SMOOTH MOVES

Argonne's SLIDE program seeks to reduce friction, increase efficiency

SLIDE'S TESTING, CHARACTERIZATION AND DEVELOPMENT CAPABILITIES WORK IN CONCERT TO ACCELERATE INNOVATION.

In their efforts to make America as energy-efficient as possible, researchers at Argonne National Laboratory leave no stone unturned. From internal combustion engines to wind turbines to next-generation power plants, Argonne's expertise spans the energy spectrum.

Unfortunately, so does friction—the force that restricts relative motion between surfaces and layers. This resistance to motion both slows things down and makes parts work harder, meaning poorer performance and limited component life. It's a challenging phenomenon for researchers to overcome, but one that also presents a great opportunity: by reducing friction it's possible to both increase energy efficiency and prolong the life of valuable components, a rare win-win in the arena of energy conservation.

The field concerned with this critical research is known as tribology, and Argonne is setting the standard with the launch of its Surfaces and Lubrication Interaction Discovery and Engineering (SLIDE) effort.

With an expert staff, and a suite of state-of-the-art analysis and validation tools, SLIDE builds on Argonne's rich history of tribological innovation by partnering with industry and research institutions to develop solutions for today's most pressing problems in materials and friction reduction.

Since its inception in 1983, Argonne's tribology program researchers have authored more than 300 peer-reviewed journal articles and won six *R&D 100* awards.

According to Section Manager George Fenske, "What sets SLIDE apart is the way we approach friction challenges. All the capabilities in the world won't help you fix something if you don't understand the underlying problem. Because our team has such a wide range of research and industrial backgrounds, we bring a unique set of perspectives to testing, characterization and development that enable us to look at things very differently than many others in the field."

To Fenske's point, when companies come to Argonne, they are looking for expertise and capabilities our SLIDE group can offer to not only replicate the conditions under which their products (materials, lubricants, additives) operate to provide data for optimizing their performance, but, more importantly, to investigate and understand how their systems behave on a microscopic/atomic level—how the additives, lubricants and materials respond to stress, speed and temperature to form ultrathin tribochemical films that control friction, wear and resist surface failure. While many organizations have the ability to test existing materials or develop new materials, they do not have Argonne's unique combination of multidisciplinary expertise and extremely sophisticated characterization tools (such as the Advanced Photon Source) to discover how additives, lubricants and materials interact and to engineer entirely new approaches to improve friction, wear and reliability.

In achieving those objectives, SLIDE pushes the tribological envelope via three core capabilities: lab-scale testing, to match real-world conditions as closely as possible and identify promising technologies; surface characterization, in which researchers observe and model the evolution of surface properties over time; and technology development, or the design of coatings and lubricants engineered to work in tandem with specific materials.

ENHANCED LAB-SCALE TESTING

In order to evaluate a wider range of technologies and bring innovation to the marketplace rapidly, tribologists often rely on lab-scale rigs that simulate engine conditions as closely as possible—from these initial experiments researchers can identify the most promising candidates for system-level validation.

Principal Mechanical Engineer Nick Demas examines a steel specimen with a reciprocating tester.

And while lab-scale testing rigs and their operating conditions can offer a variety of testing conditions, differences between apparatuses can greatly affect research outcomes, making the prediction of system performance in the real world exceptionally difficult. Therefore, in order to extract meaningful data, researchers must select the most useful platform and the best conditions for each experiment and apply industry-standard methods to ensure reproducible outcomes.

SLIDE employs a comprehensive suite of customizable equipment, including 15 bench-top tribometers, for conducting tests in extreme environments to emulate real-world conditions, identify critical test parameters and pair materials with lubricants and coatings for optimum performance.

SLIDE's assortment of lab-scale analysis tools can also quantify numerous phenomena including simple wear, abrasive wear, scuffing and contact fatigue across a range of controlled environments—including dry sliding (e.g., in vacuum, air or controlled gases), or, lubricated sliding with organic and inorganic fluids. Because tribological phenomena occur in a wide range of extreme environments, such as the heat inherent in the operation of internal combustion engines, SLIDE testing capabilities can replicate a broad spectrum of temperatures, from -20°C to 850°C, and stresses over six orders of magnitude.

The SLIDE program's test equipment also enables the rapid evaluation and validation of lubricants, coatings and materials across unique motions and geometries.

These evolving testing platforms, along with SLIDE expertise across the tribological spectrum—from transportation to energy production to medical devices—make Argonne the perfect setting in which to test different friction-reducing technologies.

SURFACE CHARACTERIZATION

As surfaces in motion come into contact, their properties—such as microstucture, chemistry, roughness and hardness—change.

Understanding how these surface interactions alter a material's properties over time is critical for predicting performance across a range of technologies.

