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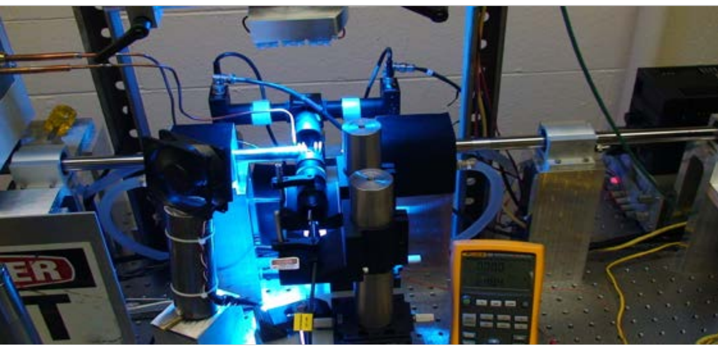

Dynamic High-Temperature Tensile Characterization of an Iridium Alloy

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U.S. Department of Energy   NNSA National Nuclear Security Administration

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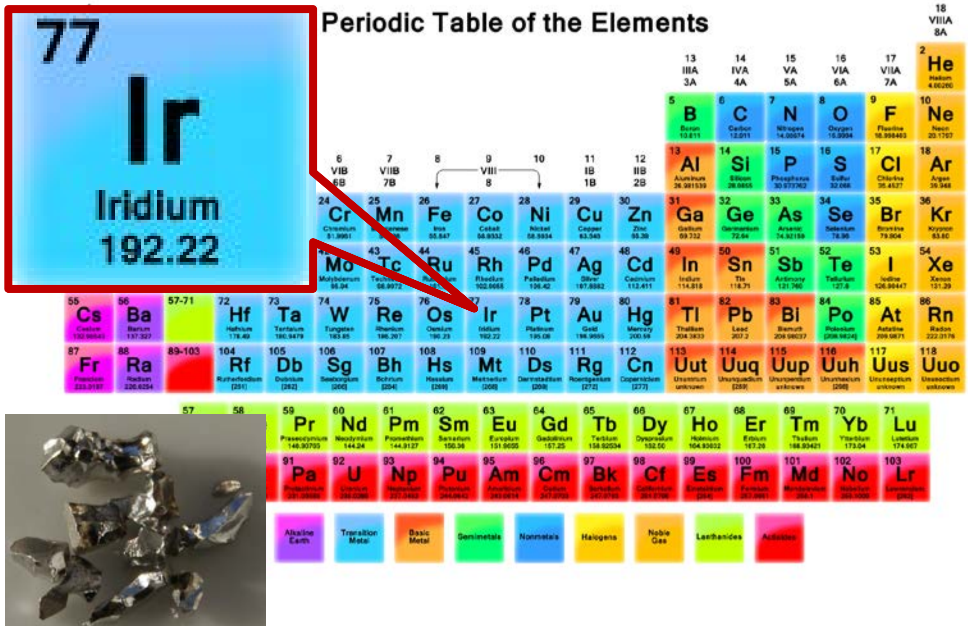
Outline

- Background
- Challenges in high-temperature Kolsky bar techniques
- Dynamic high-temperature tensile characterization of a DOP-26 iridium alloy
- Experimental Results
- Summary
- Acknowledgments

Background



Physical properties	
Phase	solid
Density (near r.t.)	22.56 g·cm^{-3}
Liquid density at m.p.	19 g·cm^{-3}
Melting point	2739 K, 2466 °C, 4471 °F
Boiling point	4701 K, 4428 °C, 8002 °F
Heat of fusion	41.12 kJ·mol^{-1}
Heat of vaporization	563 kJ·mol^{-1}
Molar heat capacity	25.10 J·mol^{-1}·K^{-1}

Thermal expansion	6.4 µm/(m·K)
Speed of sound (thin rod)	(20 °C) 4825 m·s^{-1}
Young's modulus	528 GPa
Shear modulus	210 GPa
Bulk modulus	320 GPa
Poisson ratio	0.26
Mohs hardness	6.5
Vickers hardness	1760 MPa
Brinell hardness	1670 MPa

DOP-26 Iridium Alloy (developed by ORNL)

- *By weight:*
  - *0.3% tungsten to enhance weldability*
  - *60-ppm (parts per million) thorium to increase ductility*
  - *50-ppm aluminum*
- *Unique properties*
  - *High-melting point*
  - *Good high-temperature strength*
  - *Good oxidation resistance*
  - *Compatibility with the fuel and graphitic heat-source components*
  - *High impact ductility at high temperatures*

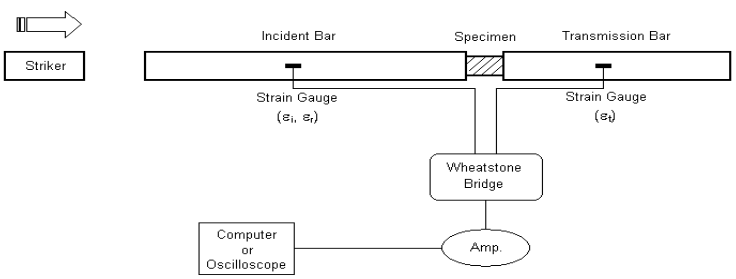
Dynamic High-temperature Compression:

Song et al., Strain (2014), 50, 539-546
Song et al., SAND2014-15442

Dynamic High-temperature Tension (up to 50/s):

