FEBRUARY/MARCH 2017 | VOL 175 | NO 2

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION

AEROSPACE MATERIALS/
MICROSCOPY & METALLOGRAPHY

A CENTURY OF AEROSPACE INNOVATION

P.24

ASM INTERNATIONAL

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Many of our customers have found each Nadcap audit to be a unique process (depending on their specific Prime specifications, processes, equipment and more), but the overall process of receiving Nadcap accreditation typically involves a set number of steps.

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"While the Nadcap audit process is lengthy and complex, we have found that those who adequately prepare are able to make it through the audit process without difficulty."

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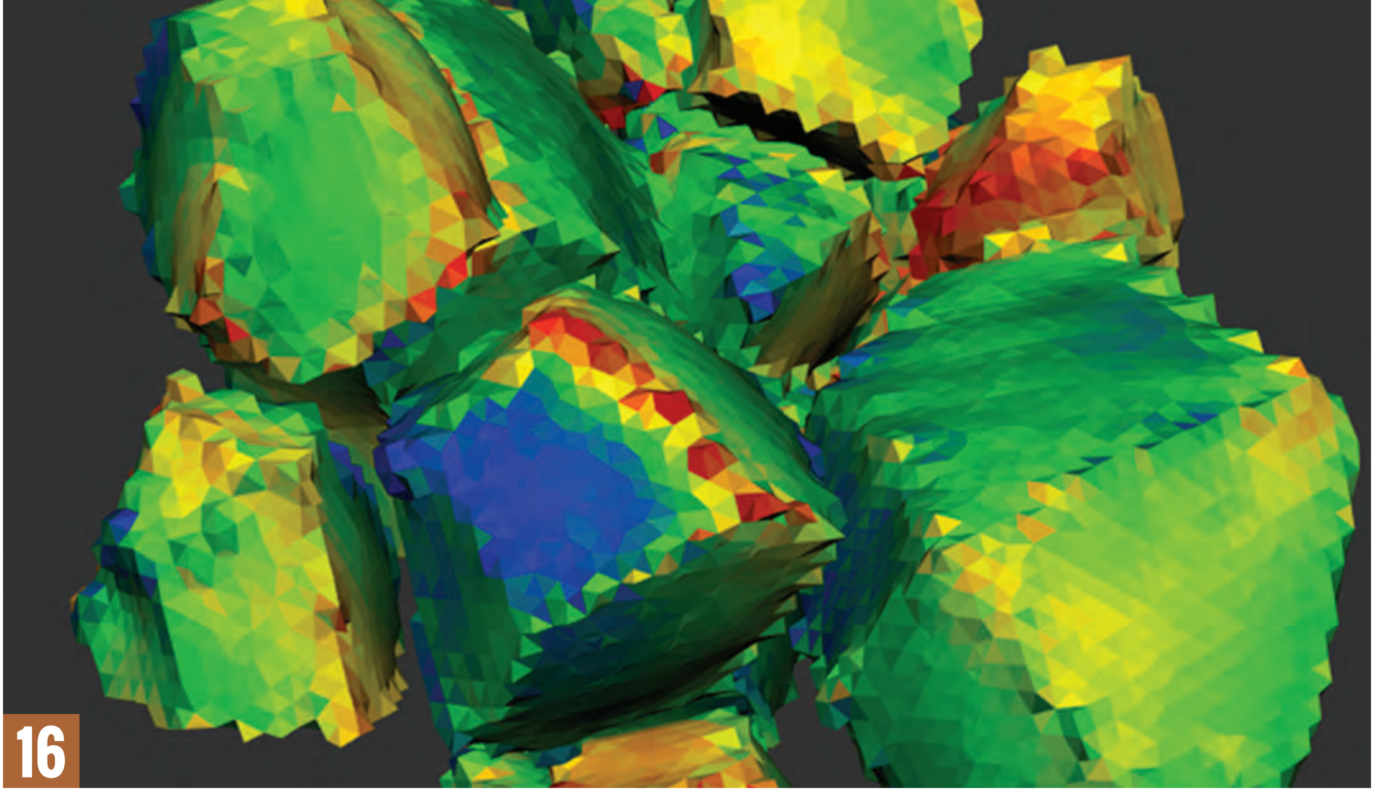

On The Cover:

During the 1960s, the Air Force Research Laboratory's Materials and Manufacturing Directorate developed high temperature materials including high strength titanium and improved aluminum alloys, with results transitioned to aircraft such as the Lockheed SR-71 "Blackbird."

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LOOKING FORWARD, LOOKING BACK

Welcome to our first double issue of 2017, covering aerospace materials and advances in microscopy and materials characterization. As part of a slew of changes related to the ASM Renewal, *AM&P* will publish eight issues in 2017, two per quarter, as we focus more efforts into our digital transformation. As the times change, so must ASM. However, our flagship magazine will continue to report on the latest developments in materials science and engineering and also highlight the great work of individuals within our ASM family.

In February, we lost one of our dear colleagues—Charles R. "Bob" Simcoe—author of our popular "Metallurgy Lane" series. Simcoe was almost 90 when he contacted me in 2013 to pitch the idea of an article series about the early history of the U.S. metals and materials industries. I had only been at ASM for two months and my predecessors had passed on his idea a few years before. Simcoe thought he would try again with the "new editor" and I loved the idea. Since his debut article in January 2014, Simcoe has authored nearly 40 pieces in this series to rave reviews and numerous letters in our "Feedback" department. ASM is now working on a book based on this series, which we will publish later this year. As a testament to his motivation and initiative to begin a massive writing project at the age of 90, Simcoe's alma mater, Purdue University, named him Alumnus of the Year in 2014.

Charles R. Simcoe

Because engineering publications tend to be laser focused on new and emerging technologies, it is also critically important to look back and think about how ideas and science have progressed. The act of looking back helps orient us in time and space. Simcoe's series begins in Massachusetts in 1645, in the British Colonies at the Saugus Iron Works. These early days of ironmaking were the precursors of our domestic steel industry and Simcoe does a fantastic job of chronicling this history over the next 350 years. His final articles tell the sad story of the decline of the U.S. steel industry, a devastation of epic proportions that began in the 1950s and continues today.

Speaking of history, our current issue includes a fascinating tour of a century of aerospace progress at the Materials and Manufacturing Directorate (ML). In 1917, ML was launched at McCook Field in Dayton, Ohio, to develop lighter and stronger materials for the newly emerging aerospace community. It's interesting to note that initial research focused on improving the flexible wooden components of airplanes. Just another point of orientation to think about going from simple "wood" to things like metal matrix nanocomposites reinforced with carbon nanotubes and graphite nanoplatelets in the span of 100 years. Onward and upward!