In their efforts to reduce friction and increase efficiency, SLIDE tribologists have developed unique methods for characterizing surfaces with predictive fidelity in order to bring novel coatings and lubricants to market faster and more cheaply.

SLIDE researchers apply tailored scientific approaches to understand how lubricants interact with surfaces to form thin tribochemical films that reduce friction and protect components. They use analytical techniques to measure critical tribofilm properties such as film thickness, hardness, structure and chemical make-up and develop mechanistic models that predict tribological performance (friction, wear, and failure). The mechanistic models are in turn used in the development of advanced technologies that combine basefluids, additives, coatings and engineered/textured surfaces to reduce parasitic friction losses while maintaining or improving reliability, durability and compatibility with transformational technologies.

The unique combination of expertise and equipment in SLIDE enables the collection of data to predict and quantify both performance and failure, providing partners with a critical roadmap to optimization.

By quantifying the aging process and revealing how components change over time, SLIDE researchers enable their partners to control surface properties for both improved component performance and prolonged life, both of which are essential for increasing energy efficiency in numerous technologies.

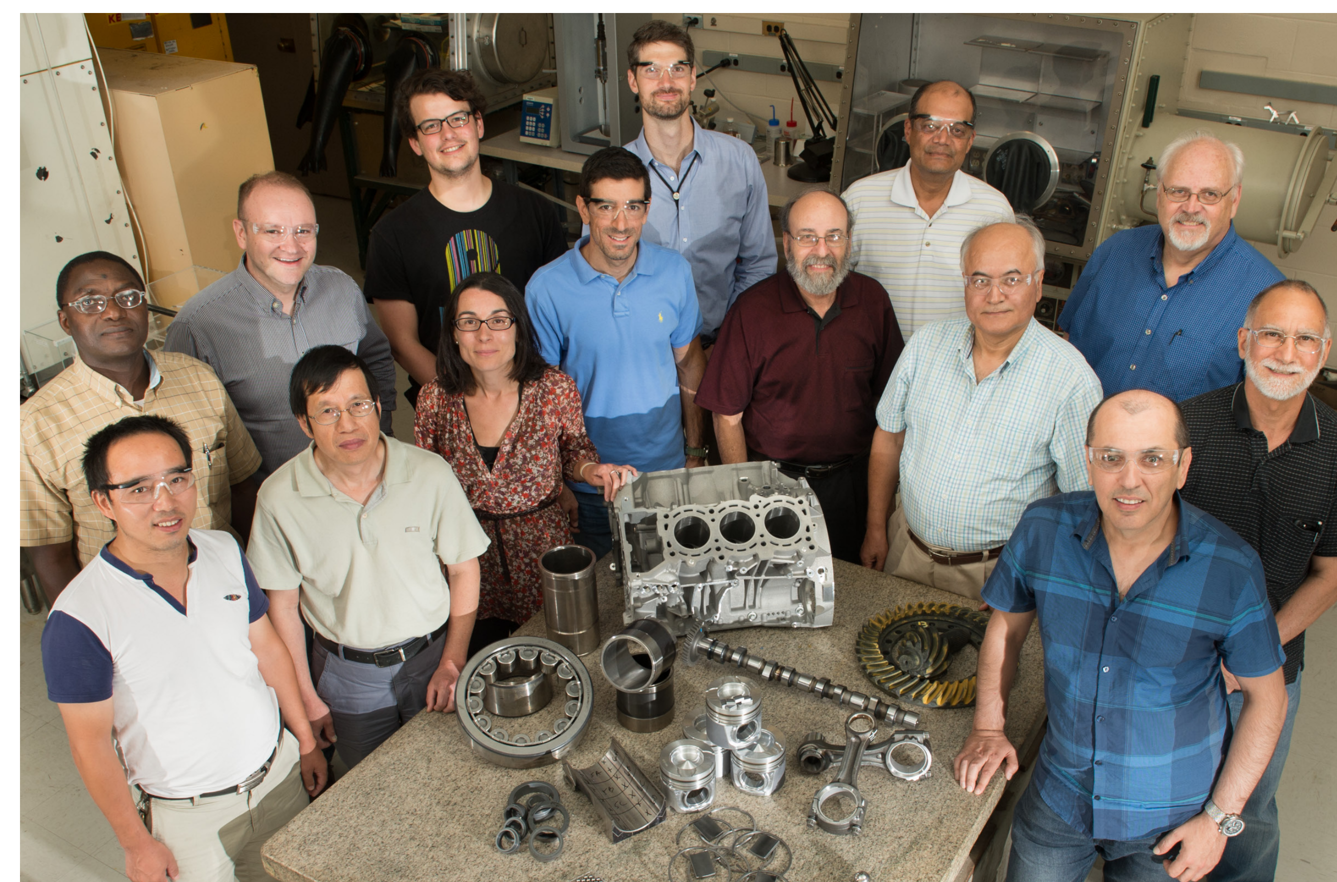
TECHNOLOGY DEVELOPMENT

Novel lubricants and coatings have the ability, when paired with the right material, to increase efficiency and extend component life.