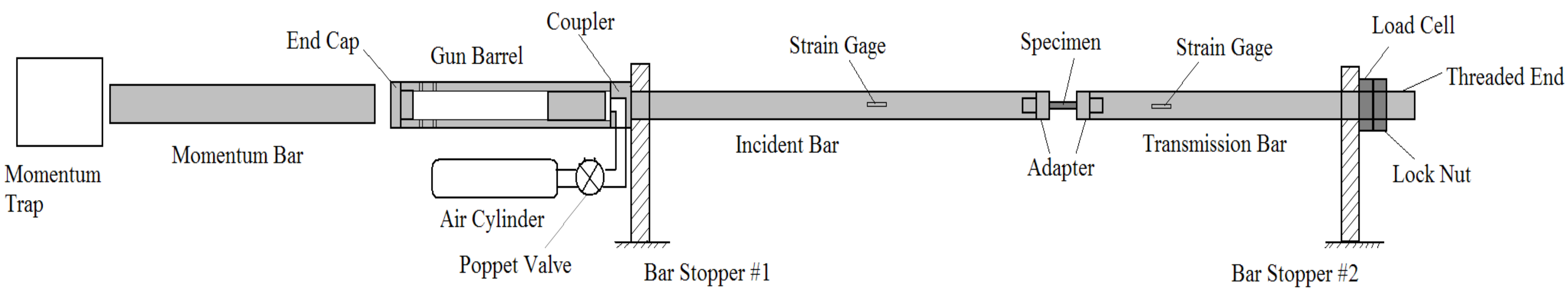
Schneibel et al., ORNL/TM-2007/81

Kolsky Bar (Split Hopkinson Bar) Techniques



$$\dot{\varepsilon} = \frac{u_1 - u_2}{l_0} = \frac{C_b}{l_0}\left(\varepsilon_i - \varepsilon_r - \varepsilon_t\right) \rightarrow \varepsilon = \int_0^t \dot{\varepsilon}(\tau)\,d\tau$$

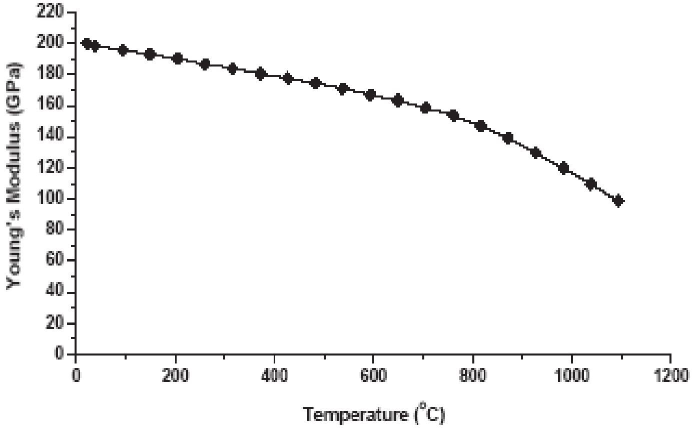
$$\sigma = \frac{F_1 + F_2}{2A_0} = \frac{E_b A_b}{2A_0}\left(\varepsilon_i + \varepsilon_r + \varepsilon_t\right) \rightarrow \sigma \sim \varepsilon$$



High-Temperature Kolsky Bar Principles

- Avoid “hot” pressure bars
  - Heat specimen individually
  - Hot Specimen/Cold Bars
    - Heat transfer
      - Specimen temperature drops
      - Bar temperature increases – thermal gradient in the bars

      Cold Contact Time (CCT) is the time during which the “hot” specimen stays in contact with the “cold” pressure bars until being dynamically loaded

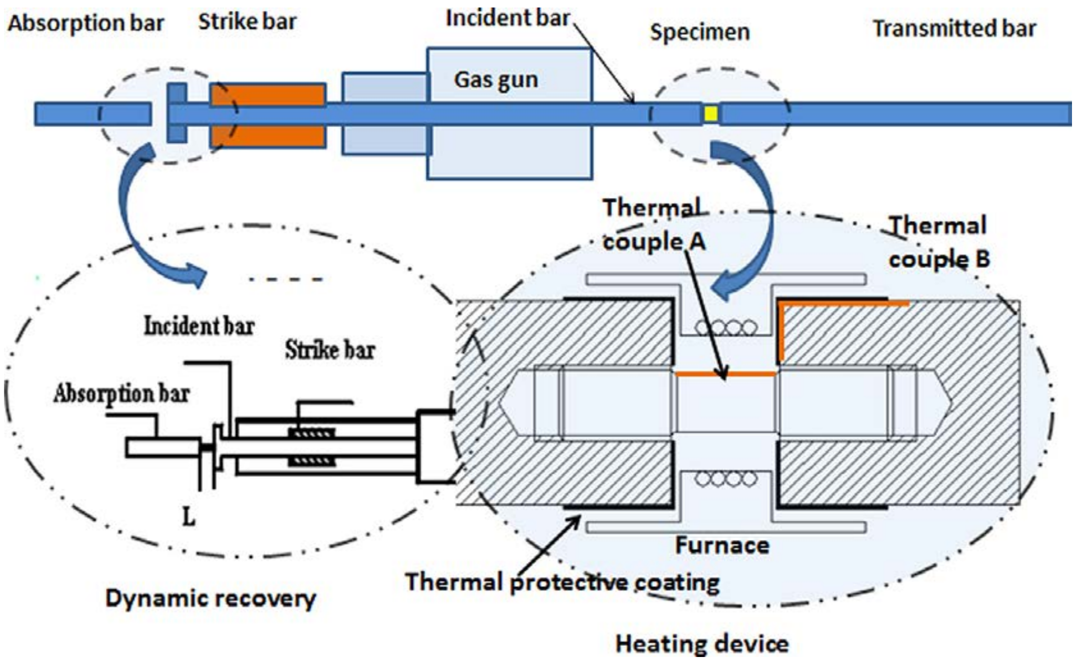


- Good for high-temperature Kolsky compression bar tests
  - Frantz et al. (1984)
  - Lennon and Ramesh (1998)
  - Apostol et al. (2003)
  - Song et al. (2012, 2014)

