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Sandia National Laboratories

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High-Temperature Mechanical Properties of a DOP-26 Iridium Alloy under Impact Loading

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

- **Background**
- **Kolsky bar techniques for dynamic characterization of materials**
  - High-temperature Kolsky compression bar technique
  - High-temperature Kolsky tension bar technique
- **Dynamic high-temperature characterization of iridium**
  - In compression
  - In tension
- **Experimental Results**
- **Summary**
- **Acknowledgments**

Background

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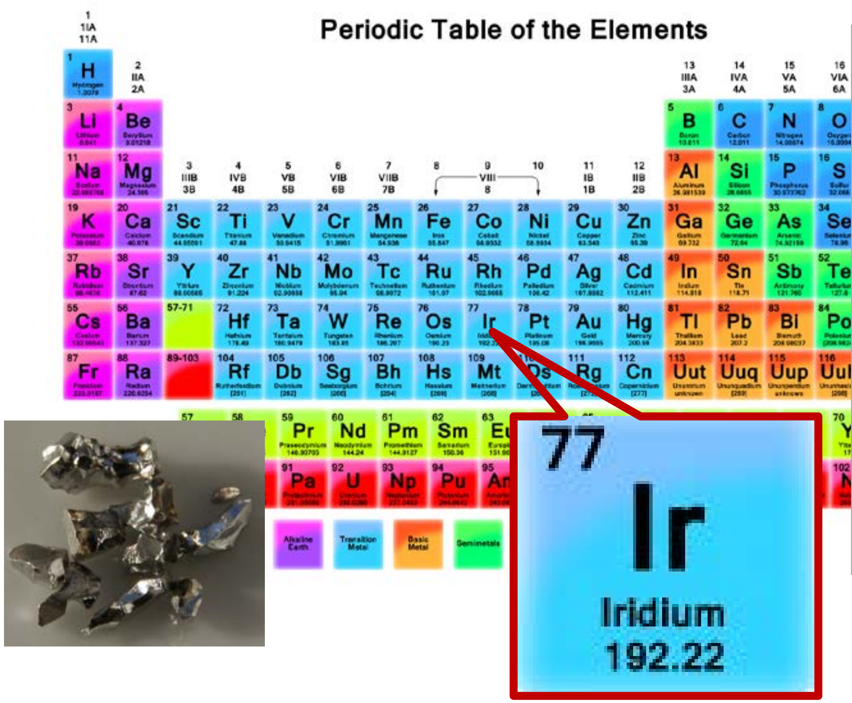
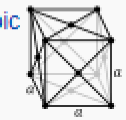


Physical properties	
Phase	solid
Density (near r.t.)	22.56 g·cm^{-3}
Liquid density at m.p.	19 g·cm^{-3}
Melting point	2739 K, 2466 °C, 4471 °F
Boiling point	4701 K, 4428 °C, 8002 °F
Heat of fusion	41.12 kJ·mol^{-1}
Heat of vaporization	563 kJ·mol^{-1}
Molar heat capacity	25.10 J·mol^{-1}·K^{-1}

Miscellanea	
Crystal structure	face-centered cubic 
Magnetic ordering	paramagnetic[1]
Electrical resistivity	(20 °C) 47.1 nΩ·m
Thermal conductivity	147 W·m^{-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
CAS registry number	7439-88-5

A very hard, brittle, silvery-white transition metal of the platinum family, iridium is the second-densest element (after osmium) and is the most corrosion-resistant metal, even at temperatures as high as 2000 C.

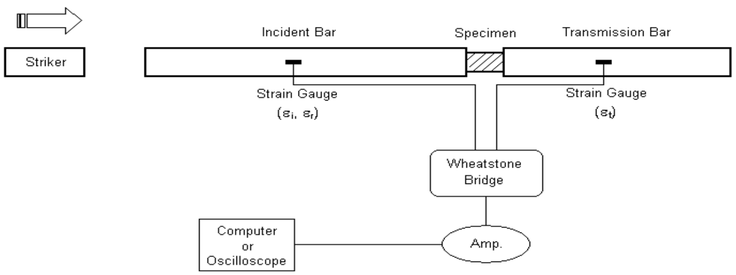
Background

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*

Kolsky Bar (Split Hopkinson Bar) Techniques

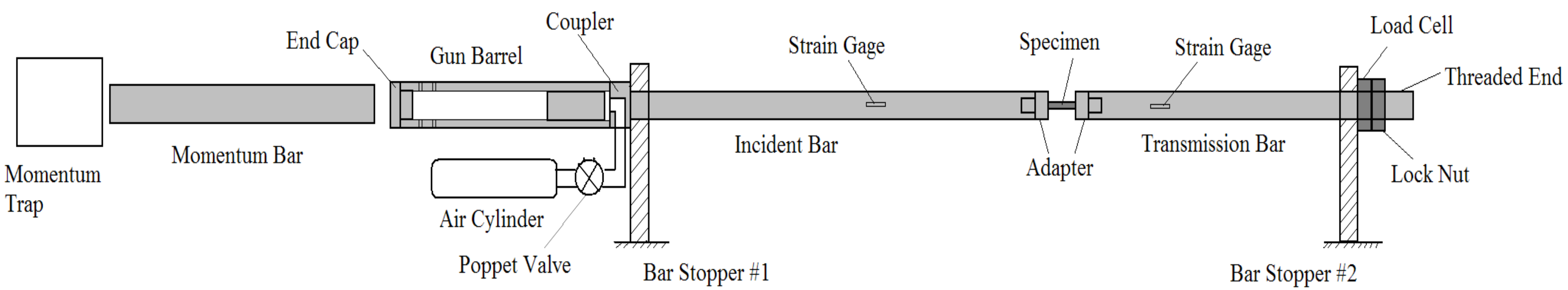


$$\dot{\varepsilon} = \frac{u_1 - u_2}{l_0} = \frac{C_b}{l_0}\left(\varepsilon_i - \varepsilon_r - \varepsilon_t\right)$$

$$\varepsilon = \int_0^t \dot{\varepsilon}(\tau)\,d\tau$$

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

$$\sigma \sim \varepsilon$$



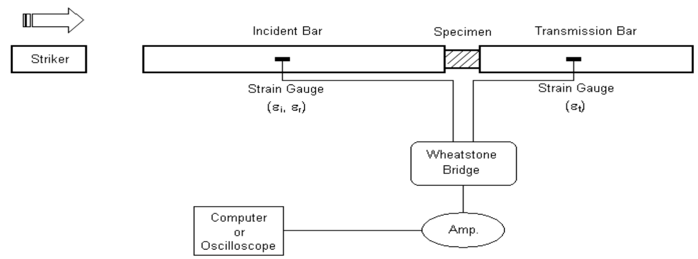
High-Temperature Kolsky Bar Principles

$$\dot{\varepsilon} = \frac{u_1 - u_2}{l_0} = \frac{C_b}{l_0}(\varepsilon_i - \varepsilon_r - \varepsilon_t)$$