Through advanced testing and materials characterization techniques, SLIDE researchers optimize and validate next-generation lubricants and additive combinations, engineer custom coatings and integrate ideal lubricants and coatings with materials.

Because lubricants typically contain performance-enhancing additives that often compete with one another and react undesirably with other additives, materials and coatings, SLIDE researchers discover new approaches to achieving the desired properties of conventional additives with more environmentally friendly alternatives.

SLIDE researchers gather around some of the many components that their efforts protect and improve.



Principal Materials Scientist Cinta Lorenzo Martin uses a transmission electron microscope to gain an enhanced understanding of structural and chemical characterizations of materials and surface interactions.

The discovery of new coatings for friction management lies at the core of the SLIDE mission—many traditional coatings designed for manufacturing applications are not compatible with some of today's most common performance-enhancing additives, meaning SLIDE researchers must design novel coatings that complement newer additives under a wide range of conditions.

WINNING OUTCOMES

The combination of SLIDE's scientific expertise and methodologies produces unique, multi-dimensional approaches to truly understanding friction and wear challenges, leading to insightful solutions that improve fuel economy, increase durability and reliability and enhance emissions performance.

Interested organizations can engage the SLIDE team through a variety of partnership and licensing arrangements described at http://www.anl.gov/technology/partnerships.

FOR MORE INFORMATION
George Fenske
Section Manager, Tribology and Thermo-Mechanical Research
Energy Systems Division
630-252-5190
gfenske@anl.gov

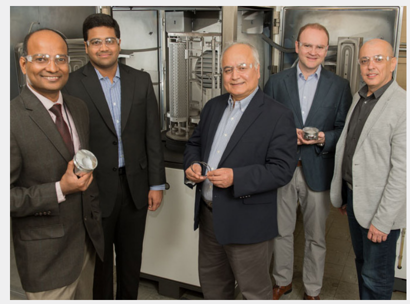
ARGONNE DISCOVERY YIELDS SELF-HEALING DIAMOND-LIKE CARBON

Argonne scientists recently discovered a revolutionary diamond-like film generated by the heat and pressure of an automotive engine. The discovery of this ultra-durable, self-lubricating, diamond-like carbon (DLC) tribofilm (a film that forms between moving surfaces) was reported recently in the journal *Nature*, and it could have profound implications for the efficiency and durability of future engines and machinery.

"This is a unique discovery, and one that was a little unexpected," said Argonne Distinguished Fellow Ali Erdemir. "We have developed many types of diamond-like carbon coatings, but we've never found one that generates itself by breaking down lubricating oil molecules and regenerating the tribofilm as it is worn away."

The original discovery occurred when Erdemir and colleague Osman Eryilmaz coated a small steel ring with a catalytically active nanocoating—tiny molecules of metals that promote chemical reactions to break down other materials. They then subjected the ring to high pressure and heat using a base oil without the complex additives of modern lubricants. Examining the ring after the endurance test, they didn't see the expected rust and surface damage, but rather, an intact ring with an odd blackish deposit on the contact area.

Evaluation showed that the deposit was a tribofilm of diamond-like carbon, similar to several other DLCs developed at Argonne. But it works even better—reducing friction by 25 to 40 percent and wear to unmeasurable values. Better yet, the new catalytic nanocoating allows the tribofilm to be renewed continually during operation. Further experiments revealed that multiple types of catalytic coatings can yield DLC tribofilms.



Argonne researchers, from left, Subramanian Sankaranarayanan, Badri Narayanan, Ali Erdemir, Giovanni Ramirez and Osman Levent Eryilmaz show off metal engine parts that have been treated with a diamond-like carbon coating similar to one developed and explored by the team. The catalytic coating interacts with engine oil to create a self-healing diamond-like film that could have profound implications for the efficiency and durability of future engines.

Because the new tribofilm develops in the presence of base oil, it could allow manufacturers to reduce or eliminate some of the modern anti-friction and anti-wear additives in oil—substances that can decrease the efficiency of catalytic converters and harm the environment due to their heavy metal content.

Citation
"Carbon-based Tribofilms from Lubricating Oils," A. Erdemir, G. Ramirez, O. Eryilmaz, B. Narayanan, Y. Liao, G. Kamath and S.K.R.S. Sankaranarayanan, *Nature* **536**, 65–71 (2016). doi:10.1038/nature18948.

The research was funded by DOE's Office of Energy Efficiency & Renewable Energy.

FOR MORE INFORMATION
Ali Erdemir
Argonne Distinguished Fellow
Energy Systems Division
630-252-6571
erdemir@anl.gov