- Not applicable to Kolsky tensile bar tests

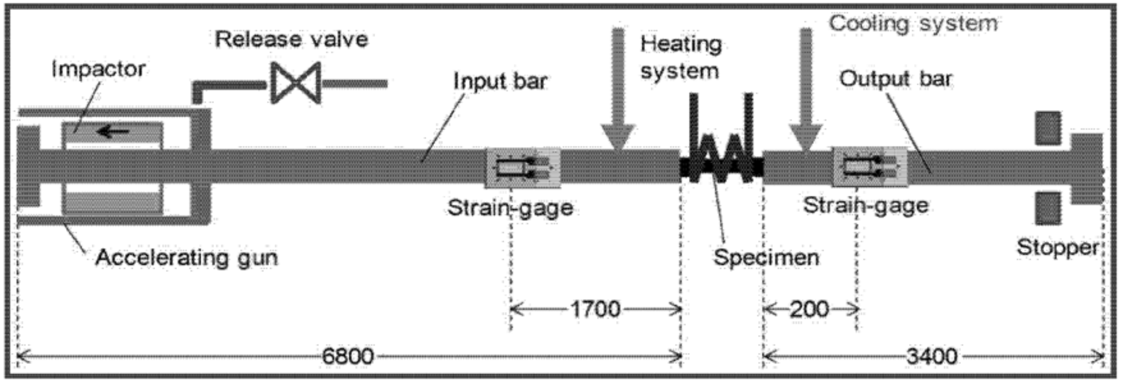
High-Temperature Kolsky Tensile Bar Tests

Su et al. (2013)



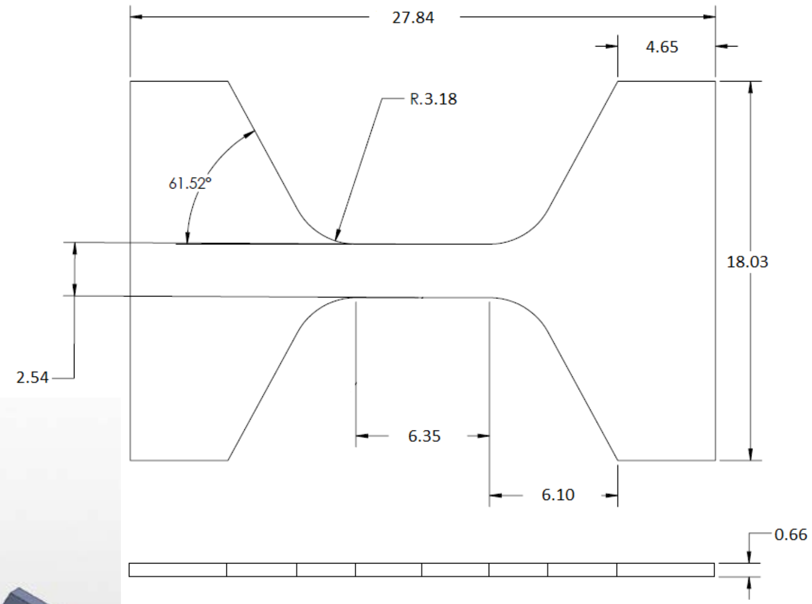
T < 600C

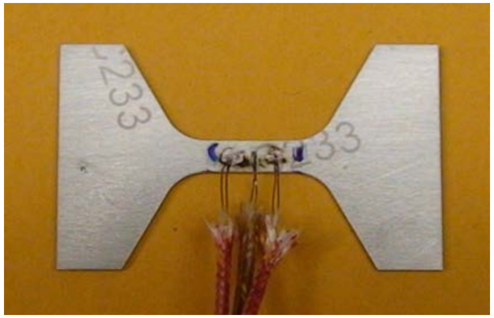
Scapin et al. (2014)



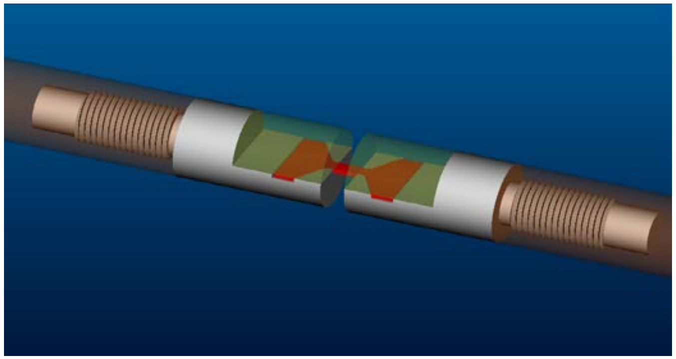
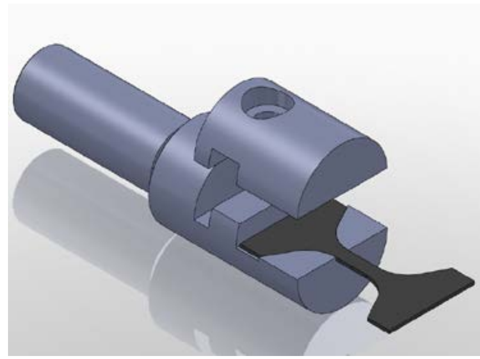
Challenges in High-Temperature Kolsky Tensile Bar Tests of Iridium

