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DYNAMIC BEHAVIOR OF PU & U (INTERMEDIATE STRAIN RATES) - LA12

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EnhancedSurveillanceProgramAnnualReportFY98

PIT FOCUS AREA: Dynamic Behavior of Pu & U (Intermediate Strain Rates) - LA12

Abstract

The Kolsky-Hopkinson Bar Dynamic Test Facility in Building PF-4 at TA-55 recently became operational and the first series of plutonium samples from a baseline alloy were successfully tested on December 8, 1997 through the dedicated efforts of a large number of people in groups NMT-9, NMT-11, MST-8, NMT-5, and JCI. The Enhanced Surveillance Program provided the necessary support for this achievement.

The Kolsky-Hopkinson bar is an instrument designed to measure the uniaxial compression stress-strain characteristics of special nuclear materials (SNM) in a glovebox environment at intermediate strain rates (typically 500 s^{-1} to 10,000 s^{-1}), over a wide temperature range (cryogenic up to near-melting temperatures), and up to strains of about 50% per test. Due to radiation contamination hazards, SNM samples are contained within a specially designed glovebox with only a small portion of the bar system.

The uniaxial high-strain-rate deformation behavior of SNM materials is revealed by stress-strain-strain rate curves calculated from strain signals acquired by gauges on the pressure bars. The compressive stress-strain mechanical behavior of a range of weapons-relevant SNM materials (both "baseline" and stockpile-aged plutonium and enriched uranium), measured over a wide range of strain rates and temperatures, is necessary to support the development of predictive constitutive models and allows assessment of the mechanical response of SNM as a function of age, processing, and composition. Accurate constitutive material models are essential for simulating the high-rate deformation response of weapon materials.

Most FY98 milestones and deliverables were successfully met or were partially completed on schedule. In the case of enriched uranium, testing began six months ahead of schedule. Upgrading the testing temperature capability took six months more than originally planned as a result of the highly formalized and rigorous design change plan (DCP) requirements at TA-55. Specimen availability continues to be a "bottle-neck" beyond our control due to over-subscribed plutonium fabrication resources.

Objectives

Stress-strain mechanical property data required for modeling and performance evaluation will be measured at intermediate strain rates on baseline weapons materials and stockpile-returned plutonium and uranium. The compressive deformation response will be obtained as a function of aging, processing, temperature, and composition. This data, along with low strain rate (10^{-3} to 10^{0} s^{-1}) compression, shock EOS test data, chemical and metallurgical characterization studies

funded by separate programs, is needed for a comprehensive understanding of the material behavior.

Milestones - FY98

Description	Planned	Actual
Initiate "hot" testing in the new Kolsky-SHPB facility on baseline ("new") plutonium materials.	11/97	12/97
Begin Kolsky bar testing of aged plutonium from the surveillance program or when samples are available.	1/98	Specimens not available
Initiate high and low temperature testing on the Kolsky bar	3/98	Installation 9/98
Initiate studies on the influence of processing (wrought vs. cast) and chemistry on Pu alloy properties	7/98	Chemistry 8/98
Complete testing and analysis on the initial selection of baseline and aged plutonium as a function of temperature and deliver to X, T, and ESA Divisions.	9/98	Ambient 9/98 (WWG 468)
Begin WR uranium studies on baseline materials, when samples are available.	9/98	3/98

Deliverables - FY98

Description	Planned	Actual
NMT-9 / MST-5 will initiate "hot" operation of the new Kolsky-Hopkinson bar dynamic test facility in TA-55's PF-4.	11/97	12/97
Report the dynamic constitutive response of selected baseline and aged Pu alloy material of interest to SBSS as a function of temperature to determine the magnitude and reproducibility of aging.	9/98	Ambient baseline 9/98 (WWG 468)

Accomplishments

The Kolsky-Hopkinson Bar Dynamic Test Facility in Building PF-4 at TA-55 became operational for SNM testing after five years of development and the first plutonium samples from a baseline alloy were successfully tested on December 8, 1997. The facility has been used to measure the intermediate-strain-rate mechanical properties of three alloys to-date. Two baseline plutonium and one surveillance enriched uranium materials have been tested at strain rates from 800 to 8000 s^{-1} at room temperature. Experiments were performed using different striker velocities (controlled by the breech pressure) and striker bar lengths that yield a series of stress-strain curves at different applied strain rates and total strains.

