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MST-6: Metallurgy

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Hot and cold rolling of metals is used to meet customer dimensional and crystallographic requirements.

Sigma Complex

The original and enduring mission of the Sigma Complex focuses on prototype fabrication and materials research for the nuclear weapons program. Over the years, however, this mission has expanded to include threat reduction and homeland security activities.

Today, the Sigma Complex supports a large, multidisciplinary materials technology base. Research and development activities include a synergistic blend of metallurgy and ceramics focused on the integration of synthesis and processing, characterization, and fabrication combined with fundamental computer modeling and process simulation. These extensive capabilities reflect significant investments in metal casting; thermo-mechanical processing; electrochemistry; powder processing; sol gel synthesis and colloidal processing; laser and microwave processing; process modeling; and microstructural, mechanical, and thermophysical properties characterization.

The Sigma Complex is unique at the Laboratory—and perhaps within the United States—because this capability investment provides a highly integrated approach where materials can be processed on a large scale from the raw state to a final product. In this facility ceramists and metallurgists work with engineers and physicists to solve mutual problems and to extend understanding of materials processes and applications.

Highly qualified personnel and capability investments have maintained state-of-the art technology to create

Materials science and engineering from start to finish

a responsive infrastructure that can quickly respond to customers' needs. The facility is ideally suited for rapid turnaround of small lot production and prototype development. Several collaborations between Los Alamos and other Department of Energy (DOE) complex sites utilize Sigma's unique capabilities to solve design and production issues across the nuclear weapons program. For example, Los Alamos is assisting Y-12 with welding and casting development to improve production quality and efficiencies.

Our unique machining capabilities are routinely used by customers throughout the Laboratory and the DOE complex. The expertise within Sigma is regularly used to evaluate materials issues for providing input to re-use/re-manufacture decisions and to develop alternative materials and processing methods for the nuclear weapons programs.

Bulk nanocrystalline manufacturing

Nanocrystalline materials and nanotechnology have revolutionized many engineering technologies. Unique properties are possible with highly reduced length scales and new properties controlled by interfacially dominant features. One technological challenge

Graduate student Tom Nizolek with a redundantly roll bonded sheet of bulk nanocrystalline copper-niobium.

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has been the ability to produce large-scale structures that can take advantage of the interfacially dominant structures. The processing capabilities within Sigma have afforded scientists and engineers the ability to fabricate large-scale, bulk nanocrystalline materials. Using redundant roll bonding methods, sheets of copper and niobium are rolled, cut, stacked and re-rolled multiple times (similar to the fabrication of Samurai swords) to make large sheets of materials with novel microstructures and properties.

$h = 2 \text{ mm}$

$h = 500 \text{ nm}$

The microstructural evolution of roll bonded bulk nanocrystalline copper-niobium.

Prototype fabrication and small lot manufacturing

The Sigma Complex represents an advanced manufacturing research facility with unique capabilities to improve manufacturing and fabrication processes and to produce prototype components in support of the Laboratory's stockpile stewardship programs. Most teams within MST-6 contribute to this effort including the Foundry Team, the Forming and Machining Team, the Powder Materials Processing Team, the Welding and Joining Team, and the Corrosion and Electrochemistry Team.

Some of the fabrication methods available at the Sigma Complex include: multi-axis computer numerically controlled/electric discharge machining (CNC/EDM); casting, rolling and forging; hydroforming, electroforming, swaging and drawing; heat treating; high-energy density welding, such as electron beam welding and laser beam welding (both continuous wave and pulsed); precision arc welding, brazing, plasma spraying; and near net shape (NNS) hot isostatic pressing. Projects include more than original fabrication. Objects are re-created for customers using a coordinate measuring machine (CMM) and CNC. Declassification of classified metal parts by melting and machining is an important contribution to security.