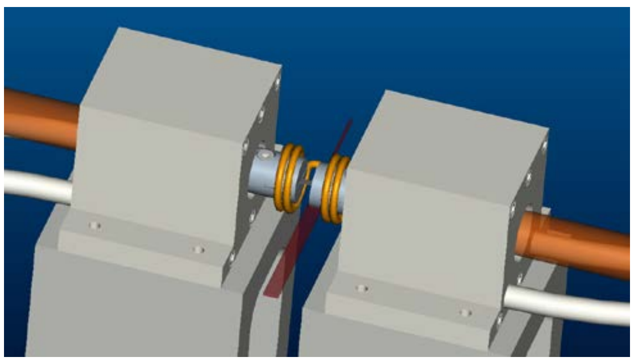
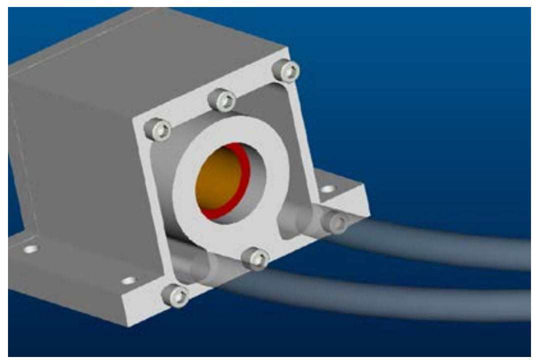
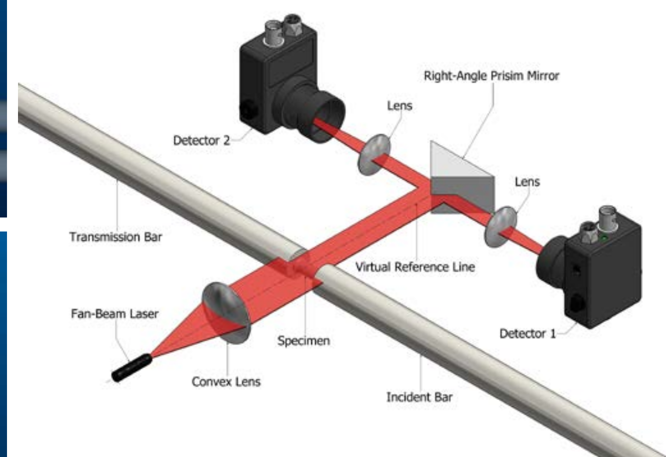
- DOP-26 iridium alloy: only 660-um-thick thin sheet
  - Special grips/fixtures
  - Specimen geometry design
  - Small cross-sectional area
    - Small transmitted force
- Ultra-high temperatures
  - 750 and 1030C
  - Hot specimen/cool bars
  - Thermal expansion
    - Possible buckling

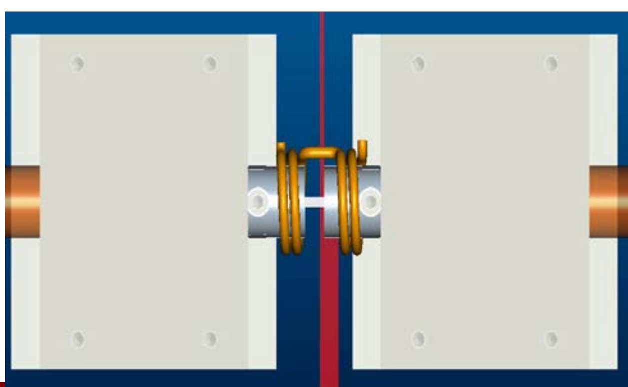
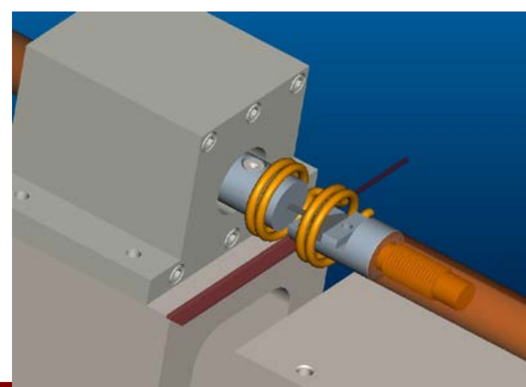




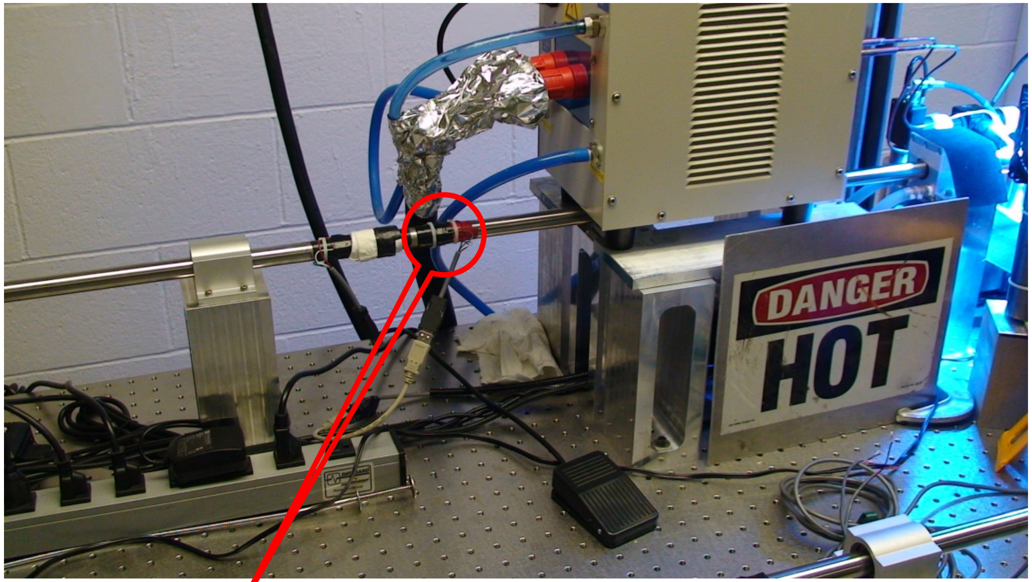
High-Temperature Kolsky Tensile Bar Tests