A design change package (DCP) for glovebox modifications and upgrading the testing temperature capability of the Kolsky Bar was submitted, approved by NMT-8 facility management, and installed in September 1998. Stockpile-to-target-sequence (STS) temperature-range data can be

obtained by uniformly heating or cooling the sample with a helium gas heat exchanger. Higher temperatures (up to near the melting point) will be achieved by using a small resistance furnace positioned around the sample. Tests can also be performed at cryogenic temperatures of -196°C (77°K) by placing the sample in a bath of liquid nitrogen during the test. Figure 1 shows the temperature control panel for the helium gas heat exchanger and the resistance furnace prior to installation.

Experiments have been designed to quantitatively evaluate the influence of aging and other material parameters on the constitutive behavior of plutonium-based and enriched-uranium alloys using surveillance (WR-grade) and research-synthesized materials over the next several years. Specimens are typically 5 millimeters in diameter by 5 millimeters long, but can be as small as 2 millimeter in diameter by 1 millimeter in length. These compact sizes allow for a large number of tests to be performed on most sources of material. Essential complements to the mechanical behavior measurements are microstructural and chemical characterization, such as optical metallography, transmission electron microscopy, and X-ray diffraction. These additional techniques are applied before and after mechanical testing to help determine the controlling deformation mechanisms and the occurrence of phase transformations.

Figure 2 demonstrates an example data set for high-purity copper illustrating the influence of temperature and strain rate on the stress-strain response of a ductile metal. Copper atoms are organized in a face-centered-cubic (fcc) lattice crystal structure and delta-phase plutonium possesses this same crystal structure as well.

Figure 3 shows incorporation of high and low-strain-rate stress-strain data for high-purity copper (based on data in Figure 2), high-purity nickel, and 304L stainless steel tested over a range of temperatures. In this plot, it can be seen that when stress-strain data are plotted against an expression capturing the correct normalized activation energy a wide range of data for a given material can be fit by a single linear relationship or curve. Linearization of this wide range of data validates the correct modeling of the " thermally-activated" kinetics of the mechanism controlling plastic flow. In the present case of Cu, Ni, and 304L SS, the deformation is dominated by dislocation slip. Thermally-activated dislocation kinetics form the physical basis for material constitutive models, such as PTW (Preston-Tonks-Wallace) and MTS (Mechanical Threshold Stress), which are utilized in large-scale finite-element system calculations of weapon performance.

Taken collectively, Kolsky-Hopkinson Bar results, low strain-rate compression data, 40-mm plutonium EOS tests, and experiments at the NTS U1a complex form an integrated approach to characterizing the mechanical response of weapons materials needed to support NWT's surveillance, re-manufacturing, and recertification missions.

Acknowledgments

The author wishes to acknowledge the dedicated efforts of a number of people who contributed to the success of this project. These include: Charles Frantz, Martin Reisfeld, Benito Jacquez, Carl Trujillo, Paul Contreras, Johnny Montoya, Steve Boggs, Ben Lopez, George (Rusty) Gray III, Elizabeth Foltyn, Tim George, and Joe Martz.

Figure Captions

Figure 1: Shows the new temperature control panel for the helium gas heat exchanger and the resistance furnace located below the Kolsky Bar barrel and incident bar. The control panel regulates the specimen temperature within the adjacent glovebox.

Figure 2: Representative stress-strain curves for high-purity copper showing strain rate and temperature dependence typical of fcc metals.