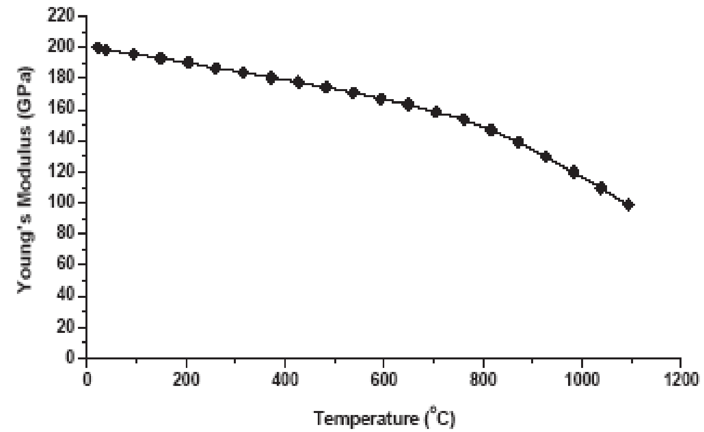
$$\varepsilon = \int_0^t \dot{\varepsilon}(\tau)d\tau$$

$$\sigma = \frac{F_1 + F_2}{2A_0} = \frac{E_b A_b}{2A_0}(\varepsilon_i + \varepsilon_r + \varepsilon_t)$$

$$\sigma \sim \varepsilon$$

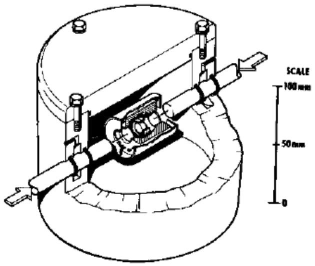


- Avoid “hot” pressure bars
  - Heat specimen individually
  - Hot Specimen/Cold Bars
    - Heat transfer
      - Specimen temperature drops
      - Bar temperature increases – thermal gradient in the bars

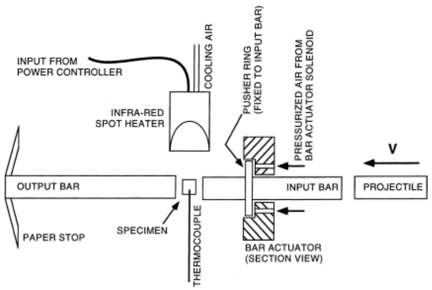


Cold Contact Time (CCT) is the time during which the “hot” specimen stays in contact with the “cold” pressure bars until being dynamically loaded

