National Aeronautics and Space Administration

Marshall Space Flight Center

Materials Diagnostics, Metallurgy, and Failure Analysis

The Materials Diagnostics, Metallurgy, and Failure Analysis capabilities at Marshall Space Flight Center (MSFC) reside within the Materials and Processes Laboratory. They provide world-class support for materials design, development, characterization, and constituent hardware failure analysis. These capabilities help solve materials design issues, foster manufacturing process optimization, create new materials when existing systems are inadequate, and help rectify component life cycle service issues when failures occur.

The development and operation of both simple and complex engineering components requires the integration of recognized materials categories with known or developing manufacturing processes.


Today's cutting-edge engineering systems operate under extreme conditions that exceed the known performance envelope of many materials. To ensure system safety and effectiveness, some hardware components must be analyzed to better understand materials degradation. Through bulk and surface chemical analysis, fractography, and microstructural analysis, the Laboratory's scientists and engineers collect physical and chemical evidence of a material's performance.

By incorporating this knowledge into new or existing systems, hardware reliability can be maximized, and risk can be minimized. The concentration of equipment and expertise has resulted in the Laboratory being at the forefront of the solutions to some of NASA's most complex hardware issues.

The Laboratory's materials diagnostics capability embodies a broad core of experience in materials, as




well as failure analysis. Qualitative and quantitative data on materials characteristics such as microstructure, bulk chemical composition, surface composition, crystal structure, and atomic configuration can be collected and coordinated with expert interpretation for any material – metallic or nonmetallic. A comprehensive combination of modern analytical tools is utilized to provide a complete understanding of material conditions.

The Laboratory also hosts a combination of traditional metallurgical engineering services and cutting-edge materials research and development. The coordinated interaction between hardware engineers and Laboratory personnel helps make aerospace systems safer, cheaper, and more reliable through materials and process optimizations. If existing materials are not sufficient to meet current needs, the Laboratory can assist in the development of new alloys that are robust in specific applications, with improved resistance to environmental degradation.



Key Benefits

- Unique combination of engineering and scientific knowledge and experience with the availability of state-of-the art tools and facilities.
- Outcome-driven organization that coordinates relevant aspects of materials and manufacturing processes to ensure the production of robust hardware.
- Successful failure analysis enables technical excellence in space flight hardware by reducing engineering risk within the constraints of programmatic cost and schedule.

Capabilities

Material Diagnostics

- **Sample Preparation**
  - Sectioning, Mounting, Polishing, and Etching
- Microscopy Services
  - Optical Microscopy, 3-D Stereomicroscopy, Scanning Electron Microscopy (SEM)
  - Analysis of all material types (metallic, ceramic, composite, geological, plastics, and biological)
  - High-resolution images of surfaces and internal microstructures can be captured at magnifications up to 1,000,000 times
- **Bulk Chemical and Crystallographic Analysis**
  - Energy Dispersive X-Ray Spectroscopy (EDS in SEM)
  - Wavelength Dispersive X-Ray Spectroscopy (WDS in SEM)
  - X-Ray Diffraction (XRD)
  - Electron Backscatter Diffraction (EBSD in SEM)
  - Elemental determination by combustion analysis for carbon, sulfur, nitrogen, and oxygen
- **Surface Analysis Services**
  - Secondary Ion Mass Spectroscopy (SIMS)
  - Electron Spectroscopy for Chemical Analysis (ESCA)/X-ray Photoelectron Microscopy (XPS)
- **Metallic Materials Analysis**
  - Decades of analytical experience with metallic materials that range from common steels to exotic single crystal superalloys
  - Staff metallurgists employ the latest analytical techniques to document hardness testing, microstructure, morphology, crystallography, and chemistry
- **Thermophysical Properties Characterization**
  - Electrostatic Levitation (ESL), Electromagnetic Levitation (EML), and Aqueous Solutions Levitation (ASL) — see Materials Levitation Laboratory Capabilities Flyer
  - Differential Scanning Calorimetry (DSC), Differential Thermal Analysis (DTA), Thermogravimetric Analysis (TGA), Thermal Diffusivity, Thermomechanical Analysis (TMA)
- **Ceramics and Composites Analysis**
  - Examination of nonmetallic materials with the same depth of analysis as metallic materials using optical microscopy and variable pressure SEM
- **Biological and Geological Materials Analysis**
  - High-resolution environmental SEM can analyze living organisms and preserve their structures by pumping water vapor into the analysis chamber
- **Failure Analysis**
  - Over 100 years of combined engineering and materials failure analysis experience in aerospace materials
  - All the Laboratory's analytical tools and techniques are combined with hardware operations and engineering knowledge to develop the most efficient approach to documenting and resolving hardware failures

Metallurgy

- **Engineering Materials Development**
  - Development of new and improved materials including refractory alloys, aluminum alloys, heat-resistant superalloys
  - Reformulation of existing alloys to optimize material performance in the expected operational environment
  - Arc Melting, Small-batch powder processing, Powder spheroidizer, Additive Manufacturing
  - Powder metallurgy processing equipment: Spark Plasma Sintering (SPS), Powder milling, and Hot Isostatic Pressing (HIP)
  - Furnace capabilities exist up to 3,000 °C (vacuum, forming gas, and flowing hydrogen environments)
- **Materials Process Development**
  - Extensive experience with tracking material property changes through manufacturing processes
  - Broad technical expertise in mechanical deformation processes such as forging, rolling, spin forming and stamping
  - Decades of experience in characterizing metal joining such as fusion welding, friction-stir welding, and brazing
- **Fundamental Materials Research**
  - Laboratory scientists and engineers are engaged in fundamental materials research to address some of NASA's advanced and unique material needs
  - Facilities available to support materials research and development include high-temperature processing equipment, thin film coating tools, and equipment for optical, electrical, and magnetic property measurements

Nuclear Fuel Development

- Advanced nuclear fuel processing, characterization, and testing
  - Hot hydrogen environmental exposure (< 3,000 °C)
  - High temperature testing in inert atmosphere (< 3,000 °C)
  - Hot Isostatic Pressing (HIP) in inert atmosphere up to 200 MPa (<1900 °C)
  - Micro-Tensile testing
  - Scanning Electron Microscopy
- Experienced researchers in fabrication, testing, and characterization of a broad spectrum of nuclear fuels including uranium oxide, uranium carbide, uranium nitride, TRISO, and metallic uranium fuel among others

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