Recent projects

Pit Manufacturing Project (PMP): PMP is an ongoing and high visibility project. Many of the teams in MST-6 contribute either directly or indirectly to support this high-profile project. The project demands high quality and the deliverables are tracked frequently. *Customer: DOE NNSA defense program*

Chemical Milling of Critical Shape: Chemical milling was used to produce a tapered stainless steel joint for a 100 Tesla research magnet at NHMFL. Multiple sheets were required with a tapered joint between sheets to prevent stress risers and failure. The size of the SS sheets made

tapering by mechanical means impractical. *Customer: National High Field Magnetic Laboratory*

Micro-Compression Pillars: Focused ion beam (FIB) was used to produce Cu-Nb and U-6Nb micro-compression pillars for mechanical testing. *Customers: Global Nuclear Energy Partnership (GNEP), Enhanced Surveillance, DOE Office of Basic Energy Sciences, Los Alamos National Laboratory-Directed Research and Development (LDRD)*

Joint Test Assembly and Hydrotest: These projects involve high-profile deliverables and, at times, compressed schedules to enable quality testing. Many of the teams within MST-6 support these programs and allow deliverables to be met early. Rolling, punching, hydroforming, spin forming, and welding are a few of the processes used. *Customer: DOE NNSA defense program*

High Performance Beryllium High Heat Flux Divertor: Prototypes were made using a unique beryllium plasma spraying system. A patent disclosure was filed for the technology which allowed deposition of 10-mm-thick deposits. These prototypes passed severe high heat flux testing in the United States and European Union and qualified the process for use in International Thermo-nuclear Experimental Reactor. *Customers: DOE Department of Fusion Energy Sciences, European Fusion Development Association (EFDA)*

Additive manufacturing

In the mid-1990s, engineers in Sigma pioneered directed light fabrication, a patented process for directed energy powder deposition of complex parts. This revolutionary capability has recently gained considerable international attention for complex fabrication of parts—built up a layer at a time. Conventional manufacturing consists of casting large ingots and then forming, machining, and finishing to fabricate the desired part. This advanced concept developed within Sigma offers the opportunity to dramatically alter the conventional manufacturing paradigm: the ability to produce multifunctional components with complex features, economical use of materials, and flexible materials selection for tailored engineering applications.

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Materials characterization

Characterization—a critical aspect of every materials program—is an important tool for understanding the properties and processing of materials and for applying that understanding to materials development. The Sigma Complex supports a collection of tools for characterizing materials including mechanical testing, hardness testing, electron microscopy, optical metallography, interstitial element analysis (O, N, C, H), trace element analysis using inductively coupled plasma, differential thermal analysis, thermogravimetric analysis, bulk density, surface area analyses, x-ray diffraction, and powder characterization capabilities.

Recent projects

Pit Manufacturing Project: The large suite of optical microscopy techniques were used to certify that a piece of equipment involved in pit production is working within operational parameters. *Customer: NNSA defense program*

Surface Damage in Beryllium: Orientation imaging microscopy (OIM) was used to quantify the amount of surface damage in Be from different machining techniques. *Customer: Weapons Engineering Technology Division*

Mechanism for Uranium-Niobium Alloy Aging: Detailed examinations of accelerated-aged specimen microstructures were made to clarify the exact aging mechanism and insure that the aging model had the correct scientific basis. In this study the distribution of Nb atoms and phases were probed with a variety of techniques, each of which had its particular strengths. These included induction dilatometry, light and electron microscopy, and x-ray, neutron diffraction and three-dimensional atom probe tomography. Spatial resolution

The dual focused ion beam/high resolution scanning electron microscope, housed in Sigma's Electron Microscopy Laboratory, is used for a variety of projects, including producing micropillars for compression testing.

<1 nanometer was needed to differentiate among several aging mechanisms that have been proposed. *Customer: Stockpile Stewardship*

Hydrogen Interactions in Neutron Target Tube Loading: Valence band x-ray photoelectron spectroscopy (XPS) was used to identify and characterize erbium oxide compounds found at pre-load, at post load, and at various stages of aging. Structure could be deduced from behavior observed at the Fermi edge. *Customer: NNSA Neutron Tube Target Loading*

Measuring Properties from Small Selected Areas: Successfully developed micro tensile specimen which allows measurement of properties in very small locations. *Customer: Pit Certification Program*

Modeling and process simulation

Researchers at the Sigma Complex use fluid flow and heat flow computer codes to model microwave-material interactions, welding processes, rapid solidification by melt spinning, and the casting of near net shape components. They also use solid deformation modeling to examine sheet-forming processes and predict workpiece response to a number of different process variables. Scientists are involved with modeling and analysis of crystallographic texture development as a result of processing.

