ABSTRACT FOR 2010 NSMMS

Improved Creep Measurements for Ultra-High Temperature Materials

Robert W. Hyers¹, X. Ye¹ and Jan R. Rogers²

¹ University of Massachusetts, Amherst
² NASA/MSFC/EM50

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.
Improvised Creep Measurements for Ultra-High Temperature Materials

Robert W. Hyers1, 2, X. Ye1, and Jan R. Rogers3
1University of Massachusetts Amherst, 2R. Hyers and Associates, Amherst, MA 3NASA Marshall Space Flight Center

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 \geq 0.4-0.5 T_{\text{melting}})
• High-temperature materials (T_{\text{melting}} \geq 2500 ^\circ C) are being developed and ready to use
  - i.e. ultra-high-temperature ceramics and platinum group metals
• Conventional methods limited to \sim 1700 ^\circ C
• Non-contact method demonstrated up to 2350 ^\circ C

Applications
• Next Generation turbine blades
  - \sim 1250 ^\circ C for more than 4000 hours
• Rocket Nozzle
  - Up to 3000 ^\circ C, high stress
• Hypersonic Flight
  - Leading edge materials
  - \geq 2700 ^\circ C

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 ^\circ C

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

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

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

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 ^\circ C and 100 MPa
  (rotation rate 32,500 Hz)
  2.8 GPa / 150,000 Hz needed for 2 hour experiment.
• ZrB2 + 25 vol% SiC: Model predicts 5.6 hours to get 10% equatorial strain
  at 1900 ^\circ C and 100 MPa
  (rotation rate 32,500 Hz)

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: \sim 3,000 rev/sec \sim 1 MPa max.
  - Present induction motor and measurement: \sim 30,000 rev/sec \sim 100 MPa max.
• NASA developing new rotation measurement: even higher speeds, stresses.
• Higher torque to reduce experiment duration.
• More automation of analysis.

2010 NSMMS
This work was supported by the NASA Innovative Partnerships Program and AFOSR STTR Grant FA9550-09-C-0089