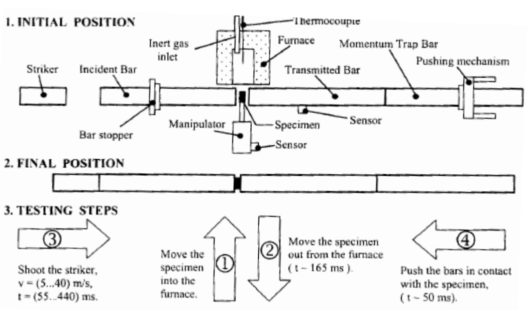
High-Temperature Kolsky Compression Bar



Follansbee et al. @LANL

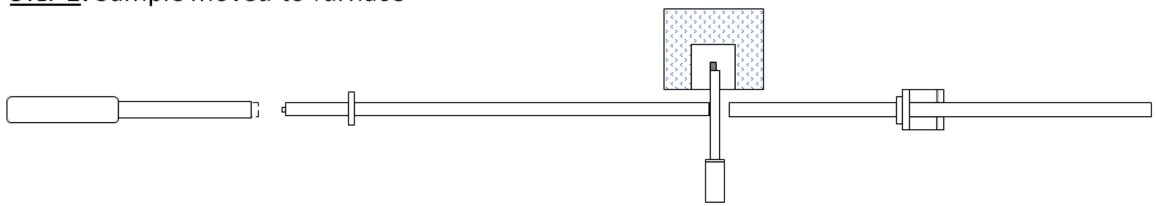


Ramesh, et al. @ JHU

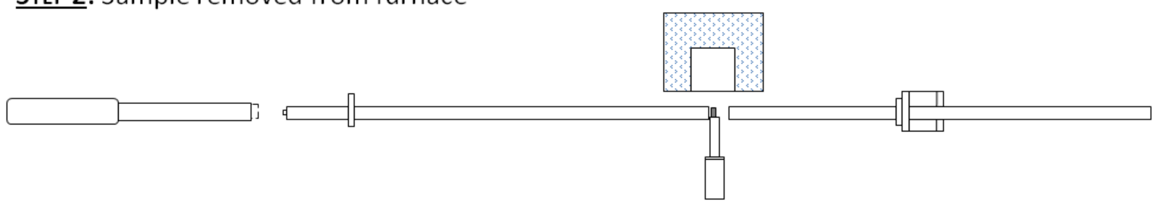


Kuokkala et al. @ TUT, FINLAND

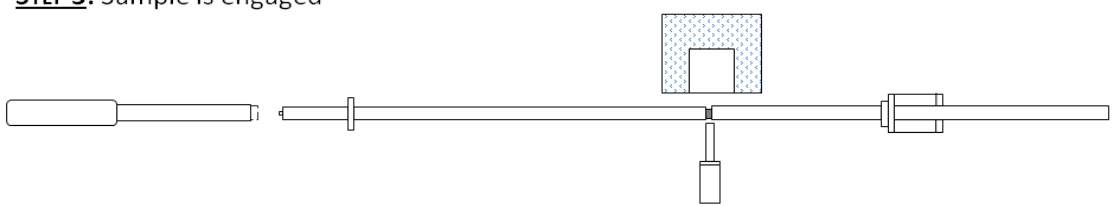
STEP 1: Sample moved to furnace



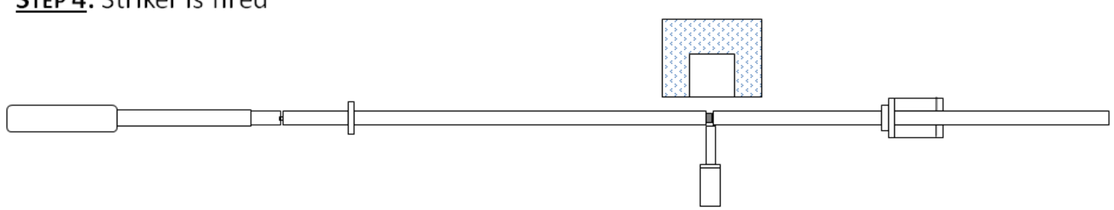
STEP 2: Sample removed from furnace



STEP 3: Sample is engaged

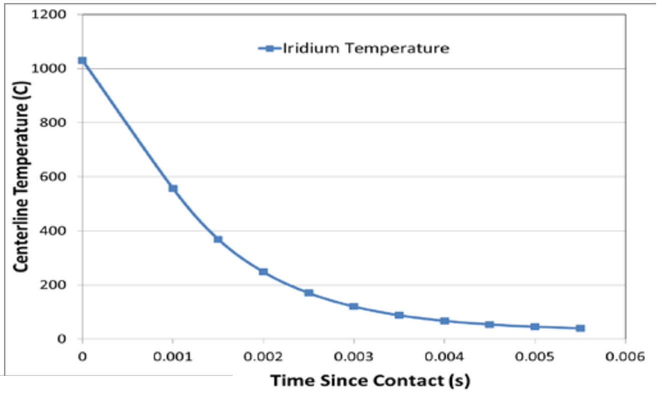


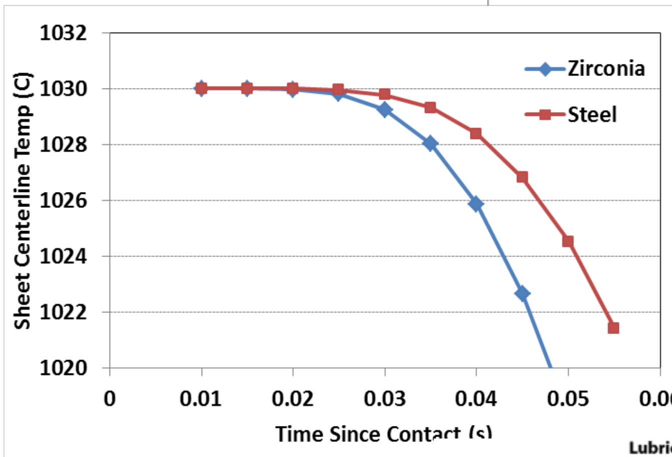
STEP 4: Striker is fired

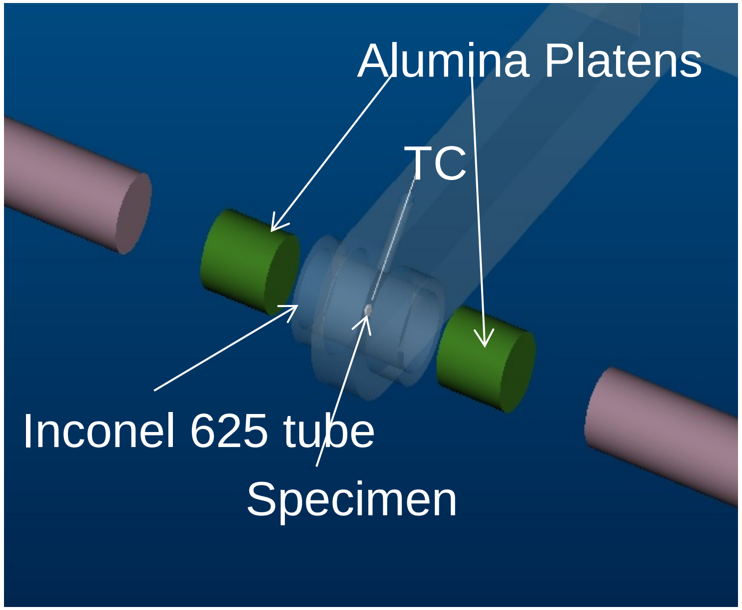


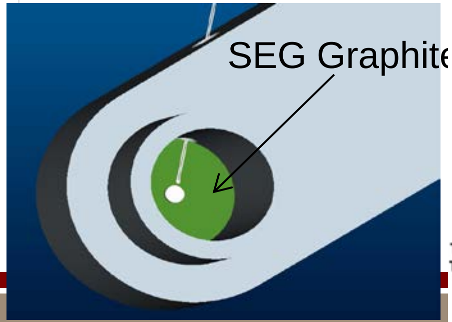
Additional Challenges for High-Temperature Kolsky Bar Testing of Iridium

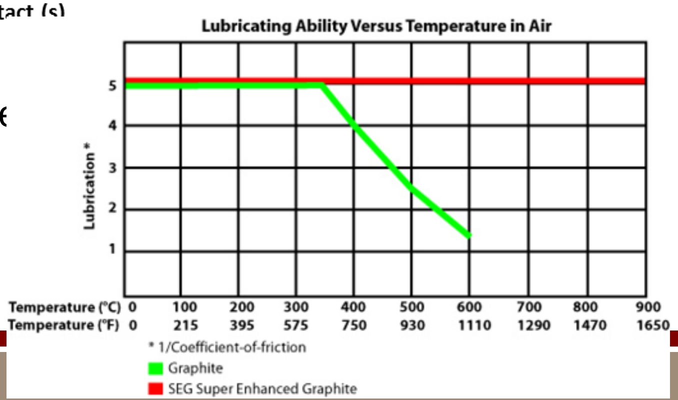
- Small/Thin Iridium Specimen
  - Temperature drops very quickly when the specimen starts in contact with cold pressure bars
  - High strength at high temperature
  - High-Temperature Lubrication



