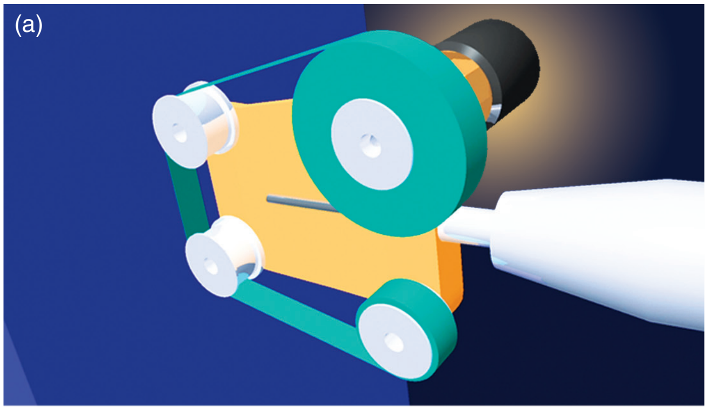
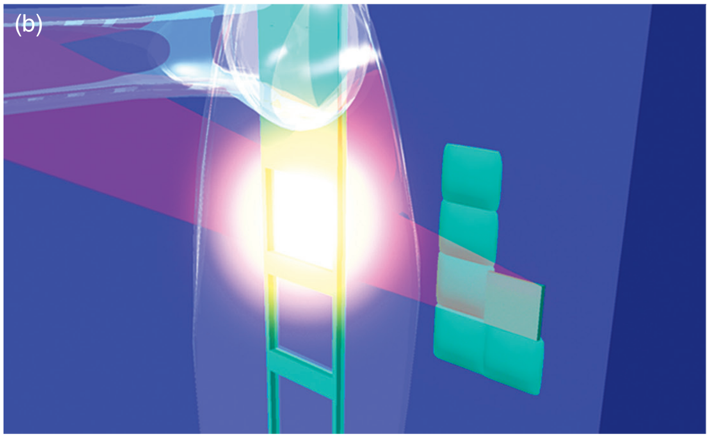
High-Performance Metal Coatings Produce Exceptional Bond Strength

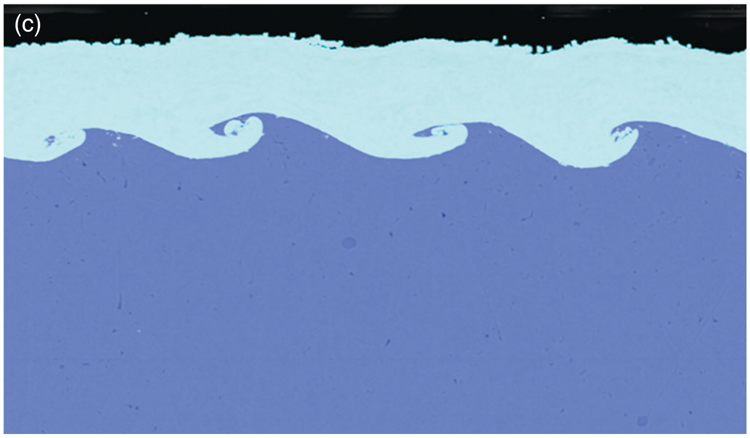
HIGH-VELOCITY laser-accelerated deposition (HVLAD) uses advanced lasers to produce protective coatings with ultrahigh-strength, explosively bonded interfaces. These coatings prevent corrosion, wear, and other modes of degradation in extreme environments. HVLAD leverages high-power pulsed laser technology developed for laser inertial-confinement fusion research as well as key components of laser peening technology. Laser peening, which was also developed by the Laboratory and won an R&D 100 Award in 1998, has been in commercial production for nearly a decade, extending the fatigue life of aerospace equipment. (See *S&TR,* October 1998, pp. 12–13.) The HVLAD process can be applied using the hardware in current use for laser peening, with the addition of a water-delivery fixture and a coating-film cartridge. Livermore chemical engineer and corrosion scientist Joe Farmer and physicist Alexander (Sasha) Rubenchik, along with Lloyd Hackel of Curtiss-Wright Surface Technologies–Metal Improvement Company, won an R&D 100 Award for their development of the technology.