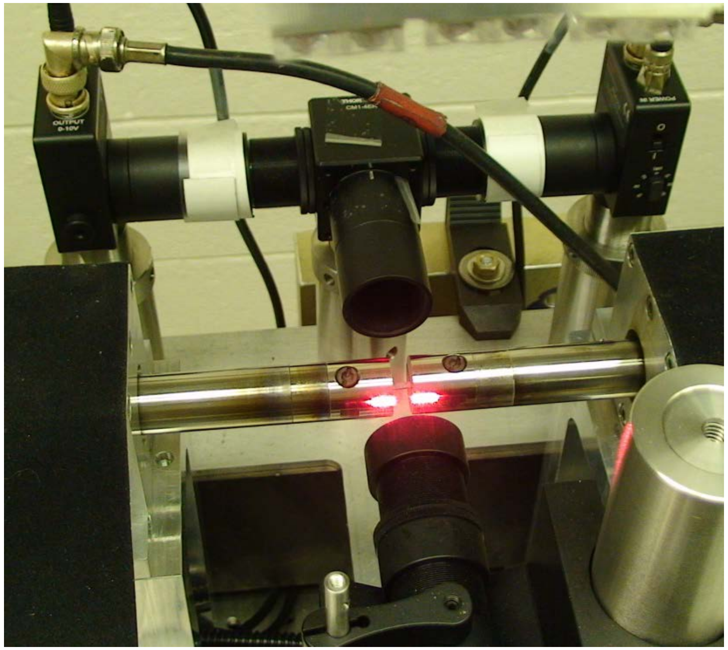




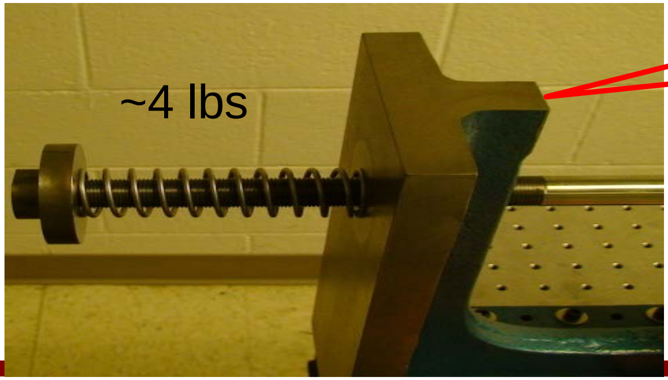



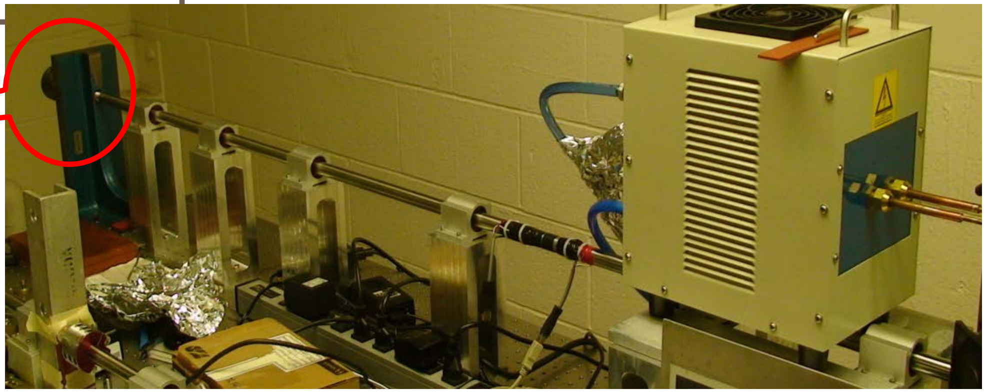
Stress and Strain Measurements



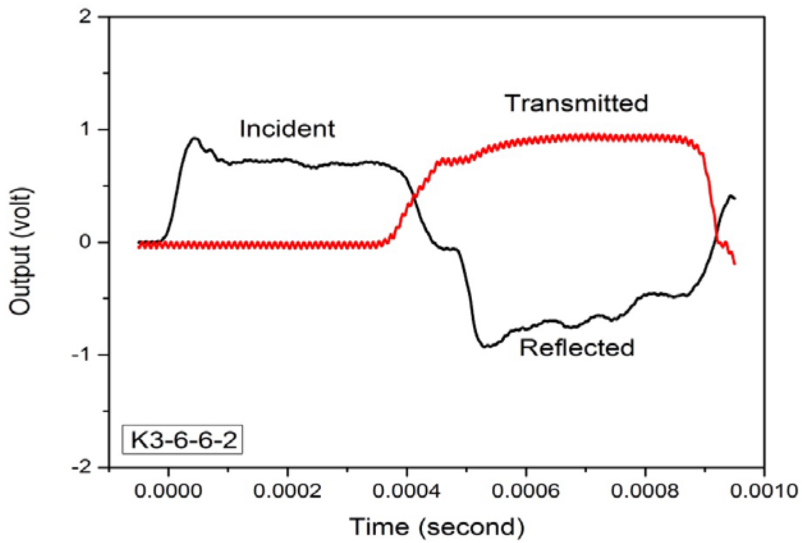
Semiconductor strain gages – specimen stress measurement
(GF: 139 vs. 2 for regular foil strain gage)