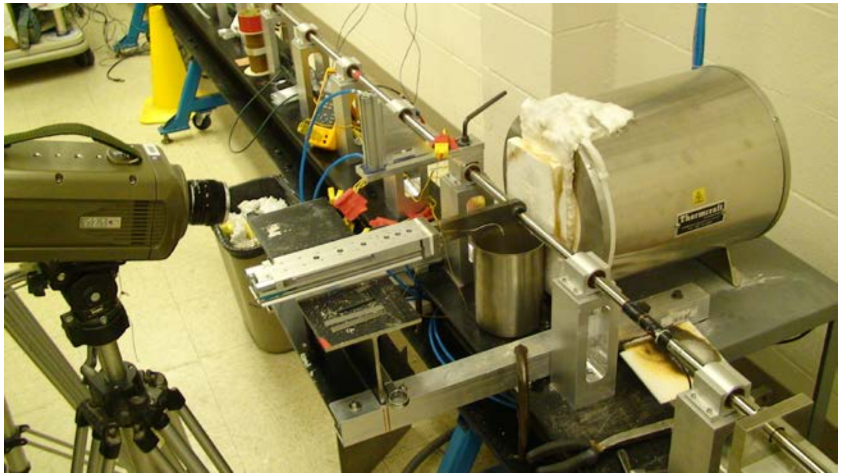


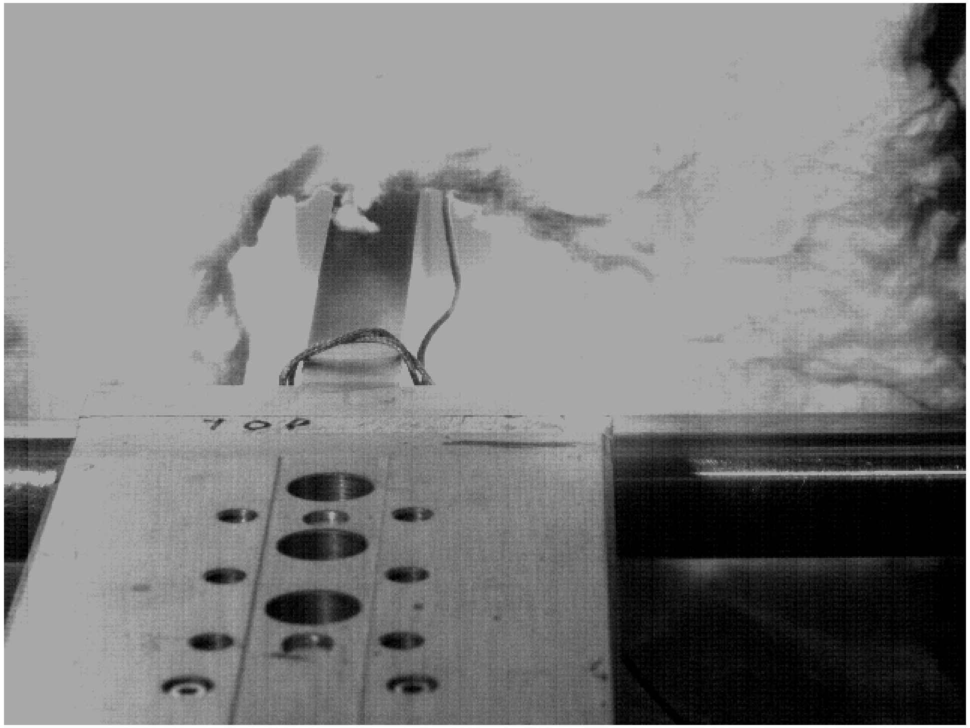




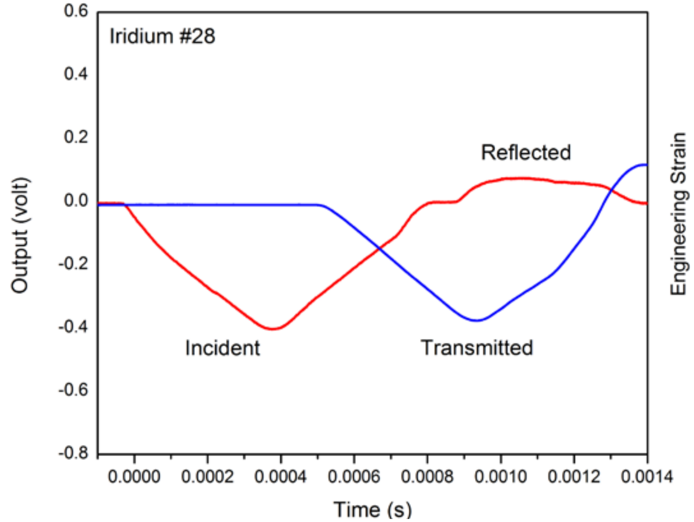


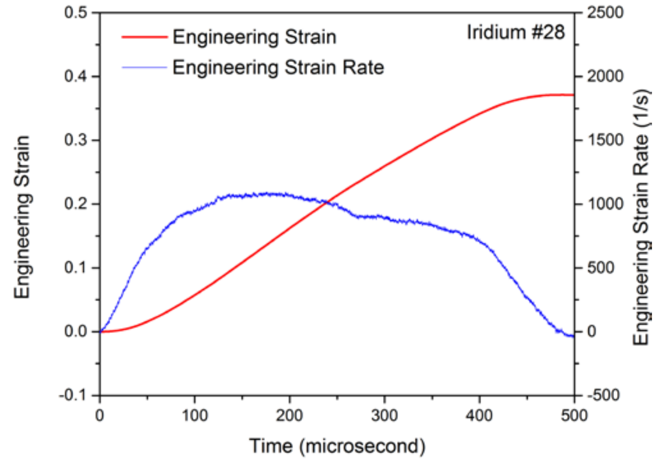
Compression Test Setup and Procedure





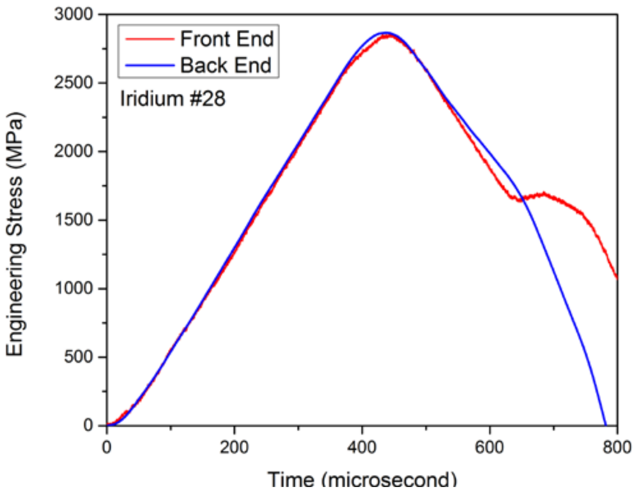
Compression Test at 1000 s^{-1}/750C



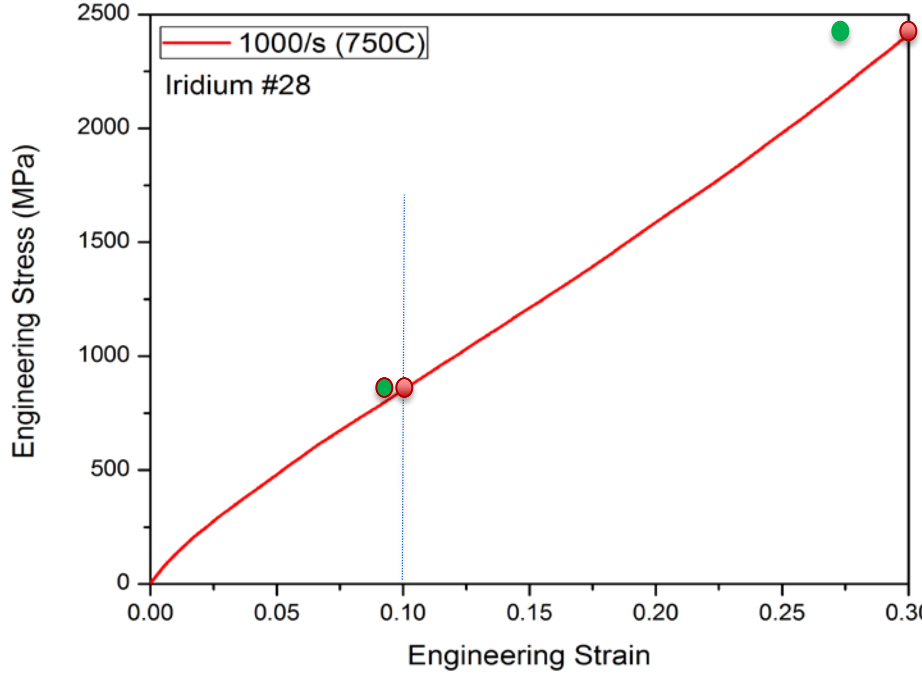


$$\dot{\varepsilon} = \frac{u_1 - u_2}{l_0} = \frac{C_0}{l_0}\left(\varepsilon_i - \varepsilon_r - \varepsilon_t\right)$$

$$\varepsilon = \int_0^t \dot{\varepsilon}(\tau)\, d\tau$$

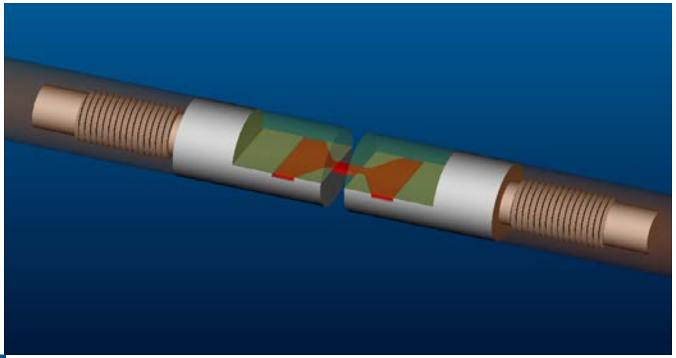


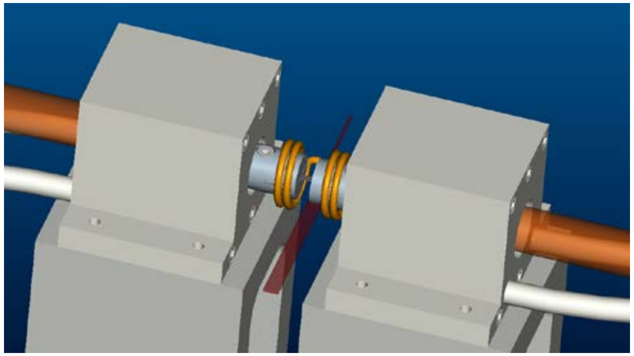
$$\sigma_1 = \frac{A_b}{A_0} E_b\left(\varepsilon_i + \varepsilon_r\right) \qquad \sigma_2 = \frac{A_b}{A_0} E_b \varepsilon_t$$