F. Richards

frances.richards@asminternational.org

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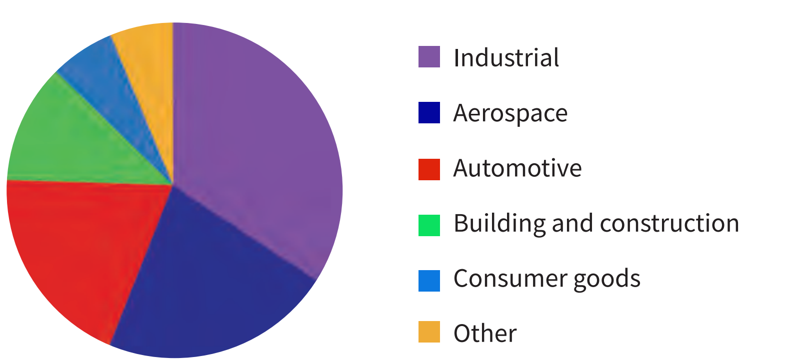
AEROSPACE APPLICATIONS SPUR STEEL FORGINGS MARKET

According to a new report from Grand View Research Inc., San Francisco, demand for stainless steel forgings in aviation applications is expected to grow at a CAGR of 7% from 2016 to 2024. The product's versatility with regard to size, shape, and properties make it an ideal component for the manufacture of bulkheads, wing roots and spars, hinges, engine mounts, brackets, beams, shafts, landing gear cylinders and struts, wheels, brake carriers and discs, and arresting hooks. In the automotive market, stainless steel forgings are expected to grow at a CAGR of 4.5% during the same period. Increased demand for lightweight forged products with enhanced wear and tear resistance is driving growth in the transportation sector. "Stainless Steel Forgings Market Size and Forecast by Product (Cold/Hot Forged Products, Castings, Sintered Parts), by Application (Building & Construction, Industrial, Automotive, Aviation, Consumer Goods), by Region and Trend Analysis from 2013 to 2024" discusses major trends taking place in this market segment.

Global market size is valued at $7.51 billion for 2015. Stainless steel forgings demand is driven by growing manufacturing activity around the world. The ability of stainless steel to withstand chemical, physical, and electrical wear and tear is the main factor responsible for market growth. The high recyclability of stainless steel is another factor driving demand. However, parts manufactured from aluminum and plastic composites are expected to pose a major threat to the growth of stainless steel forgings over the forecast period.

Cold/hot forged parts are the dominant product segment with a market share of over 80% in 2015. However, castings are the fastest growing segment with an expected CAGR of 4.5% from 2016 to 2024. Sintered parts are a niche segment within the market and feature properties such as electrical conductivity, translucency, and thermal conductivity. Research and development efforts involving sintered products with enhanced strength are expected to drive demand for these products. The report includes analysis of the stainless steel forgings market in the U.S., Europe (Germany, UK, France), Asia Pacific (China, India, Japan), Latin America (Brazil), and the Middle East and Africa. For more information, visit *grandviewresearch.com.*

GLOBAL STAINLESS STEEL FORGINGS MARKET, BY APPLICATION, 2015



Source: Grand View Research Inc.

FEEDBACK

BERYLLIUM REBUTTAL

The letter in the July/August "Feedback" department ("Beware of Beryllium") was misleading in two areas. First, it is no secret that fine particles of beryllium can restrict lung capacity. I worked in two different organizations processing beryllium in the 1960s. In both facilities, employees were told multiple times about the potential hazards of fine beryllium particles. Since then, the EPA has formalized limits on particles of this metal. As far as I know, bulk beryllium has never caused a health issue. Second, it is not a gamble to use beryllium for the space mirror project. Beryllium has been successfully used in space since Telstar was launched in the early 1960s. Beryllium has unique combinations of properties that outweigh the requirements to use the metal safely.

George Meyer

BRING BACK STEEL

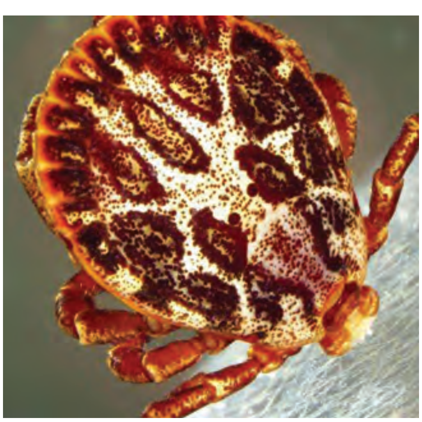
The recent piece on the decline of the integrated steel industry ("Metallurgy Lane," Nov/Dec 2016) was fascinating. I grew up in Pittsburgh and left for the Air Force after high school in 1974. I remember the mill jobs going away and watching the US Steel building rise up from my neighborhood, Mt. Washington. What a lesson this article paints. Having lost our place in steel, it is a wonder how we kept our place in the world. It also makes one realize how close we are to losing it in other industries. We must bring steel back to the U.S.—figure out how to make it cleaner and cheaper. More Nucors and determine how to leapfrog the current technology for processing steel from ore. This is low-hanging fruit for jobs and security, and once we figure out how to make clean steel, we can sell the plants to China and get the air cleaned up. Thank you for publishing this very interesting history lesson.

Carmen Vertullo

OMG!
OUTRAGEOUS MATERIALS GOODNESS

TICK CEMENT HOLDS PROMISE AS BIOADHESIVE

Ticks are famous for their ability to anchor themselves firmly to human skin where they can suck blood for several days. This anchoring mechanism is highly effective because it is based on a cement-like substance with excellent adhesive properties, so it works like a dowel for the mouthparts of the tick. Researchers from MedUni Vienna and Vienna University of Technology want to study this “tick cement” and recreate it chemically for use in biomaterials research. “It is totally conceivable that it will be possible to use this substance to produce a biological adhesive for human tissue, for example for anchoring tendons and ligaments to bone without using any metal,” says project leader Sylvia Nürnberger. Tissue adhesives currently used in surgery, such as for serious skin injuries or liver tears, are somewhat toxic. However, other adhesives are not strong enough. Biological alternatives could be an ideal solution. The tick project aims to find new alternatives and applications for existing adhesive products for skin, cartilage, ligaments, and tendons. *www.meduniwien.ac.at.*



Tick cement is a potential bioadhesive for human tissue. Courtesy of Medical University of Vienna.

Researchers at UCSD investigate why hair is so strong and resistant to breaking. Courtesy of iStock.com/natevplas.