Figure 3: Plot of the normalized flow stresses of three fcc metals (copper, 304L stainless steel, and high-purity nickel) versus the normalized activation energy. These cases demonstrate the inverse relationship between temperature and strain rate on metal plasticity termed "thermal activation" for dislocation slip.

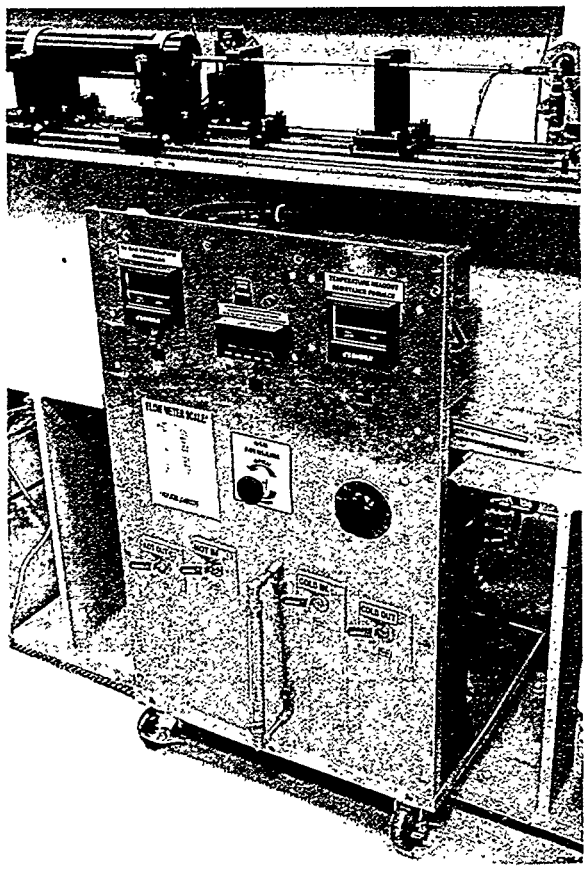

Figure 1

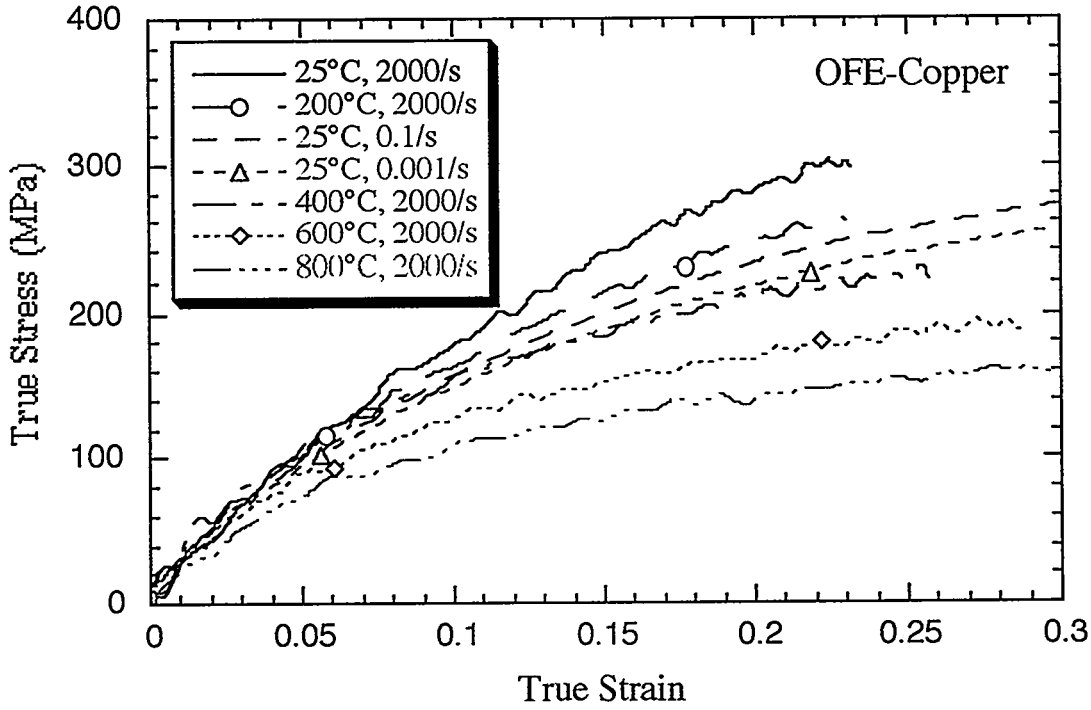
OFE-Copper
25°C, 2000/s
200°C, 2000/s
25°C, 0.1/s
25°C, 0.001/s
400°C, 2000/s
600°C, 2000/s
800°C, 2000/s
True Stress (MPa)
True Strain
0
100
200
300
400
0
0.05
0.1
0.15
0.2
0.25
0.3