Recent projects

Optimum Design for Hydrotest Casting: The multi-physics code Truchas, developed under the ASC Telluride project, was used to simulate the performance of several mold designs for casting a hydro test part. This saved time and money. *Customer: Testworks Program (part of an Enhanced Collaboration with the UK Atomic Weapons Establishment on radiation cases)*

Robust Manufacturing: The sensitivity of part properties to production parameter variations was modeled using the Truchas code. *Customer: Stockpile Stewardship*

Advanced casting diagnostics and characterization

One of the current great engineering and scientific challenges is to develop “process-aware” materials throughout an engineering component’s entire lifecycle. The goal is develop experimental results and theoretical models that are linked across multiple time and length scales to provide a fundamental understanding of the manufacturing process of a material so that the material’s performance can be predicted through its service lifetime. As a result, better designs for performance and lower failure rates can be realized in engineering components. Scientists and engineers within Sigma are actively developing experimental methodologies and theoretical simulations that link the temporal and spatial resolutions for castings. A major component of the investigation is to link the mesoscale development dur-

Al-12 at.%Cu. ~200 μm thick, $G \sim 72 \text{ K/cm}$, $V \sim 135 \mu\text{m/s}$

$G \sim 72 \text{ K/cm}$, $V \sim 100 \mu\text{m/s}$

ing solidification with theoretical models. In situ measurements of solidification structures are being interrogated with high energy beams to capture physics never before observed. Collaborations between Los Alamos and Northeastern University have prompted an exciting interaction to model the experiments.

Synthesis and processing

Over the history of the Sigma Complex almost every element on the periodic table between hydrogen and uranium has been handled or processed—and this capability still exists today. Since many of these elements have hazardous characteristics, this facility provides the appropriate safeguards for both personnel and environmental protection. The Sigma Complex provides an appropriate workplace for researchers who must work with a variety of materials, including beryllium, uranium, and thorium. Some of the processing techniques available at the Sigma Complex include induction heating or arc heating for alloy melting and casting; powder atomization and melt spinning; solution processes to synthesize ceramic powders or coatings; solution and plasma spraying to produce functionally gradient materials; slip casting, cold pressing and sintering, hot pressing, hot isostatic pressing; and microwave processing.

Recent projects

Composite Material in Specialized Shapes: Tungsten-powder-reinforced uranium 1/4 scale long rod penetrators with enhanced armor penetration and W-Ni-Fe 1/4 scale long rod penetrators were produced using hybrid processes. *Customer: DARPA Armor-Anti Armor Program*

* Transferred technology to Westinghouse, Union Carbide, and IIT

New Large Format Radiation Detection Material: Nanocrystalline LaBr_3 material was made in bulk quantities using rapid solidification and a novel consolidation technique for large format radiation detection scintillators.

Customer: Domestic Nuclear Detection Office (DNDO)

Heavy Fermion Superconductors: Synthesis of single crystals of the actinide beryllides UBe_{13} and ThBe_{13} has been performed in beryllia crucibles by precipitation from molten metallic fluxes. The electronic properties of UBe_{13} are thought to be related to the electronic properties of high-temperature superconductors. *Customer: DOE Office of Basic Energy Sciences*

Foams with Nanometer Features: A self-propagating combustion process for the synthesis of high surface area, low density metal foams has been discovered. To our knowledge, the observed surface area of the metal foams exceeds any reported in the literature. The process is in development for numerous metals including iron, cobalt, nickel, copper, palladium, platinum and silver and for lithium nitride. The foams are being examined for uses in hydrogen storage and catalysis.

Customer: LDRD

Sigma Complex in brief

The Sigma Complex at Los Alamos National Laboratory is a complete metallurgical facility under one roof. Totalling more than 200,000 square feet of laboratory space, the complex offers cradle-to-grave manufacturing of every element in the periodic table.