TOWARD BETTER HAIR CARE AND BODY ARMOR

Researchers at the University of California, San Diego (UCSD) are investigating why hair is so strong and resistant to breaking. Findings could lead to development of new materials for body armor in addition to better hair care products. Hair has a strength to weight ratio comparable to steel and can be stretched up to one and a half times its original length before breaking. Researchers examined at the nanoscale how a strand of human hair behaves when it is deformed. The team found that hair behaves differently depending on how fast or slow it is stretched: The faster it is stretched, the stronger it is. Hair consists of two main parts—the cortex, which is made up of parallel fibrils, and the matrix, which has an amorphous structure. The matrix is sensitive to the speed at which hair is deformed, while the cortex is not. The combination of these two components is what gives hair the ability to withstand high stress and strain. As hair is stretched, its structure changes in a particular way. At the nanoscale, the cortex fibrils in hair are each made up of thousands of coiled spiral-shaped molecule chains called alpha helix chains. As hair is deformed, these chains uncoil and become pleated sheet structures known as beta sheets. This structural change allows hair to handle a large amount of deformation without breaking. *jacobsschool.ucsd.edu.*

GRAPHENE ENABLES WORLD’S LIGHTEST WATCH

The University of Manchester recently collaborated with watchmaking brand Richard Mille and McLaren F1 to create world’s lightest mechanical chronograph by pairing leading graphene research with precision engineering. The RM 50-03 watch was made using a unique composite incorporating graphene to manufacture a strong but lightweight case to house the delicate watch mechanism. The graphene composite known as Graph TPT weighs less than similar materials traditionally used in watchmaking. The strap’s rubber was also injected with graphene, which improves both mechanical properties and wear resistance. The lightweight timepiece weighs just 40 grams and is extremely durable. *www.manchester.ac.uk*

Graphene composite watch.

Are you working with or have you discovered a material or its properties that exhibit OMG - Outrageous Materials Goodness?
Send your submissions to Frances Richards at frances.richards@asminternational.org.

METALS | POLYMERS | CERAMICS

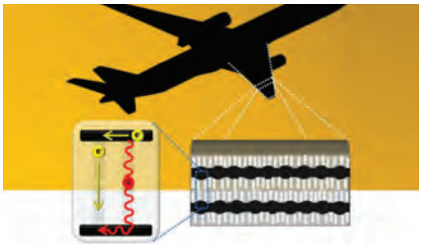
SOME LIKE IT HOT

A new record was set for the world's most heat resistant material by researchers from Imperial College London, UK. Using their new laser heating technique, the team discovered that hafnium carbide melts at a blistering 3958°C—the highest melting point ever recorded for any material. Researchers applied their method to HfC and another refractory ceramic, tantalum carbide, as individual compounds as well as in mixed compositions. They discovered that while the melting point of $Ta_{0.8}Hf_{0.20}C$ was consistent with previous research at 3905°C, each individual compound exceeded previous records, with TaC melting at 3768°C. Until now, technology to test the melting points of these compounds was not available. This work paves the way for both materials to be used in more extreme environments, such as fuel cladding in nuclear reactors or heat shielding for next-generation hypersonic space vehicles. *www.imperial.ac.uk.*

New research paves the way for more innovative heat shields. Courtesy of NASA.

COMPOSITE TECHNOLOGY GETS CONDUCTIVE

A team of researchers from the Universities of Surrey and Bristol, UK, and Bombardier, Canada, demonstrated that growing carbon nanotubes on the surface of carbon fibers in composite materials significantly enhances their electrical and thermal conductivity.



Vertically grown carbon nanotubes on the carbon fibers (horizontal black lines) enhance the composite's electrical (e-) and thermal (q) properties.

The discovery could provide significant benefits in the aerospace industry, from enhancing de-icing to lightning protection. "The aerospace industry still relies on metallic structures, in the form of a copper mesh, to provide lightning strike protection and prevent static charge accumulation on the upper surface of carbon fiber composites," explains Thomas Pozegic, research associate at Bristol's Advanced Composite Centre

BRIEFS

Largo Resources Ltd., Canada, will produce, qualify, and sell its aerospace-certified vanadium products via **Glencore International AG,** Switzerland, the exclusive offtaker of vanadium product currently produced from the Maracás Menchen Mine. High strength, low alloy vanadium steels are rapidly replacing traditional steels as demand surges for stronger, lighter products for advanced applications. *largoresources.com.*

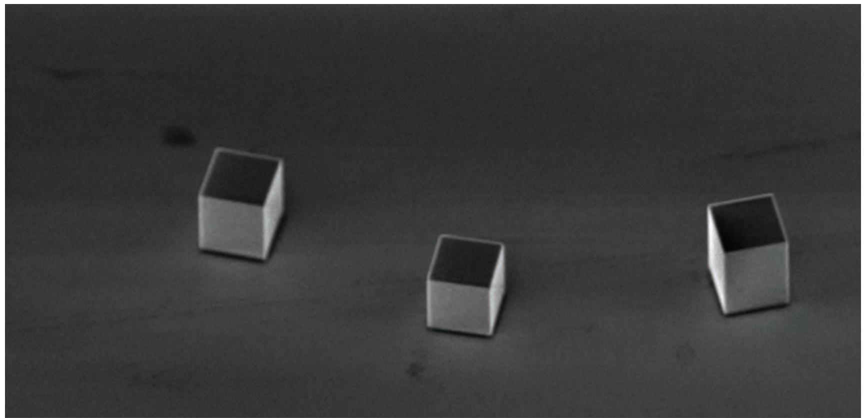
Under a multiyear, $1 billion contract launched in January, **Arconic,** New York, will serve as sole supplier to **Airbus,** France, for specific applications, including some wing, fuselage, and structural components. In addition to its proprietary alloys, Arconic plate products will be featured on every Airbus platform, including material from the company's new thick plate stretcher. Arconic's most significant share gain in the contract is the A320 family, Airbus' highest growth program. *airbus.com, arconic.com.*

Airbus A320

Magna International Inc., Canada, in cooperation with the **U.S. DOE,** Washington, and partners **FCA US,** Auburn Hills, Mich., and **Grupo Antolin,** Spain, developed a new, ultralight door architecture that achieves 42.5% mass savings compared to today's average production door. The module could be applied to roughly 70% of the light vehicle market. *magna.com.*

Ultralight door module achieves 42.5% mass savings.

for Innovation and Science. “This adds weight and makes fabrication with carbon fiber composites difficult.” The new technology, however, allows electrical transport throughout the composite material and could eventually allow a whole range of novel integrated functions—including sensors, systems for energy harvesting lighting, and communication antennae—ushering in a new era in aerospace composite technology. *www.surrey.ac.uk, www.bris.ac.uk, bombardier.com.*



Microscopic silver cubes were the bullets in Rice University experiments to show how deformation upon impact can make materials stronger and tougher. Courtesy of Rice University.