The high-power pulsed lasers produce coatings using materials that are difficult to deposit by other means, at room temperature and pressure, and with exceptional bond strength. Unlike some competing processes, HVLAD can be conducted in open production areas including factory floors, shipyards, and aircraft hangers. HVLAD enables the deposition of a variety of heat-resistant materials that can withstand temperatures above 538ºC—for example, tantalum, titanium, and tungsten—onto high-temperature steels and other inexpensive materials. Such materials are often used in power plants and shipyards and in the aerospace, chemical, gas, and oil industries.



(a) For high-velocity laser-accelerated deposition (HVLAD), a special head is adapted to a laser-peening device and associated robotics. (b) Patches of high-performance corrosion-resistant film are accelerated and bonded to a substrate in a controlled process. (c) A scanning electron microscope image shows a heat-resistant tantalum coating on a copper substrate. The tantalum was accelerated at the copper interface, and the shear forces at the interface caused the mixing of the two materials, resulting in an exceptionally strong interfacial bond. This coating was produced at room temperature and pressure, with no special process equipment other than the laser. (Renderings by Clayton Dahlen.)





How It Works

The HVLAD process uses the world's most powerful and highest-repetition-rate production lasers for localized explosive bonding. A high-intensity laser pulse is focused onto an advancing filmlike target material, which is covered by a thin layer of water that serves as a tamper. The laser pulse generates a high-temperature plasma and with it very high pressure that shears out a patch of the filmlike material, accelerating it to hypersonic velocities. The accelerated patch hits the substrate at an oblique angle, where the high-impact velocity induces plastic shear flow at the film–substrate interface, resulting in the mixing of target and substrate materials at the interface. Exceptionally strong interfacial bonds are created that approach the ultimate tensile strength of the substrate.

Farmer says, "We can place coating film on complex surfaces with millimeter resolution, adjusting the incidence angle on every pulse to attain highly uniform coverage, as we do for laser peening. The transition to HVLAD is a straightforward adaption of this established capability."

Coatings produced with conventional and physical vapor deposition processes, according to Farmer, are completed at a slow rate due to mass transport limitations. Low mass flux, or flow, and roughness amplification place limitations on coating thicknesses as well. Conventional thermal and cold-spray coatings have bond strengths on the order of only 680 atmospheres (10,000 pounds per square inch), while the HVLAD-bonded materials have ultimate tensile strengths of about 6,800 to 34,000 atmospheres (100,000 to 500,000 pounds per square inch). Furthermore, conventional coating processes rely on difficult-to-handle powder feeds through a hypersonic nozzle.

Another advantage of the HVLAD system is that it is very cost effective. "The HVLAD beam-delivering robot can be configured nearly exactly as that now used in the laser peening process for treating F-22 fighter jets, Navy arrestment hook shanks, and gas and steam turbine blades," says Farmer. "Thus, almost no additional capital investment is required to implement this technology."

Industrial Applications

Application of the HVLAD technology can be beneficial in a variety of industries. For example, HVLAD coatings could make possible the use of high-temperature materials in fossil-fuel, solar thermal, and nuclear power plants, leading to an increase in efficiency. Increasing the operating temperature of an energy conversion system from 325°C to 900°C could lead to a 20-percent gain in efficiency. Another application could involve coating a thin layer of titanium on conventional ship hulls made of steel as a cost-effective means of corrosion prevention.

Livermore development team for HVLAD: Alexander Rubenchik (left) and Joe Farmer.

Oxide-dispersion-strengthened (ODS) steels have very good high-temperature strength, are radiation resistant, and are leading candidate materials for next-generation nuclear power plants. However, these materials lack corrosion resistance in exotic high-temperature coolants. The HVLAD process could be used to deposit high-temperature corrosion-resistant coatings of expensive alloys such as tantalum–tungsten on the less corrosion-resistant ODS steel.

HVLAD coatings help prevent corrosion and pitting and leave materials resistant to stress corrosion cracking and failure from fatigue. These protective coatings and cladding with high-integrity interfacial bonds are capable of extending the operating life of valuable equipment in the aerospace, marine, and energy arenas.

—*Cindy Cassady*

Key Words: corrosion-resistant coating, high-strength bonded interface, high-velocity laser-accelerated deposition (HVLAD), laser peening, R&D 100 Award.

For further information contact Joe Farmer (925) 423-6574 (farmer4@llnl.gov) or Alexander Rubenchik (925) 422-6131 (rubenchik1@llnl.gov).