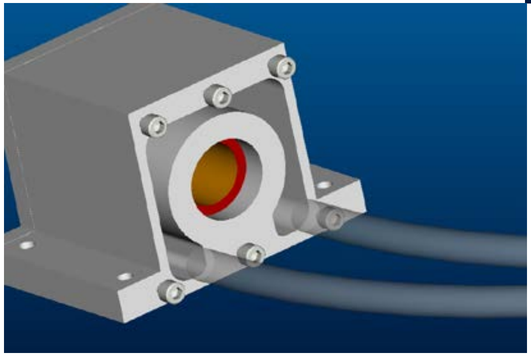


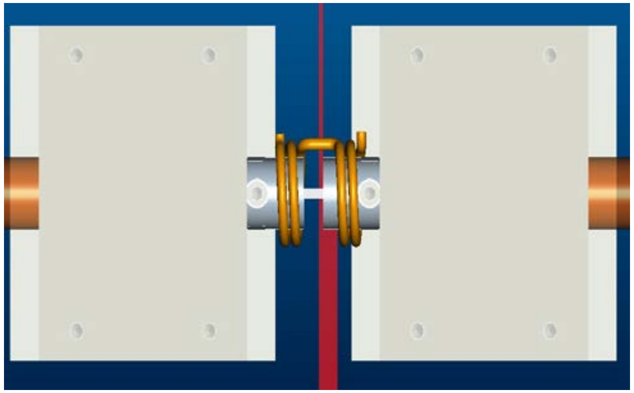
High-Temperature Kolsky Tensile Bar Tests

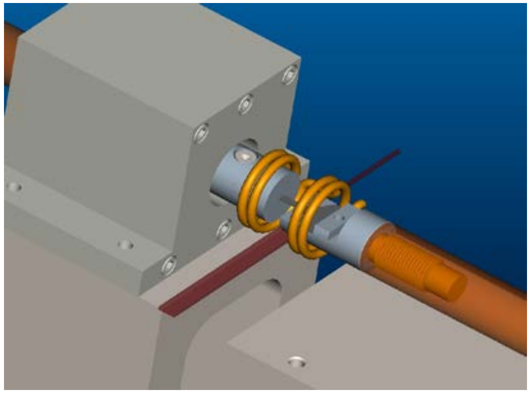
- Current high-temperature Hopkinson compression techniques are not applicable to tensile tests
- How?