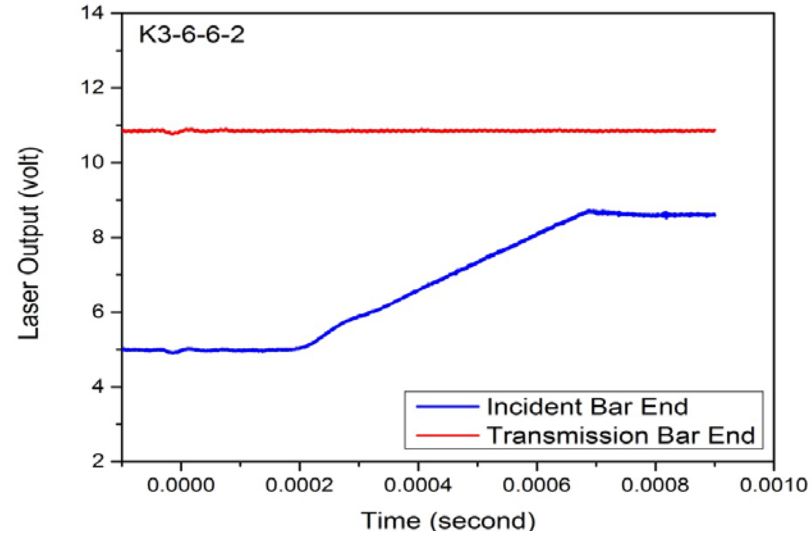


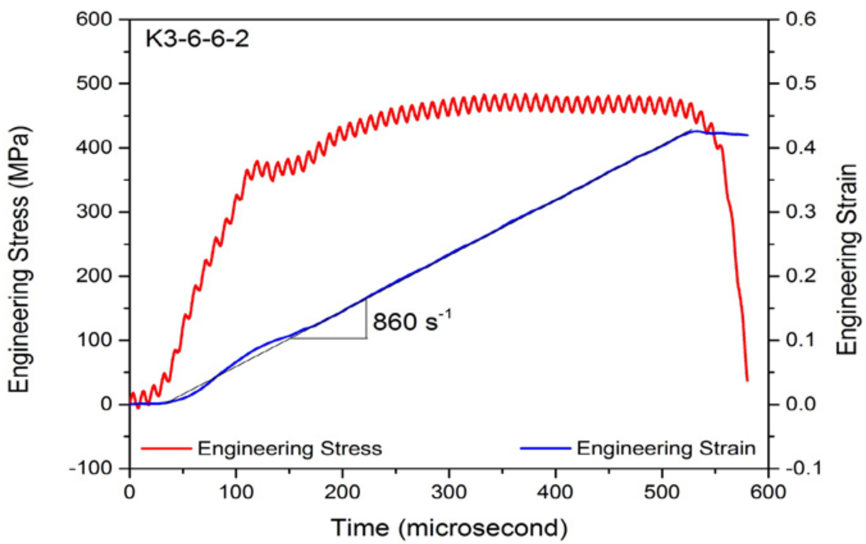


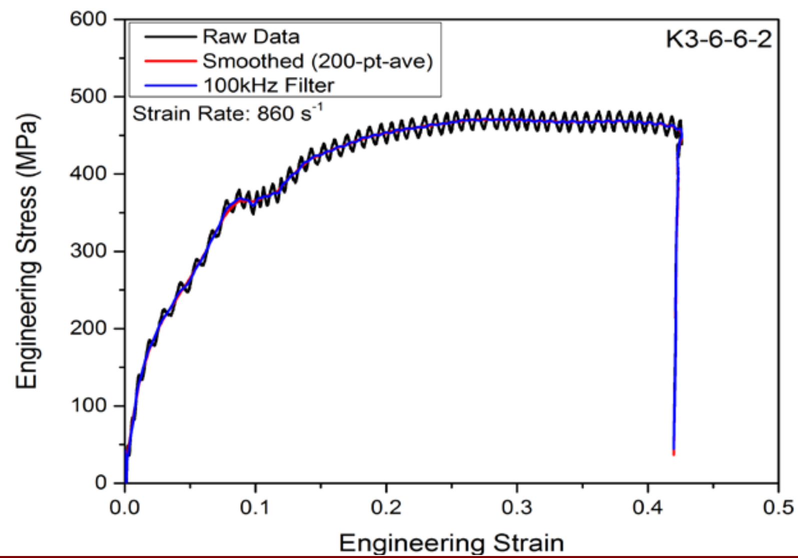


Typical Dynamic High-Temperature Tensile Test

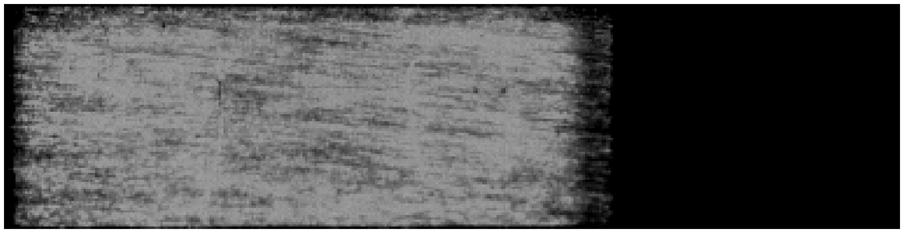


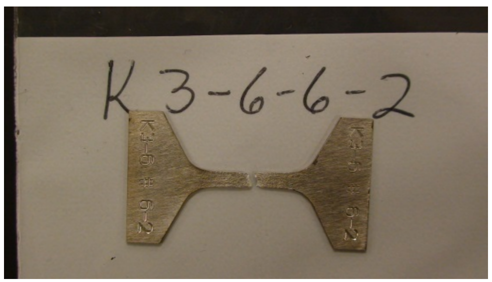






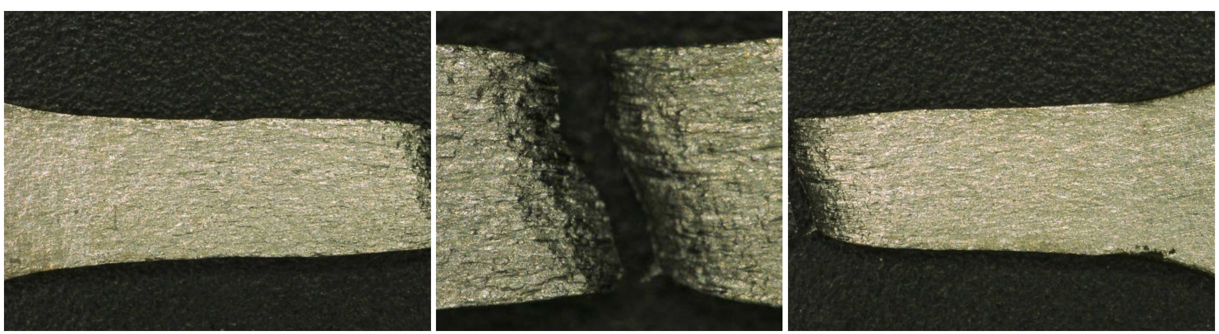
Specimen During and After Dynamic High-Temperature Test



