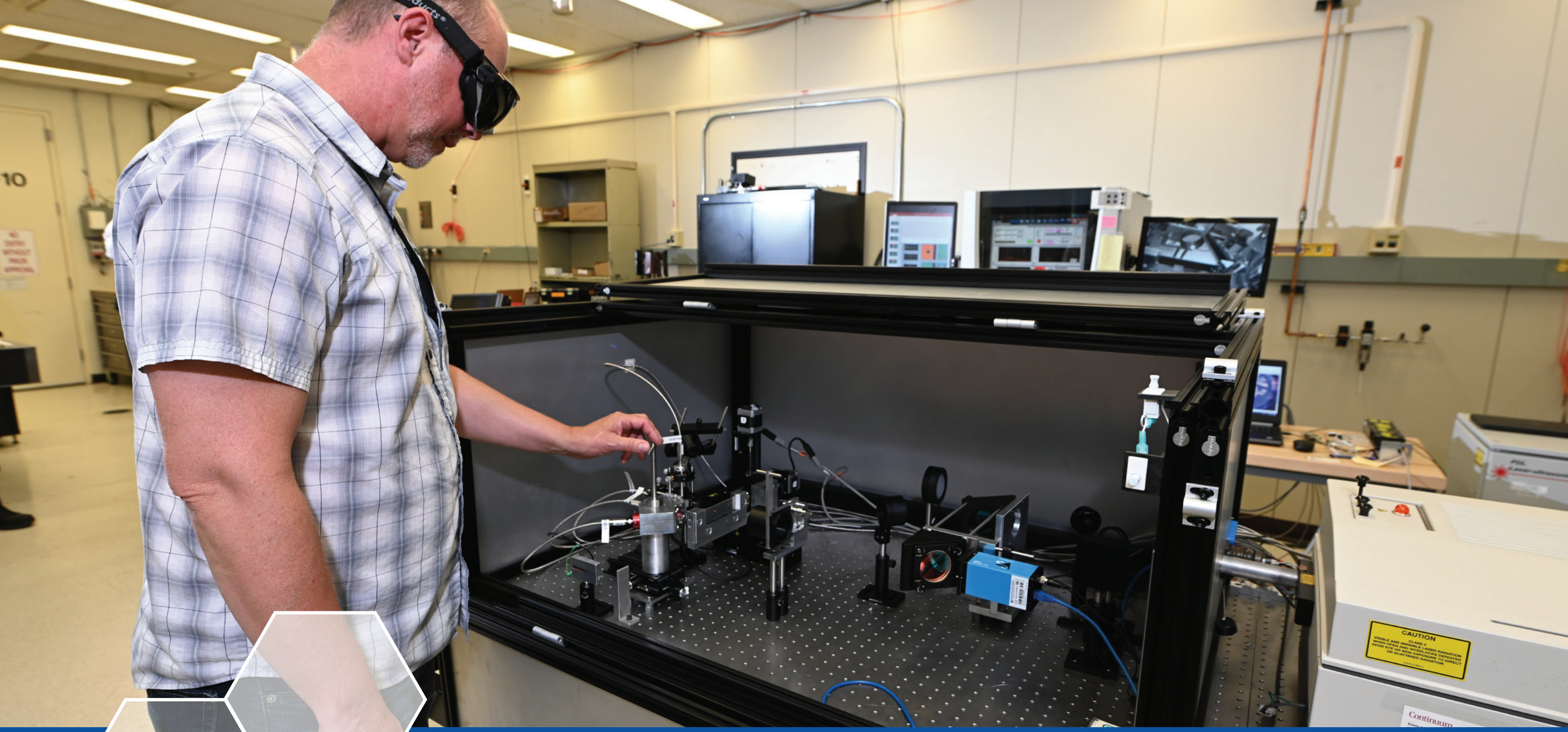


Operator using the Laser Shock System

Laser Shock System

Assessing bond strength in layered materials

Several industries, like nuclear, aerospace and electronic, use materials made of layered structures in their systems and components. Knowing the strength between each of these layers is essential to ensure predictable and reliable mechanical behavior of complex structures, such as nuclear fuel plates.

The Laser Shock System, developed by the U.S. High Performance Research Reactors (USHPRR) Program, can assess the fabricated interface strength of layered or composite structures and determine the debond stress thresholds from a production process. The laser shock technique was originally developed to determine how a production process affects interface strength in nuclear fuel plates; however, this testing system can be applied to different materials.

The Laser Shock System can also be used to characterize material properties such as hardness, elasticity and shear ratio. These laser-based, noncontact measurements mean that the Laser Shock System can be used in harsh process environments like those that have high temperature, radiation and corrosive conditions.

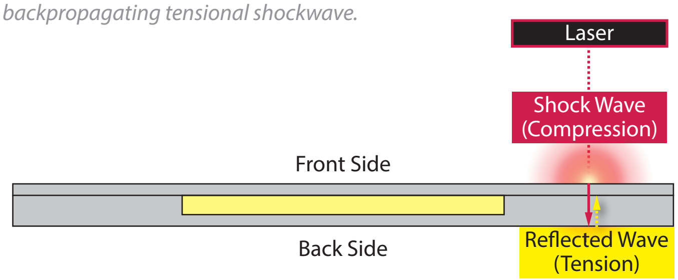
THE TECHNIQUE

The Laser Shock System creates a high-amplitude shockwave on the frontside of the layered structure via a high-energy pulsed laser.