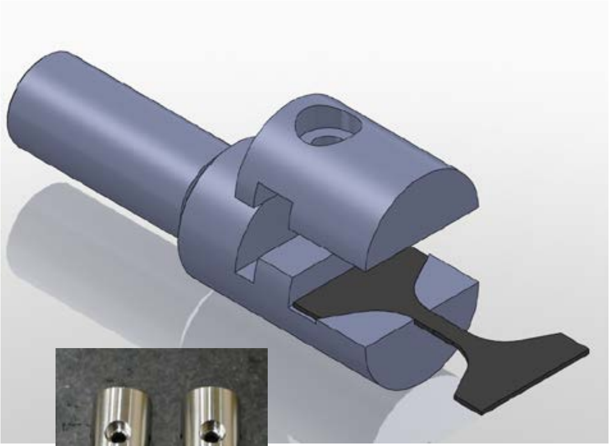




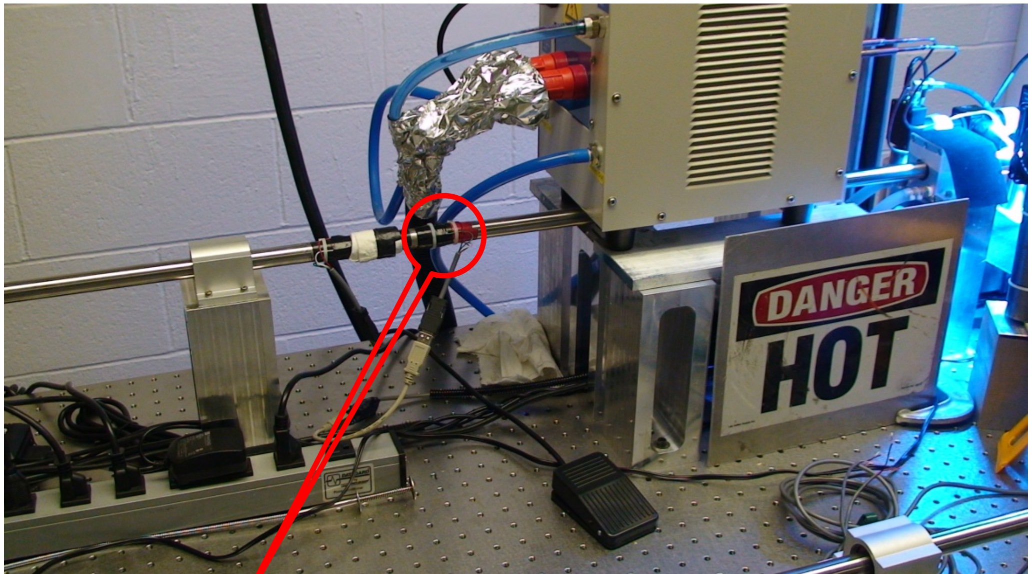


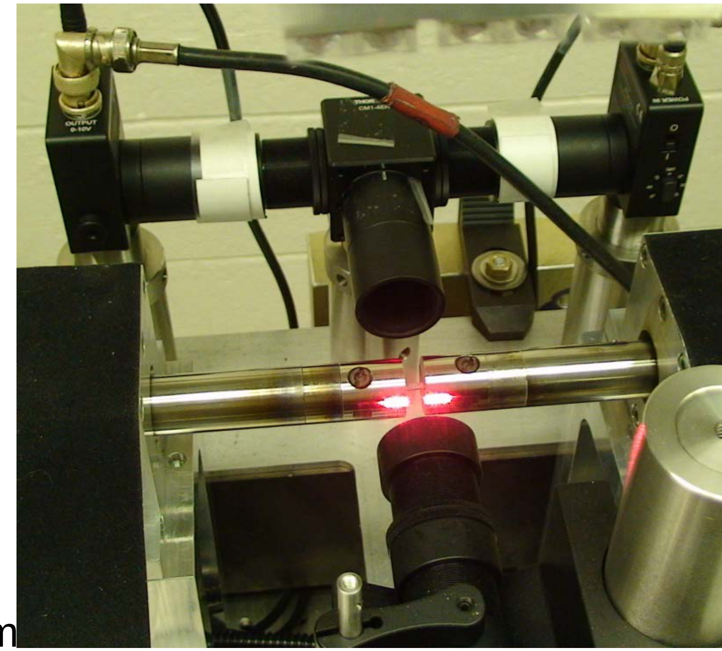






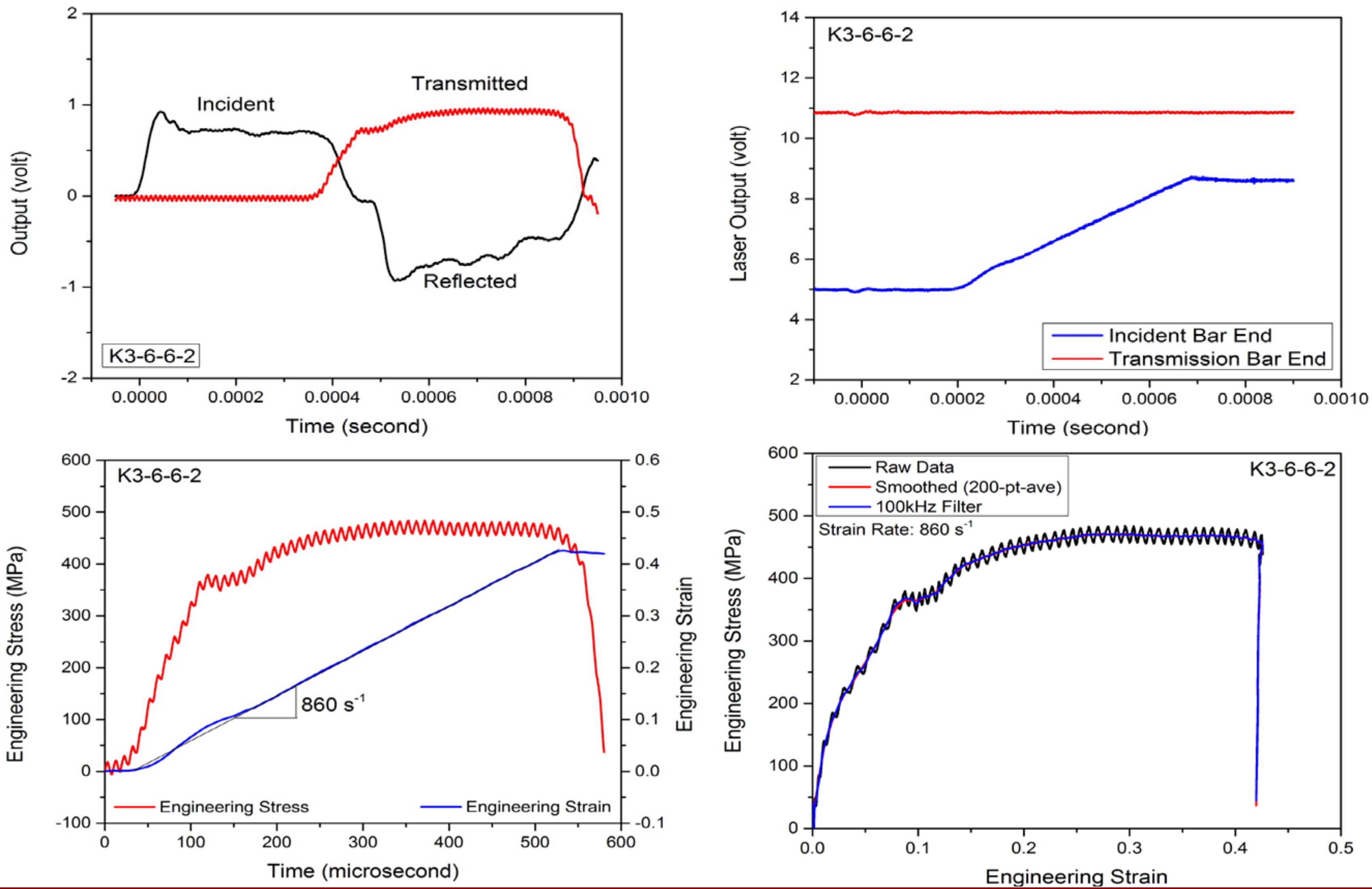
Stress and Strain Measurements



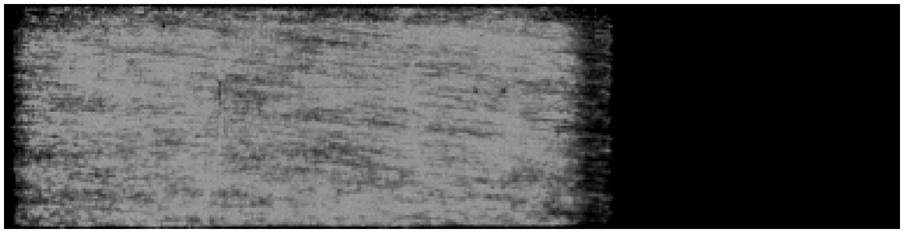


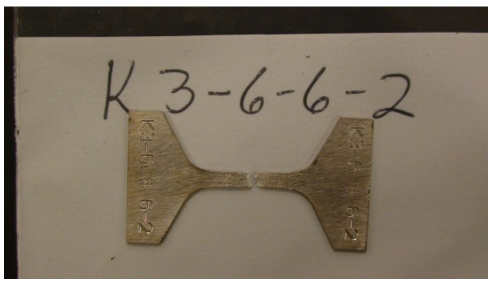
Semiconductor strain gages – specimen stress measurem
(GF: 139 vs. 2 for regular foil strain gage)

Typical Dynamic High-Temperature Tensile Test



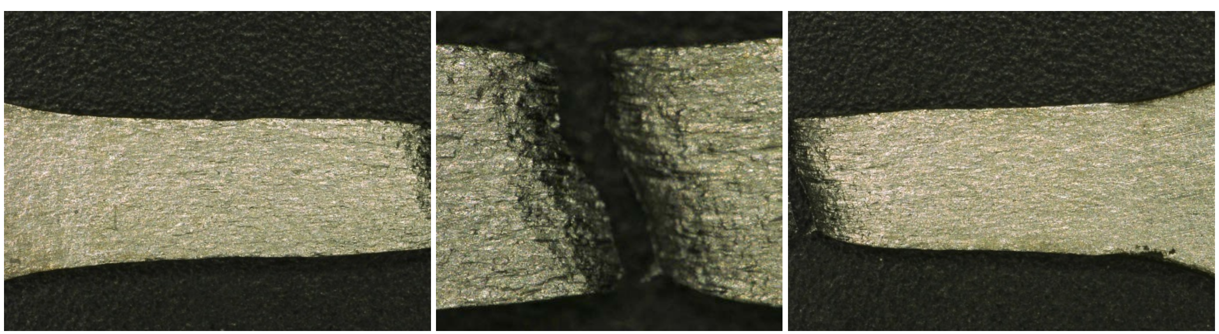
Specimen During and After Dynamic High-Temperature Test