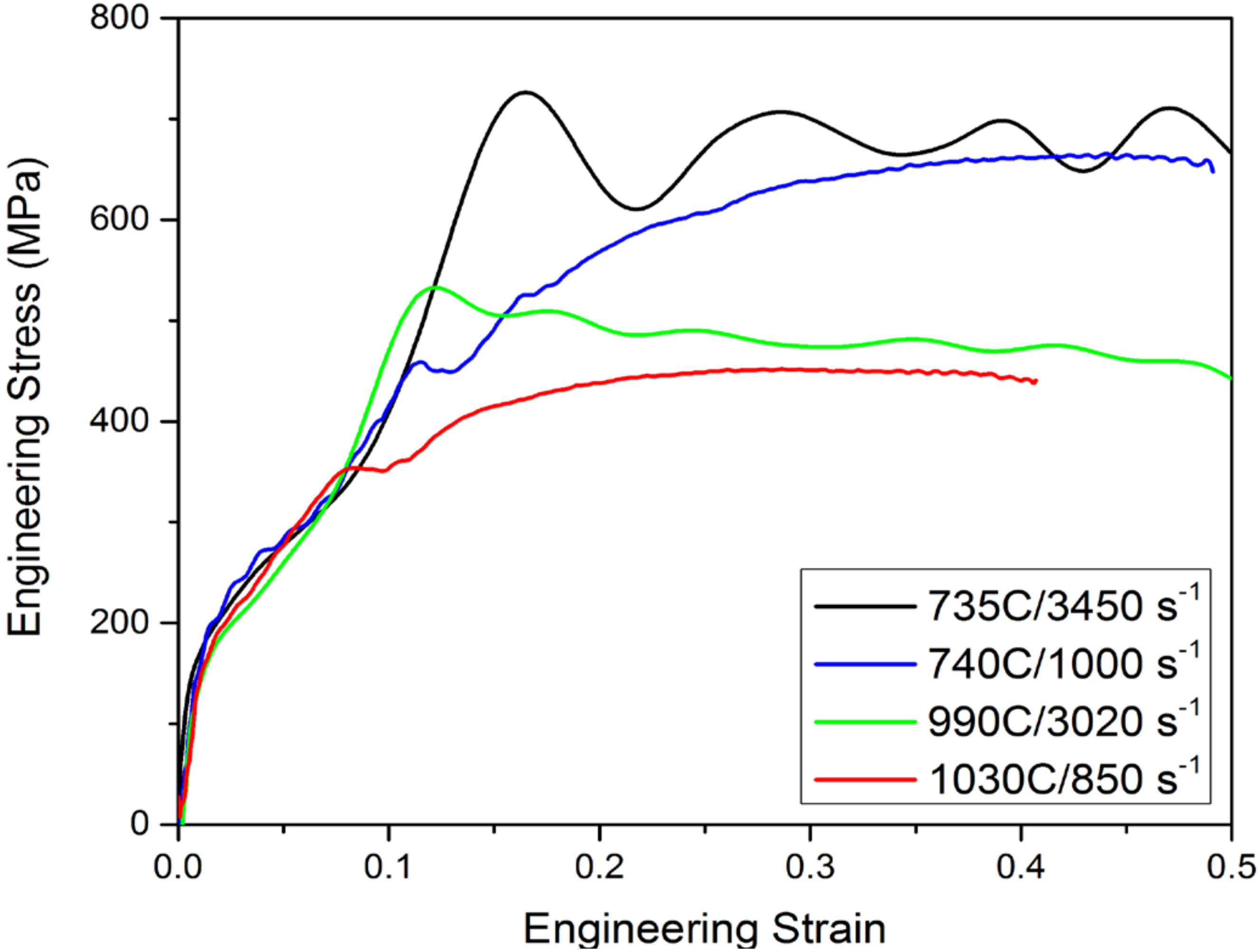


		K3-6-6-2		
Initial Measurements		After Measurements		
(in.)	(mm)		(mm)	
0.03590	0.9119	*	1.3406	
0.03495	0.8877		Break	
0.03495	0.8877	*	1.3467	
0.03495	0.8877		1.3606	
0.03485	0.8852		1.2579	
0.03505	0.8903			
Average				
0.03511	0.89175			
	3.5725		5.3058	0.485

