**PNNL High-Temperature Materials Capabilities**

Pacific Northwest National Laboratory (PNNL) has a broad range of capabilities for synthesis, measurement and testing, and characterization of high-temperature materials. PNNL possesses outstanding capabilities in powder processing of materials and can fabricate a range of materials using traditional melting and casting techniques, including metal matrix composites using centrifugal casting techniques. We have pioneered the use of displacement reactions to produce novel in situ composites with temperature capabilities up to 1200˚C in air with outstanding corrosion properties. Test and measurement equipment at PNNL can handle materials up to 2500˚C in inert environments or up to 1800˚C in oxygen or other environments. Environmental testing of materials is a specialty at PNNL and several state-of-the-art systems have been assembled for exposing and testing materials at elevated temperature under a variety of aggressive environments. Ceramic composites have been tested under slow crack growth conditions for several weeks using well-controlled aggressive environments to explore the role of the external environment on crack growth mechanisms in materials. Test frames range from small (a few N) to large (500kN), both electromechanical and servo hydraulic. Hot hardness testers are also available.

Thermal properties of materials can be examined up to 1200˚C in a variety of atmospheres, as well. Materials characterization can be performed using surface science tools, XRD, TEM, and SEM. A recent specialty developed at PNNL is the use of cross-sectional transmission electron microscopy to image crack-tips in materials down to a few nm in crack opening, under stress corrosion conditions. This has opened up a new area of research in stress corrosion cracking.

A wide variety of computational modeling have been developed in the interface and structural materials groups studying grain boundaries, dislocations, and other defects in metals and alloys. Techniques range from first-principles atomistic studies to MD to kinetic Monte Carlo models of radiation damage. New and exciting work is being performed on nanolayered materials in a joint PNNL-LANL research program. Here the expertise of the PNNL modeling team has revealed new deformation modes in these materials.

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## *High Temperature Mechanical Properties Measurement Capabilities*

Instron 4400: Electromechanical load frame with tube furnace.

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| Load Range: | 0.1 - 100 kN |
| Load Cells available: | 89 - 5000N tension/compression<br>20 - 220 N compression only |
| Loading Rates: | $5.0 \times 10^{-5}$ - 0.50 m/min |
| Current test fixtures: | Silicon carbide and inconel 1/4 4-point bend and 3-point bend, completely articulated flexural test fixtures. |
| Temperature Range: | 273 - 1273 K, Kanthal wire elements and inconel fixtures<br>1073 - 1873 K, $MoSi_2$ elements and silicon carbide fixtures |
| Environments: | Air, inert, mixed gases |
| Test capabilities: | Load, displacement, or strain controlled tensile or compressive strength, strain rate, static fatigue, creep, or fracture toughness testing. |

Instron 1125: Electromechanical load frame with controlled atmosphere furnace and non-contacting laser extensometer.

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| Load Range: | 0.1 - 100 kN |
| Load Cells available: | 89 - 5000N tension/compression<br>20 - 220 N compression only |
| Testing volume: | 10 cm dia. x 15 cm height |
| Current test fixtures: | Silicon carbide pin and clevis loading rods for tensile or compact tension specimen geometries |
| Temperature Range: | 1073 - 1873 K, $MoSi_2$ elements<br>273 - 1873 K, W mesh element |
| Environments: | $MoSi_2$ elements: air, argon with up to 20% oxygen<br>W mesh elements: 50-100 mTorr vacuum, inert gas (argon or nitrogen) |
| Test capabilities: | Load, displacement, or strain controlled tensile or compressive strength, strain rate, static fatigue, creep, or fracture toughness testing. |

Instron 1125: Electromechanical load frame with controlled atmosphere furnace.

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| Load Range: | 0.1 - 100 kN |
| Load Cells available: | 4450 N tension/compression |
| Testing volume: | 15 cm dia. x 30 cm height |
| Current test fixtures: | Silicon carbide and inconel 1/4 4-point bend and 3-point bend, completely articulated flexural |

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| | test | fixtures. Inconel tensile fixtures. Shear-punch testing up to 500°C. |
| | Temperature Range: | 273 - 2273 K, W mesh element |
| | Environments: | 50-100 mTorr vacuum, inert gas (argon or nitrogen) |
| | Test capabilities: or | Load, displacement, or strain controlled tensile compressive strength, strain rate, static fatigue, creep, or fracture toughness testing. |

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| Instron 1321: | 100 kN servo hydraulic load frame. | |
| | Load Range: | 10 kN |
| | Load Cells available: | 10kN |
| | Current test fixtures: clevis | Wedge grips, pneumatic grips, and pin and fixtures |
| | Temperature Range: | Controlled atmosphere $MoSi_2$/W furnace from the Instron 1125 frame can also be mounted on this frame (10 cm dia. x 15 cm height) |
| | Environments: | See above |
| | Test capabilities: or | Load, displacement, or strain controlled tensile compressive strength, static and cyclic fatigue, strain rate, creep, or fracture toughness testing. |
| Instron 1328: | 500 kN servo hydraulic load frame. | |
| | Load Range: | 500 kN |
| | Load Cells available: | 500kN, 45 kN |
| | Current test fixtures: clevis | Wedge grips, pneumatic grips, and pin and fixtures |
| | Temperature Range: | No specific furnace attachments |
| | Environments: | Ambient |
| | Test capabilities: or | Load, displacement, or strain controlled tensile compressive strength, static and cyclic fatigue, strain rate, creep, or fracture toughness testing. |

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| Micropull Tensile: Testing Machine | Computer controlled, stepper motor driven fiber and low-force tensile test frame. | |
| | Load Range: | 500 N |
| | Load Cells available: | 100 N |
| | Current test fixtures: | Pin loading grips for tabbed fibers, compression testing fixtures. |
| | Temperature Range: | 273-1473 K |
| | Environments: | Air |
| | Test capabilities: | Load, displacement, or strain controlled tensile strength, strain rate, static fatigue, or creep testing. |

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| Nikon QM: Hot-Hardness Tester | Hardness tester equipped with controlled atmosphere chamber and hot stage. | |
| | Load Range: | 5 kN |
| | Indenters: | Micro-Vickers - diamond and sapphire<br>Knoop - diamond |
| | Temperature Range: | 273-1873 K |
| | Environments: | Inert gas<br>Vacuum ($10^{-3}$ Pa) |
| Gas Mixing System | Gas manifold, mixing chamber and mass-flow control system for use with controlled atmosphere chambers. | |
| | Controller: | MKS Multi-Gas controller 147 |
| | Mass Flow Valves: | $1 \times 10^{-5}$ $m^3$/min. (2)<br>$1 \times 10^{-4}$ $m^3$/min (2)<br>$1 \times 10^{-3}$ $m^3$/min (2) |
| Oxygen Gettering Furnaces (2) | Titania ($TiO_2$) charged furnace, flow system, and gas analyzer for removing oxygen from gas. | |
| Questar QM-1: | Traveling microscope for in-situ crack growth measurements. | |
| | Magnification: | 200 x |
| | Display Features: | CCD camera and video monitor |