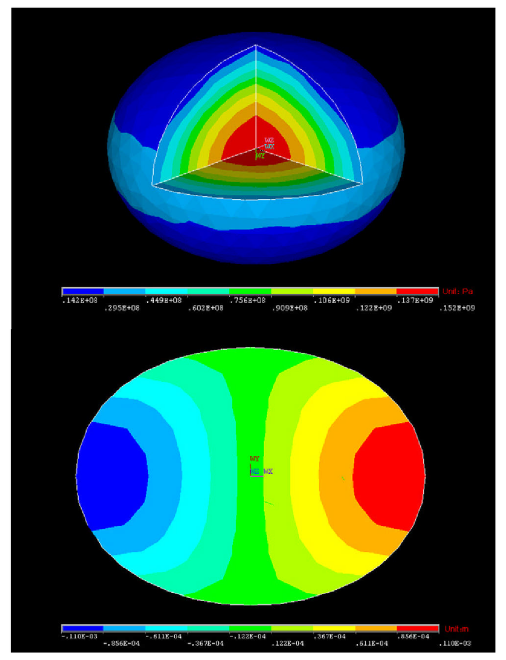


Fig. 7. Stress exponent for creep deformation of ZrB_2/SiC ceramics at 1400°C as a function of SiC content and particle size (2 and 10 µm).

I.G. Talmy, J.A. Zaykowski, and C.A. Martin, "Flexural Creep Deformation of ZrB2/SiC Ceramics in Oxidizing Atmosphere", *J. Am. Ceram. Soc.* **91** (5), 1441-1447 (2008).

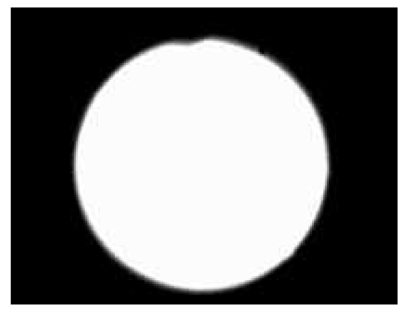
Status: Modeling and Analysis



- FE 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).

X. Ye and R.W. Hyers, "Computational Simulation of Non-contact Creep Deformation of ZrB2/ZrB2+SiC", *Journal of the European Ceramic Society* **30**, 2191-2196 (2010).

ZrB_2 and ZrB_2 + 25 vol% SiC



- ZrB2 + 25 vol% SiC at 1800°C
- Samples accelerated by ESL induction motor
  - 22,200 Hz (1.3 million RPM): 232 minutes at load, temperature
  - 25,400 Hz (1.5 million RPM): 219 minutes at load, temperature
- Total strain ~2%, 2X less than extrapolation
- Pure ZrB_2 measured at 2000ºC
  - 27,100 Hz (1.6 million RPM), 333 minutes at load, temperature.
- Total strain < 0.07% : consistent with extrapolation

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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