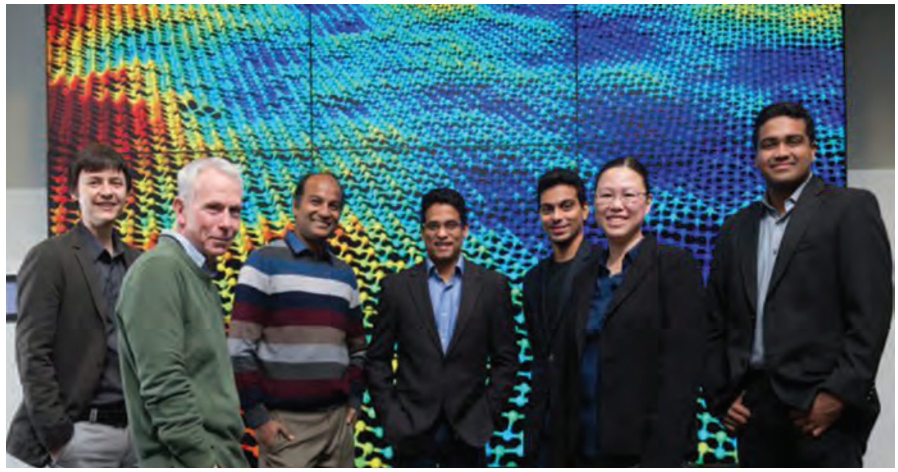
AN IMPACTFUL METHOD OF CREATING GNG STRUCTURES

Scientists at Rice University, Houston, demonstrated that firing a tiny, nearly perfect cube of silver onto a hard target transforms its single crystal microstructure into a gradient-nanograined (GNG) structure. Cubes were synthesized as single crystals via bottom-up seed growth to roughly 1.4 µm per side, then shot at room temperature at a silicon target 500 µm away using Rice’s advanced laser-induced projectile impact test rig. The cube’s temperature rose by 350°F upon impact at 400 m/s and allowed dynamic recrystallization. “The high-velocity impact generates very high pressure that far exceeds the material’s strength,” says materials scientist Edwin Thomas. “This leads to high plasticity at the impact side of the cube while the top region retains its initial structure, ultimately creating a grain-size gradient along its height.” Earlier studies show that a GNG structure from the nanometer to the micron scale could provide the high strength of nanocrystalline structures without their brittle failure susceptibility. The new process produces a range of grains from 10-500 nm over a distance of 500 nm—a gradient at least 10 times higher than other techniques. In addition to creating ultrastrong metals, the new research could influence materials processing techniques such as cold spray and shot peening. *rice.edu.*

TESTING | CHARACTERIZATION

APPLYING MACHINE LEARNING TO NANOMATERIALS

Researchers at the DOE's Argonne National Laboratory (ANL), Lemont, Ill., for the first time used machine learning to predict the physical, chemical, and mechanical properties of nanomaterials—and found it to be more accurate than traditional approaches. The team created the first atomic-level model that predicts the thermal properties of stanene—a 2D graphene-like material made of tin atoms potentially useful for thermal management in certain nanoscale devices. Badri Narayanan, postdoctoral researcher, explains, "We input data obtained from experimental or expensive theory-based calculations, and then ask the machine, 'Can you give me a model that describes all of these properties? Can we optimize the structure, induce defects, or tailor the material to get specific desired properties?'" Machine learning can be applied to a range of materials, and unlike traditional approaches, it can accurately capture bond formation and breaking events. The efficiency of the new method is unprecedented—until now, atomic-scale materials models took years to develop, and researchers relied largely on their own intuition to identify parameters. With machine learning, the need for human input is reduced and development time is shortened to a few months. *anl.gov.*



The Argonne research team who pioneered the use of machine learning tools in 2D material modeling. In the background is a 2D model of stanene, which is softer and much more rippled than its cousins graphene and silicene. Courtesy of ANL.

DIGITAL INFRASTRUCTURE PROJECT EXPLORES ADVANCED STRUCTURAL MATERIALS

An international group of organizations—including Oak Ridge National Laboratory, the Electric Power Research Institute, the European Commission Joint Research Center for Energy and Transport, and ASM International—is working together on a joint project to build a digital infrastructure for Mechanical Testing Data (called MeTeDa). The project consists of developing standard data formats for uniaxial creep, fatigue, creep crack growth, and creep-fatigue crack growth test data. The team is currently working with data generated by the nuclear energy industry, but would like to broaden the scope of its efforts to include such data from other industries as well.

MeTeDa is an outgrowth of the DOE International Nuclear Energy Research Initiative (I-NERI), established in 2001 to foster international cooperation on nuclear energy and its use. Critical to I-NERI's mission is the development of data standards for materials used in

BRIEFS

The **American Association for Laboratory Accreditation** granted the metallurgical laboratory of AM manufacturer **Sintavia LLC,** Davie, Fla., ISO 17025, the highest recognized quality standard in the world for calibration and testing. Previously, AM manufacturers offering this level of testing had to use independent laboratories for powder and material validation. Now, Sintavia's in-house accredited laboratory will allow faster analysis and more complete process security, according to company sources. *sintavia.com.*

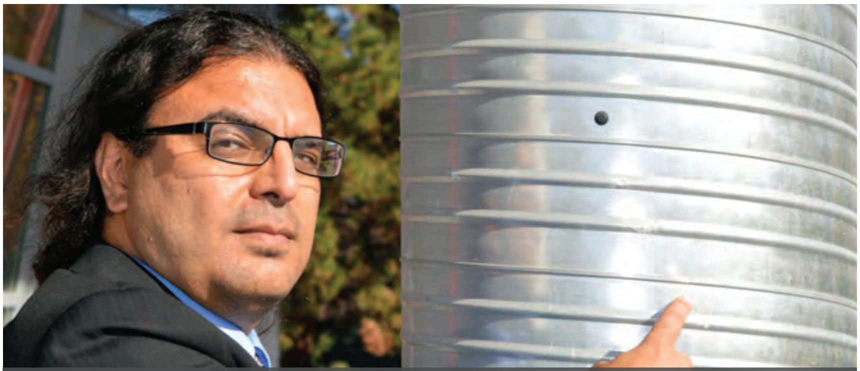
Bodycote, UK, announces that its Chesterfield hot isostatic pressing (HIP) location earned, for the second time, the highest level of Nadcap accreditation following the most recent Nadcap audit. *bodycote.com.*