The shock wave is monitored on the back surface as it travels through the layered structure, and the back surface velocity is used to characterize the interface. The resulting shockwave impacts the front surface, propagates as a compression wave through the structure to the unconstrained back surface, and then reflects backward through the material as a tensile wave (Figure 1).

If the reflected tensile wave exceeds the interface threshold stress, then an interior separation between

Figure 1. *Schematic of a layered structure and the Laser Shock System generating a compressional shockwave, which is converted to a backpropagating tensional shockwave.*



Idaho National Laboratory

Table 1. Additional material properties available from the Laser Shock System

Material Property	Measured Parameter
Hardness/temper	Hugoniot elastic limit
Elastic modulus	Primary wave velocity
Shear modulus	Shear wave speed
Residual stress	Difference between shear horizontal & vertical speeds
Material damping	Ultrasonic attenuation
Grain size and microstructure	Backscatter and frequency dispersion

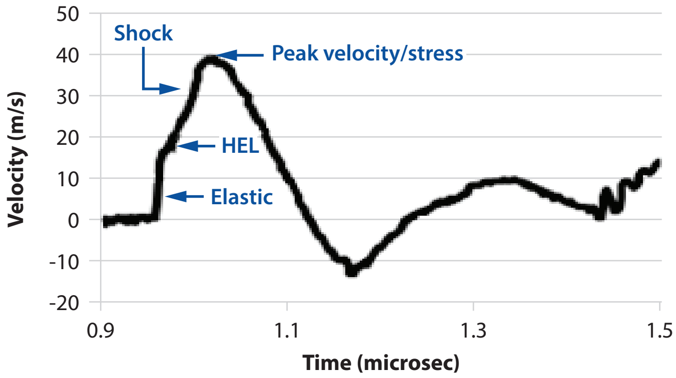
layers of material occurs. Monitoring the surface velocity on the back surface of the specimen measures the energy making it to the back surface of the structure.

CAPABILITIES

- Provides localized measurements for bond strength mapping or imaging
- Identifies interface strength variations throughout a structure
- Measures debonding threshold in terms of tensile stress
- Assesses the effects from processes and process changes on the bond strength
- Determines high- and low-performance product locations within the process
- Highlights process variations within product and between products
- Uses excess material from product to predict bond strength of the product as well as detect fabrication issues

The Laser Shock System can provide additional material characterization measurements as listed in Table 1 and shown in Figure 2.

Figure 2. Laser Shock System can determine material hardness via the Hugoniot elastic limit (HEL) and measure the maximum peak velocity of the shockwave energy at the backside of the layered structure



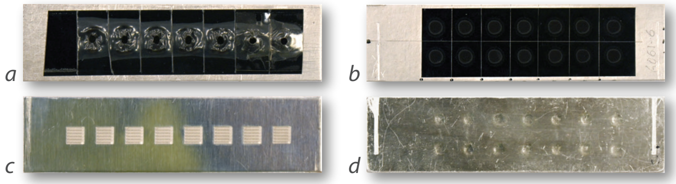
NUCLEAR APPLICATION

Nuclear fuel plates of uranium fuel foils within aluminum alloy substrates have been tested for the USHPRR Fuel Qualification Program as represented by aluminum blanks in Figure 3. The USHPRR Program endeavors to reduce proliferation risks through development of low-enriched uranium-molybdenum monolithic fuel clad in aluminum as a replacement for high-enriched uranium fuel.

In the case of nuclear fuel, weakly bonded fuel and cladding can lead to buildup of fission gases, decreasing heat transfer from the fuel. This can result in localized overheating and thermal damage and possibly fuel failure. Debonding of the cladding-cladding interface around the edge of the fuel is another possible, less-studied, failure mechanism. It can also occur from pressure buildup from fission gases or a separation failure from the plate edge propagating inward. These failure mechanisms can expose the fuel directly to reactor coolant.

These concerns must be addressed when developing new fuels and processes. The laser shock technique is the only known method to access interface integrity in producing fuel plates and can assess, in part, the suitability of the plates for insertion into the reactor.

Figure 3. Front and back of samples showing the (a) damaged transparent tape indicating the laser shock (b) outline of laser ablation, i.e., removing material with a laser, on the black tape (c) the ultrasonic raster-scan to detect interface delamination (d) plastic deformation in the aluminum



FOR MORE INFORMATION

Principal Investigator
Jim Smith
208-526-1580
james.smith@inl.gov

Lead Engineer
Brad Benefiel
208-526-7175
bradley.benefiel@inl.gov

Program Manager
Tamara Shokes
208-526-2541
tamara.shokes@inl.gov

www.inl.gov

A U.S. Department of Energy National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

22-50419_Laser_Shock_R10