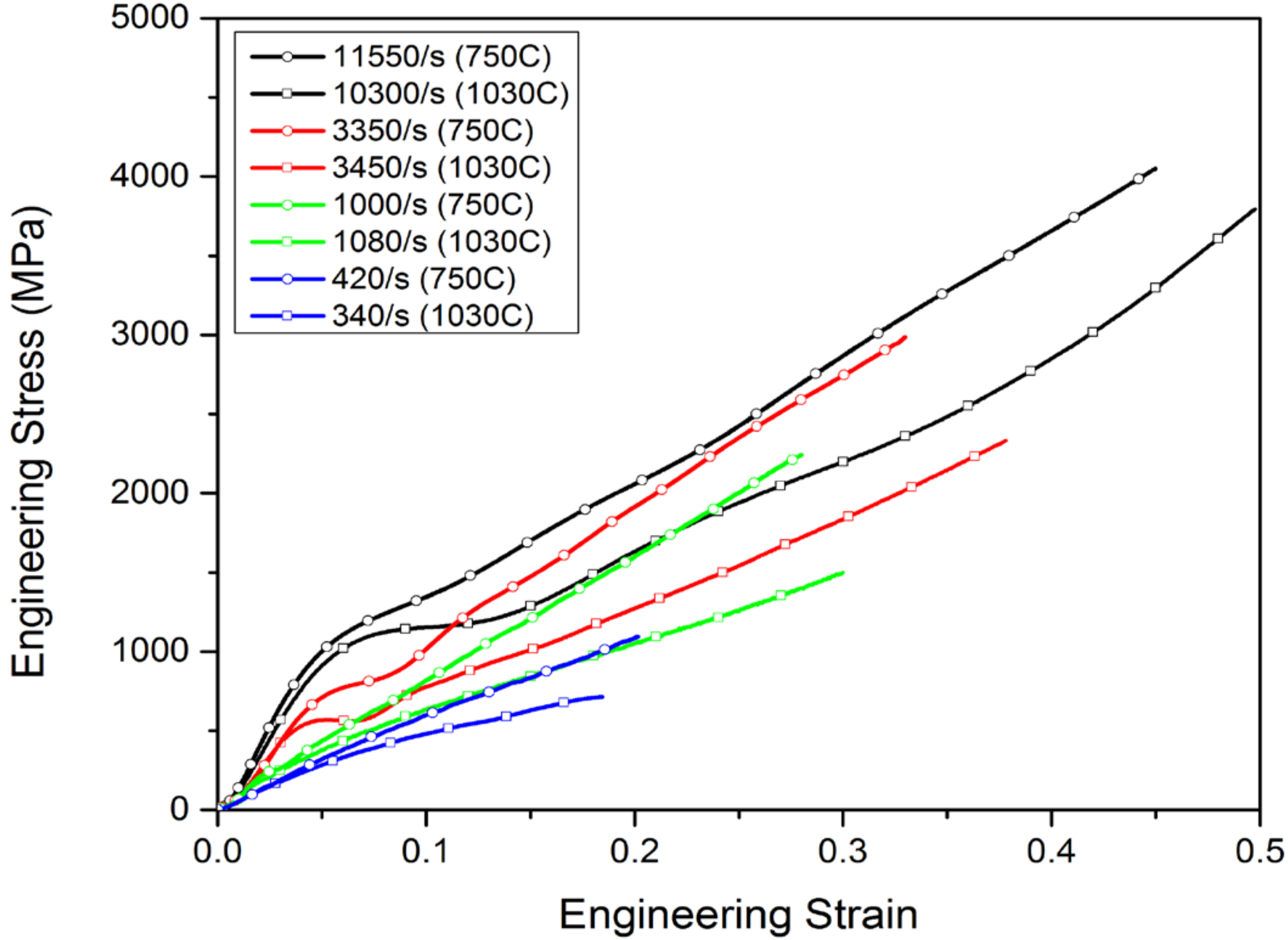


		K3-6-6-2		
Initial Measurements		After Measurements		
(in.)	(mm)		(mm)	
0.03590	0.9119	*	1.3406	
0.03495	0.8877		Break	
0.03495	0.8877	*	1.3467	
0.03495	0.8877		1.3606	
0.03485	0.8852		1.2579	
0.03505	0.8903			
Average				
0.03511	0.89175			
	3.5725		5.3058	0.485

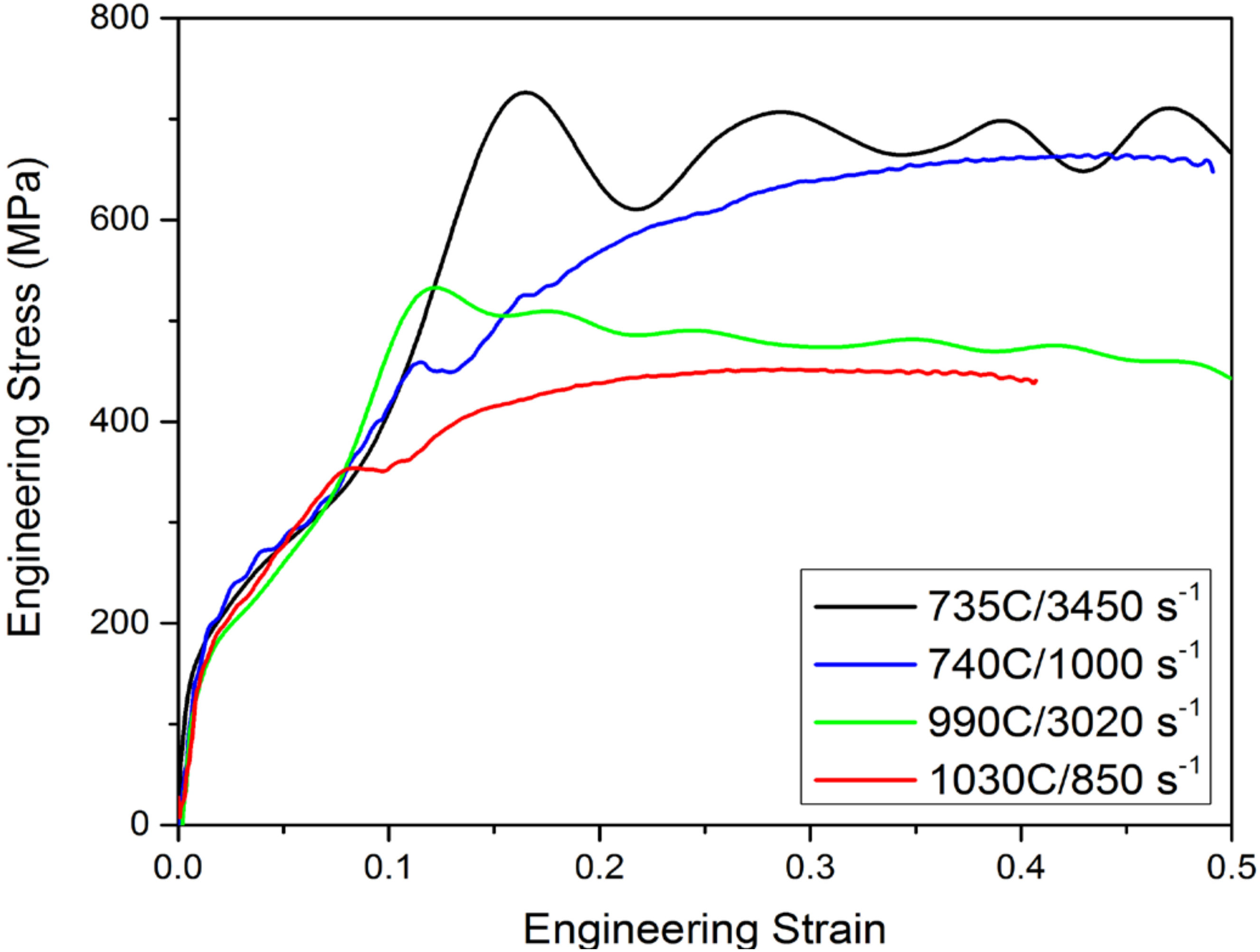
** One or both indentations were difficult to detec
Measurement value is suspect