The University of Alabama in Huntsville opened a new laboratory for predictive failure testing of electrical insulators used by utilities, component manufacturers, aerospace firms, and NASA. The Power Systems Insulation Laboratory performs real-time testing and computer modeling of insulating materials under conditions such as temperature variation, mechanical stress, electrical stress, dirt buildup, corrosion, moisture, and inherent natural decay. *uah.edu.*

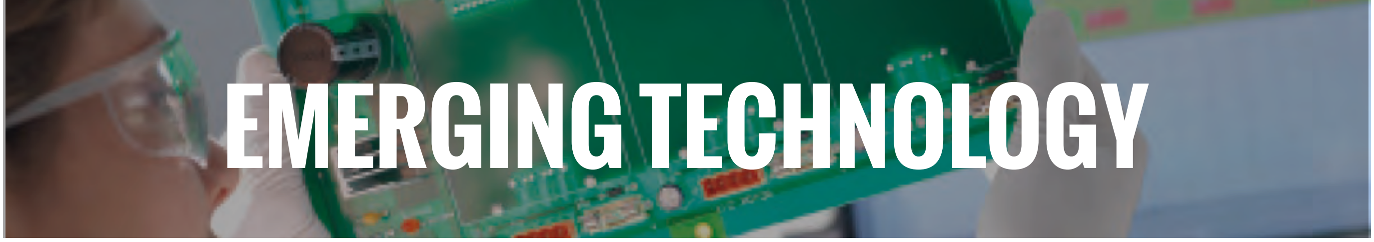
the generation of nuclear power. Test data is of particular interest and has been the focus of several European Committee for Standardization (CEN) workshops, which have produced data formats for ambient temperature uniaxial tensile testing and materials pedigree and are currently addressing fatigue. The various organizations involved in the MeTeDa project intend to extend this work, making it possible to exchange and aggregate an even broader range of test data. The second plenary session of this workshop is scheduled for the MS&T17 conference taking place in Pittsburgh in October. *For more information: www.cen.eu/work/areas/ICT/eBusiness/Pages/WS-METEDA.aspx and/or Afina Lupulescu, afina.lupulescu@asminternational.org, 440.338.5151 ext. 5627.*

SIMPLE TEST CONFIRMS PIPELINE SAFETY

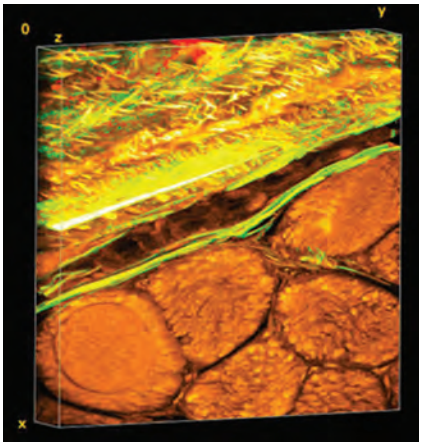
A simple vibration test could help oil and gas companies prevent pipeline spills in a way that is faster and cheaper than conventional methods, according to new research at the University of British Columbia (UBC), Canada. The study, conducted at UBC's Okanagan campus, found pipeline imperfections could be identified by tapping the side of a pipe and measuring the resulting vibrations against those predicted by computer models. "After developing the mathematical platform and entering it into a computer, we can predict what the level of vibration should be if the pipeline that is being tapped is free of imperfections," explains assistant professor Hadi Mohammadi. "This method of attaching small machines to pipelines that are above ground and having them tap and measure vibrations offers a faster and cheaper way to find cracks or patches of internal rust than the conventional method of using imaging techniques." Mohammadi began employing his "tap test" theory on pipeline material after testing its validity on human bones. The test was equally useful in identifying areas of deficient bone density, which could be used to help identify conditions such as osteoporosis. *www.ubc.ca.*



Hadi Mohammadi, UBC assistant professor.



EMERGING TECHNOLOGY



Periosteum is a tissue fabric layer on the outside of bone (upper left). The natural weave of elastin (green) and collagen (yellow) are evident under the microscope. Courtesy of Melissa Knothe Tate.

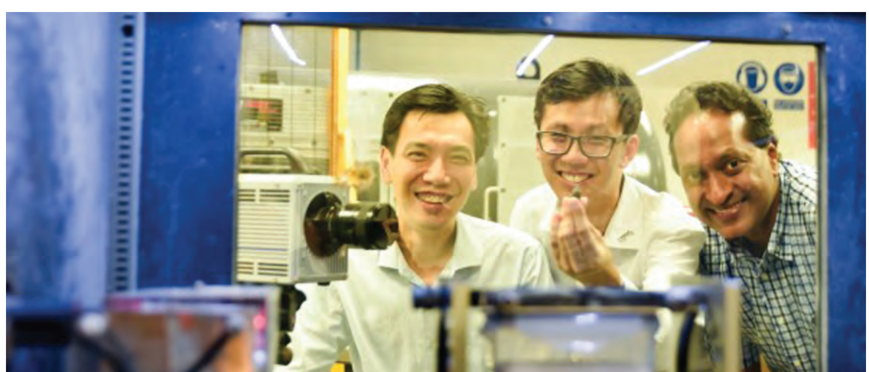
SMART TISSUES, SMART TEXTILES

Researchers at the University of New South Wales, Australia, produced an advanced functional fabric that mimics the adaptive stress-strain properties of a soft tissue from the human body, reportedly for the first time. The team used high fidelity 3D imaging to map the complex architecture of periosteum, a soft tissue sleeve that envelops most bony surfaces in the body and provides resilience and strength under high impact loads. After applying CAD modeling to scale up periosteum's pattern of structural proteins, researchers produced prototype multidimensional fabrics on a computer-controlled jacquard loom. In a first test of the concept, a series of textile swatches were woven in a twill pattern using elastic and silk instead of periosteum's collagen and elastin fibers, which are too small to fit into the loom. Mechanical testing showed the novel fabric possessed properties similar to those exhibited by the natural tissue.

The next step is to produce fabric prototypes for a range of advanced functional materials, from protective suits for skiers that stiffen under high impact to smart compression bandages for deep-vein thrombosis that respond to the wearer's movement. Eventually, the team hopes to weave tissues in the lab that can be used to replace failing joints, bringing the material full circle. *www.unsw.edu.au*.