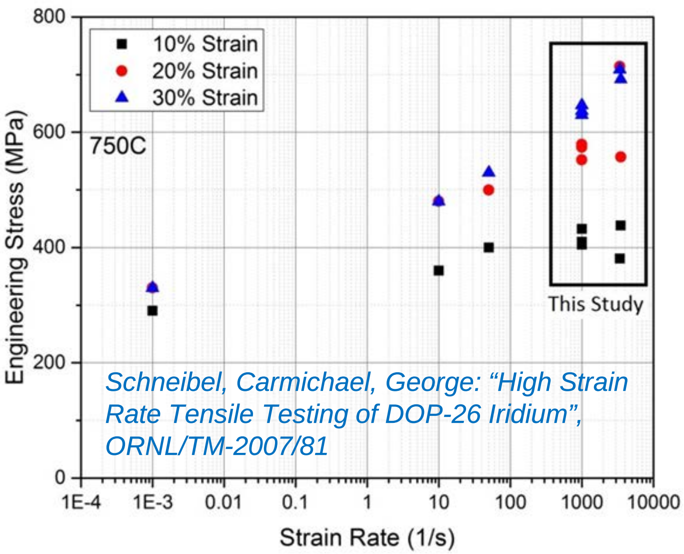
** One or both indentations were difficult to detec
Measurement value is suspect

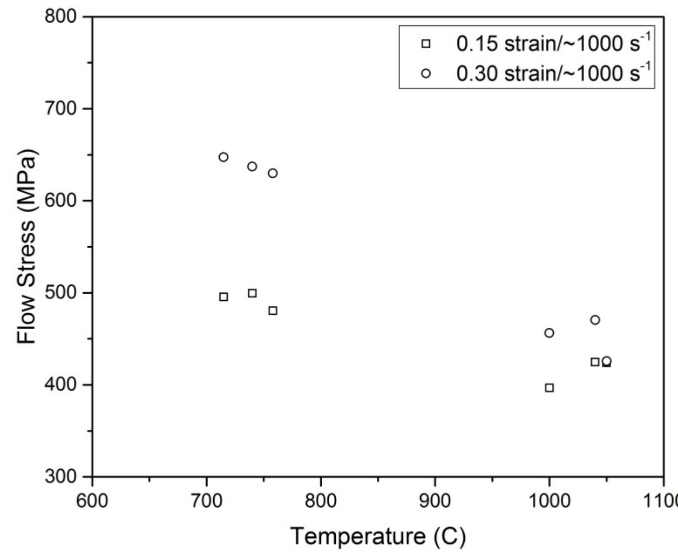


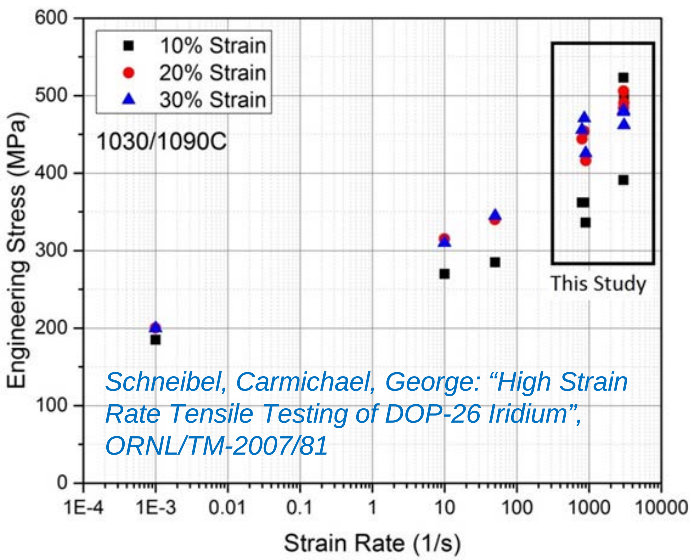
Engineering Tensile Stress-Strain Curves at Different Strain Rates and Temperatures

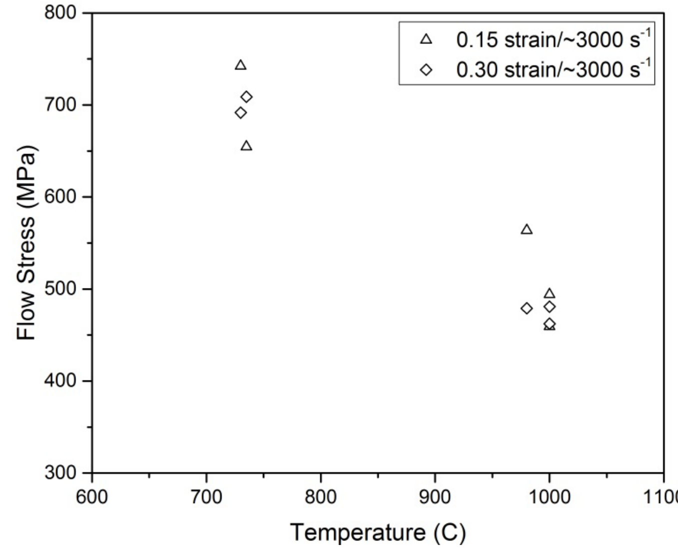


Strain-Rate and Temperature Effects









Summary and Acknowledgement

- Kolsky tension bar (split Hopkinson tension bar) techniques have been properly modified to characterize Iridium in tension at high temperatures

- DOP-26 iridium alloy has been dynamically characterized in tension at different strain rates and temperatures

- The DOP-26 iridium has shown significant strain rate and temperature effects
  - ***Flow stress increases with increasing strain rate but decreases with increasing temperature***

- ***This work was sponsored by U.S. DOE Office of Space and Defense Power Systems (NE-75).***

  - **Ryan Bechtel,** ***U.S. Department of Energy***