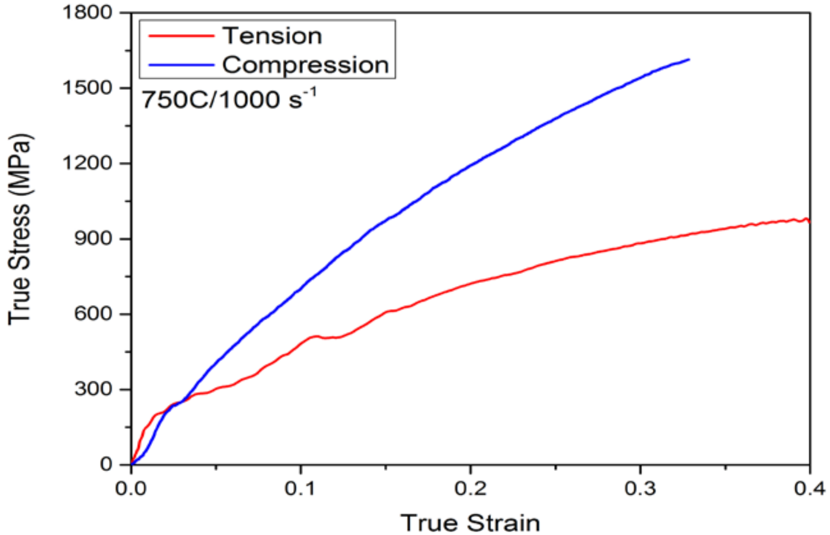
Engineering Compressive Stress-Strain Curves at Different Strain Rates and Temperatures

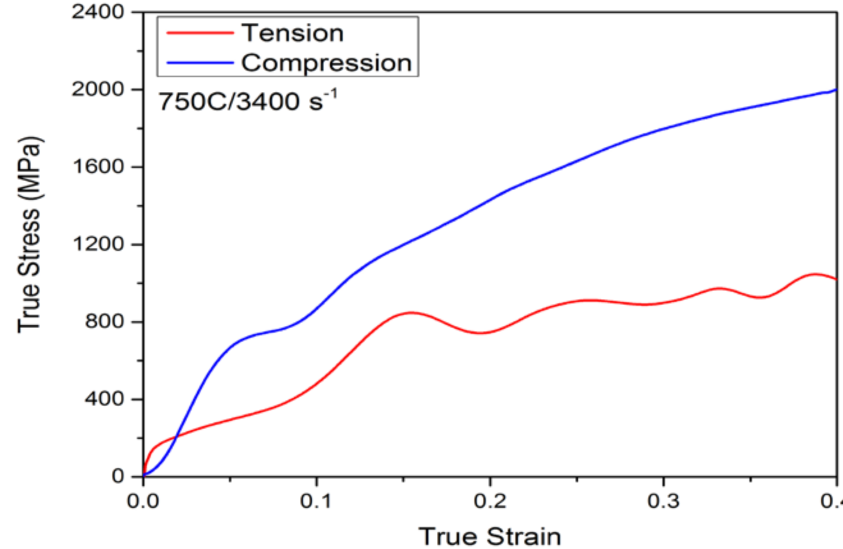


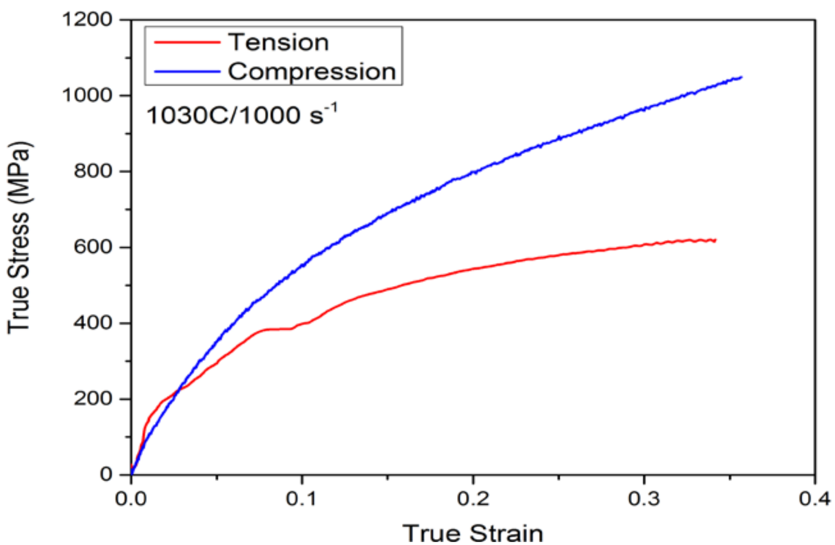
Engineering Tensile Stress-Strain Curves at Different Strain Rates and Temperatures

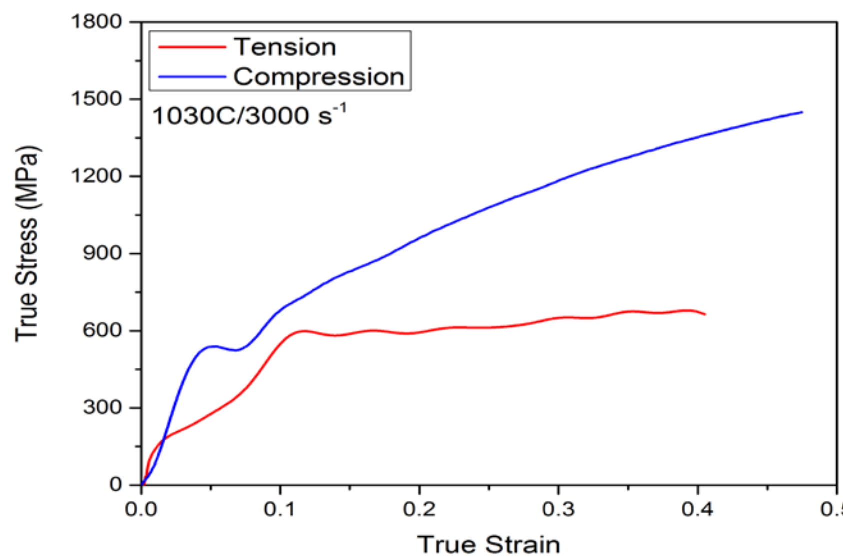


Tension vs Compression









Summary

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

- DOP-26 iridium alloy has been dynamically characterized in compression and 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***

Acknowledgments

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

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