SAND STRONGER THAN STEEL FOR ENERGY ABSORPTION

Researchers from the National University of Singapore (NUS) demonstrated that the energy absorption capability of sand is significantly higher than that of steel, suggesting it could serve as a cheaper, lighter, greener alternative to the metal in armor systems and critical infrastructure protection. After firing projectiles of various shapes and masses at a silica sand block using a wide range of velocities, the team discovered that the sand absorbs more than 85% of the energy exerted against it—an ability that increases with the projectile's speed, even at high velocities. Additionally, because the sand grains dilate on impact and resist continual penetration, an extreme frictional force is created that could potentially break the projectile into pieces. In contrast, the energy absorption capability of an equivalent steel plate reduces dramatically as projectile velocity increases due to the hydrodynamic effect: As projectile velocity surpasses the ballistic limit—the minimum velocity required to penetrate the target—steel behaves as a fluid without material strength. The team plans to explore the integration of sand with other compliant materials as well as investigate the energy absorption capabilities of other geomaterials, such as rock rubble. *www.nus.edu.sg.*



A team of researchers from NUS found that when a projectile is fired at a sand block at high speed, it absorbs more than 85% of the energy exerted against it.

Schematic of the new Advanced Manufacturing Lab at Lawrence Livermore.

BRIEF

Lawrence Livermore National Laboratory and **National Nuclear Security Administration** officials recently broke ground on the **Advanced Manufacturing Lab,** a collaborative hub for developing next-generation materials and manufacturing technologies. Construction is underway at the Livermore Valley Open Campus, Calif., with completion expected later this year. The $9.4 million, 13,000-sq-ft facility will feature a reconfigurable wet chemistry lab, dry instrument lab, and collaboration and conference space. *llnl.gov.*

PROCESS TECHNOLOGY

NASA GLENN INVITES COLLABORATION

NASA's Glenn Research Center, Cleveland, acquired a large-scale planar flow caster at its Magnetic Material Fabrication and Characterization Lab that can produce custom soft alloy magnetic ribbons measuring one mile long and up to 50 mm wide. The caster supports NASA's hybrid electric aircraft propulsion and power management work, and is the largest in the nation for conducting large-scale testing for commercial use in a variety of fields.

Glenn's Magnetic Material Fabrication and Characterization Lab offers fundamental alloy design, can produce large quantities of customized material, and can fabricate actual components, making it a one-stop shop. In addition to the large planar flow caster, a Buehler 60-g caster capable of producing approximately 25-mm-wide ribbons is available for alloy development trials or to produce smaller-scale components, such as those on circuit boards. The lab also offers an array of material characterization equipment, including an alternating current permeometer, vibrating sample magnetometer, permanent magnet hysteresigraph, and a Magneto Optical Kerr Effect microscope. The lab welcomes collaboration with federal entities, industry, academia, and other groups. *For more information, contact Randy Bowman at randy.r.bowman@nasa.gov.*

A large-scale planar flow caster produces a custom soft alloy magnetic ribbon measuring one mile long and up to 50 mm wide in NASA Glenn's Magnetic Materials Fabrication and Characterization Lab. Courtesy of NASA.

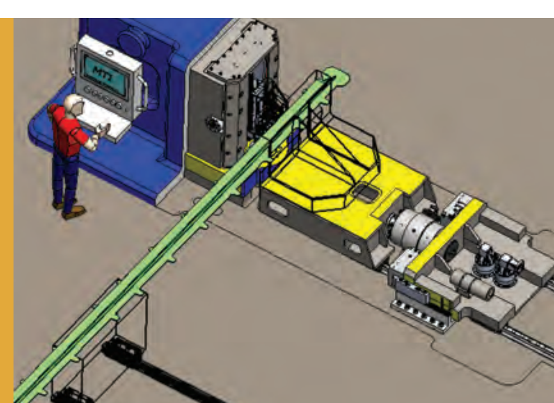
BELT CASTING BENEFITS

The Warwick Manufacturing Group (WMG) at the University of Warwick, UK, launched the ASSURE2 project to explore the potential of belt casting technology for steel production. As a near-net shape casting process, belt casting produces strip that needs minimal hot deformation to achieve required product thickness. Further, its use can minimize or eliminate the need for reheating processes—efficiencies that could cut costs by more than 300% compared to traditional continuous casting techniques. In addition, belt casting could be used to manufacture certain advanced high-strength strip steel grades that are commercially attractive but cannot be produced using conventional casting, including TWIP (twinning induced plasticity), TRIP (transformation induced plasticity), and high-Al steels.

In their work so far, WMG researchers simulated belt cast microstructures, including dynamic direct observation of the solidifying steel at different cooling rates. They demonstrated that microstructures are altered by the higher cooling rate of belt casting compared to slab casting and that further benefits such as grain size reduction in high-Al steels can be achieved by composition control. Quantitative relationships between composition, process parameters, and microstructure are being established, accounting for the higher cooling rates of belt casting and reduced hot deformation after casting to final thickness compared to conventional processing. Eventually, trials at the pilot plant facility at McGill University, Canada, will be undertaken for the steel grades developed by ASSURE2. *www2.warwick.ac.uk.*

BRIEF

Manufacturing Technology Inc., South Bend, Ind., is developing North America's largest linear friction welder—in terms of force capacity and tooling envelope—for **Lightweight Innovations for Tomorrow** (LIFT), Detroit, for use in automotive industry research and development. The first of its kind in the U.S., the LF35-75 welder will be housed in LIFT's Corktown manufacturing center and is slated for completion in spring 2018. *mtiwelding.com.*



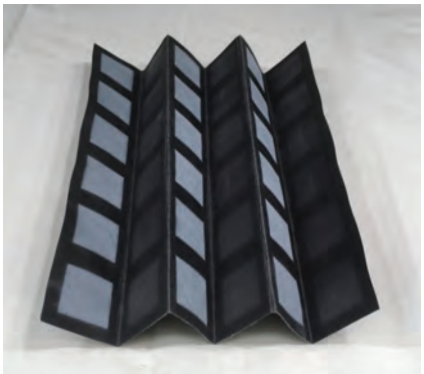
Linear friction welder now in development.

ENERGY TRENDS

A BATTERY OF CELLS

Researchers at Binghamton University, State University of New York created a bacteria-powered battery on a single sheet of paper. On one half of the piece of chromatography paper, a ribbon of silver nitrate underneath a thin layer of wax serves as a cathode. On the other half, a reservoir made of a conductive polymer serves as the anode. Once the sheet is properly folded, a few drops of bacteria-filled liquid are added, and the microbes' cellular respiration powers the battery. Tests show that different folding and stacking methods can alter the output: Six batteries in three parallel series generate 31.51 μW at 125.53 μA, and a 6x6 configuration produces 44.85 μW at 105.89 μA.