Figure 2

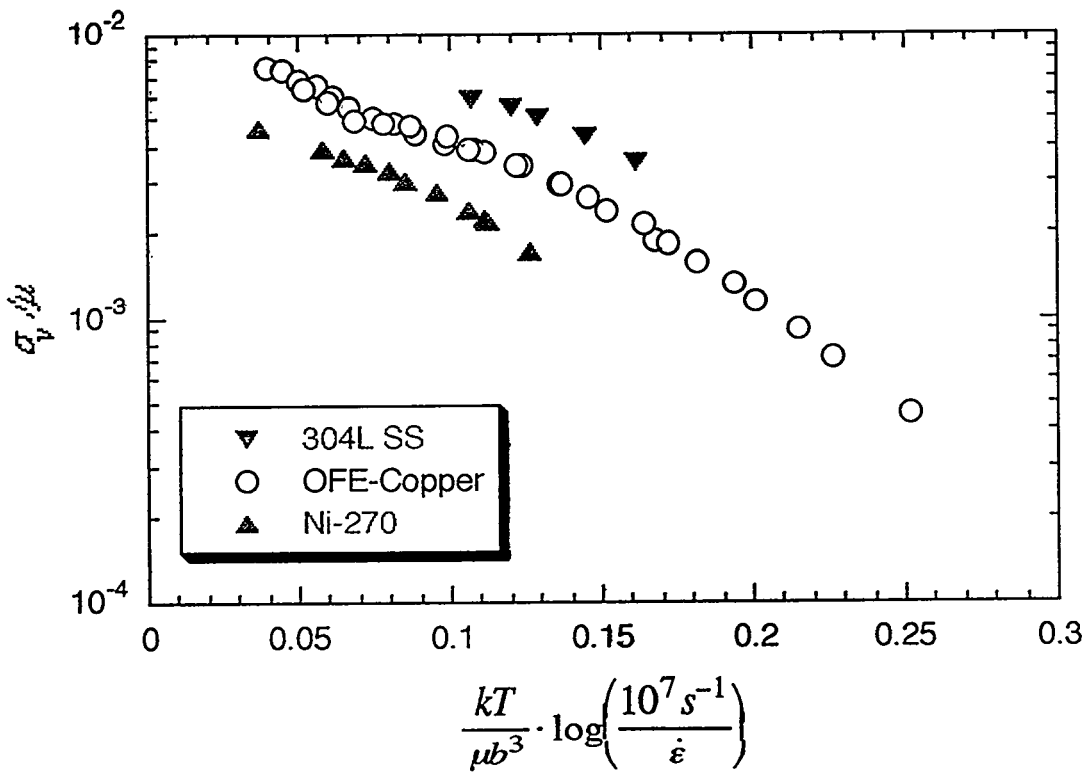
10^{-2}
10^{-3}
10^{-4}
σ_y/μ
0
0.05
0.1
0.15
0.2
0.25
0.3
304L SS
OFE-Copper
Ni-270
$\frac{kT}{\mu b^3} \cdot \log\left(\frac{10^7 s^{-1}}{\dot{\varepsilon}}\right)$

Figure 3