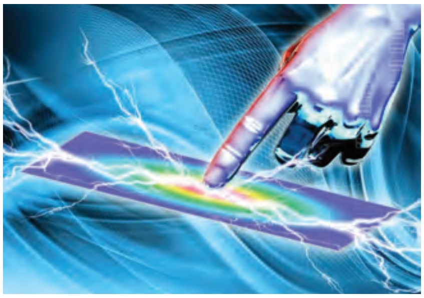
"Microorganisms can harvest electrical power from any type of biodegradable source, like wastewater, that is readily available," explains assistant professor Seokheun Choi. Because of this, bio-batteries could serve as a choice power source for disposable, point-of-care diagnostic sensors in remote areas. While it would take millions of paper batteries to illuminate a 40-W light bulb, the cells are strong enough to power lifesaving glucose monitoring or pathogen detection diagnostics. *binghamton.edu.*



Researchers created a bacteria-powered battery on a single sheet of paper that can power disposable electronics. Courtesy of Seokheun.

CAPTURING ENERGY WITH A WAVE OF THE HAND

Engineers at Penn State, State College, Pa., designed a transducer that could be used to harvest low-frequency, mechanical energy from environmental sources—such as wind, ocean waves, and human motion—and use it to power next-generation electronics. While devices that convert ambient mechanical energy into electricity are widely used today, most depend on the piezoelectric effect and are only efficient above 10 Hz. The new device—a flexible, organic, ionic diode—has a peak power density at least as great as an optimally performing piezoelectric generator, but at a frequency of only 0.1 Hz. "Right now, at low frequencies, no other device can outperform this one," asserts Qing Wang, professor of materials science and engineering.

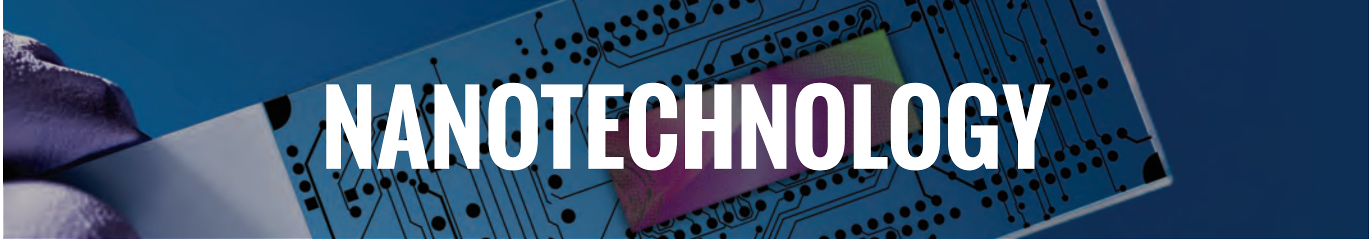


Energy-harvesting PN junction. Courtesy of Qing Wang, Penn State.

The new ionic diode is composed of two nanocomposite electrodes with oppositely charged mobile ions separated by a polycarbonate membrane. The electrodes are comprised of a polymeric matrix filled with carbon nanotubes—to enhance conductivity and mechanical strength—and infused with ionic liquids. When mechanical force is applied, ions diffuse across the membrane, creating a continuous direct current, while a built-in potential that opposes ion diffusion is established until equilibrium is reached. The flexible, lightweight polymer device could be incorporated into a smart phone, for example, where it could capture the energy used to touch the screen and use it to replenish up to 40% of the battery's capacity. *psu.edu.*

BRIEF

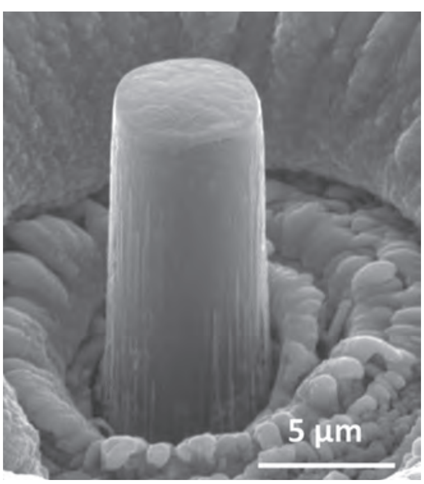
As part of the Manufacturing USA initiative, the **DOE** announced its **Reducing Embodied-energy and Decreasing Emissions (REMADE) Institute.** The new organization, led by the **Sustainable Manufacturing Innovation Alliance** (Rochester, N.Y.), will leverage up to $70 million in federal funding plus $70 million in matching cost-share commitments from more than 100 private partners. Charged with slashing the cost of technologies needed to reuse, recycle, and remanufacture materials such as metals, fibers, polymers, and electronic waste, REMADE is aiming for a 50% improvement in overall energy efficiency by 2027. *energy.gov.*



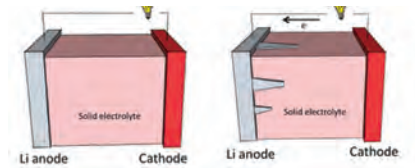
NANOTECHNOLOGY

SMALL SCALE LITHIUM FEATURES SURPRISING STRENGTH

A team of researchers from Caltech, Pasadena, Calif., and Carnegie Mellon University, Pittsburgh, measured the strength of lithium metal at the nano- and microscale, a first that could ultimately lead to improved lithium-ion battery performance. Using a special vacuum chamber at Caltech, the team formed pillars of single-crystal lithium a few micrometers tall and just a few nanometers to micrometers in diameter. They discovered that at this size, lithium is up to 100 times stronger than indicated by previous measurements at a larger scale. Additionally, researchers found that the stiffness of lithium dendrites—needlelike branching structures that advance into a battery, causing it to short-circuit or even explode—varied by as much as a factor of four according to their crystallographic orientation.



A micrometer-sized pillar of lithium. Images courtesy of J. Greer Laboratory/Caltech.



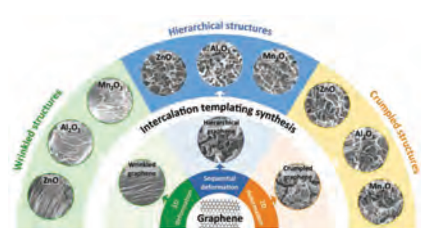
Diagrams of a lithium-ion battery. When the battery is connected and charge is flowing (at right), small needles of lithium metal grow, which can destroy the battery.

Until now, attempts to physically curb the growth of lithium dendrites have involved a solid electrolyte sandwiched between the cathode and anode to serve as a physical barrier; however, the electrolytes used thus far have not been able to withstand the force of the growing dendrites. Now that researchers know what they're up against, a stronger solid electrolyte can be developed to keep the lithium dendrites in check. *caltech.edu, cmu.edu.*

NEW METAL-OXIDE FILMS PATTERNED ON GRAPHENE

Researchers from Brown University, Providence, R.I., developed a new method for making ultrathin textured metal-oxide films that have improved properties as catalysts and electrodes. The scientists placed stacks of wrinkled graphene sheets in a water-based solution containing positively charged metal ions. The negatively charged graphene pulled the ions into the spaces between the sheets, and the particles bonded together, creating thin sheets of metal that followed the wrinkle patterns of the graphene. When the graphene was oxidized away, the textured metal-oxide film remained. The process works with a variety of metal oxides—zinc, aluminum, manganese, and copper oxides—which are too stiff to be textured with the methods the team previously developed to deform graphene films.

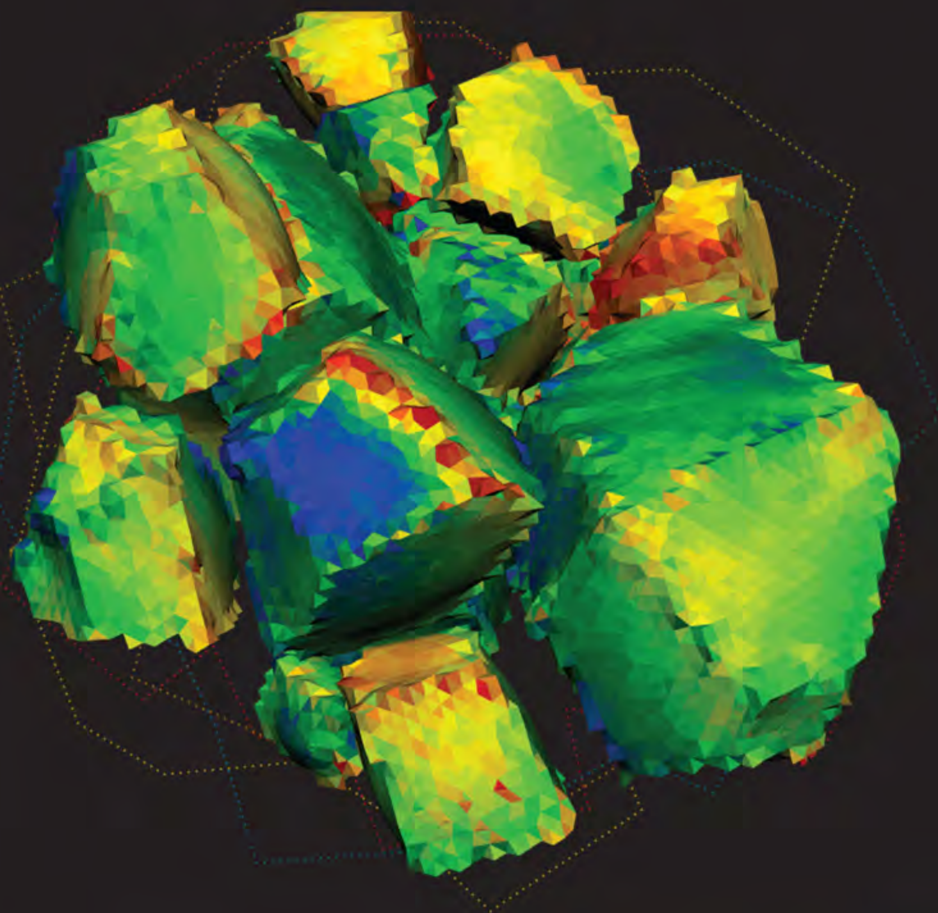
In the experiments that followed, researchers demonstrated improved properties of the new films. Wrinkled manganese oxide, when used as a battery electrode, had a charge-carrying capacity four times higher than a planar sheet, and crumpled zinc oxide film was four times more reactive than a planar film in a photocatalytic reaction—reducing a dye dissolved in water under ultraviolet light. The process represents more than just bolstered performance, according to Po-Yen Chen, a postdoctoral researcher. "Based on what we learned from making the metal-oxide films, we can start to think about using this method to make new 2D materials that are otherwise unstable in bulk solution," he explains. "With our confinement method, we think it's possible." *brown.edu.*



Using graphene sheets as tiny templates, researchers developed a method of making metal-oxide films with intricate surface textures. Courtesy of Hurt/Wong Labs, Brown University.

BRIEF

The world nanomaterials market is forecast to reach $55,016 million by 2022, registering a CAGR of 20.7% from 2016 to 2022, according to a new report available from **Report Buyer,** London. Heavy investment in R&D activities by government organizations is expected to propel market growth. *reportbuyer.com.*



3D MICROSTRUCTURES FOR MATERIALS AND DAMAGE MODELS

Veronica Livescu, Curt Bronkhorst, and Scott Vander Wiel

Los Alamos National Laboratory, N.M.

Many challenges exist with regard to understanding and representing complex physical processes involved with ductile damage and failure in polycrystalline metallic materials. Currently, the ability to accurately predict the macroscale ductile damage and failure response of metallic materials is lacking. Existing macroscale models involve simple micromechanics of pore/solid interactions, which do not take into account microstructural effects. Recent initiatives are driving greater interaction between the materials science and design engineering communities as materials research migrates to a science-based capability to design materials for specific applications. Such processing model capabilities will predict the internal structure of materials under specific processing conditions. Similarly, knowledge of internal structures will enable materials property models to predict material performance under desired operating conditions.

Past studies of the effect of microstructural and stress-state variables on the evolution of damage show that microstructure must not be neglected to enable predicting or avoiding damage and failure. Other studies show that physical processes of damage nucleation and growth leading to failure are substantially affected by material anisotropy and the presence of both intrinsic and extrinsic defects and heterogeneities[1-5]. There is general agreement that the mechanisms of damage nucleation and growth under mechanical loading strongly depend on material processing and the resulting microstructure[6]. However, the underlying mechanisms and kinetics controlling damage nucleation and growth as a function of material microstructure and loading path are still not well understood. The physics of ductile damage and failure are approached as an evolving process of nucleation, growth, interaction, and coalescence, which leads to failure. These stages are observed experimentally in images captured using circular-differential interference contrast (C-DIC) microscopy (Fig. 1). Unfortunately, these damage and failure events cannot be predicted without the use of mesoscale-aware modeling tools. Crystal plasticity-based simulations can predict the average crystallographic texture and development due to deformation, but cannot predict the nature and extent of the local intergranular misorientations due to deformation[7].

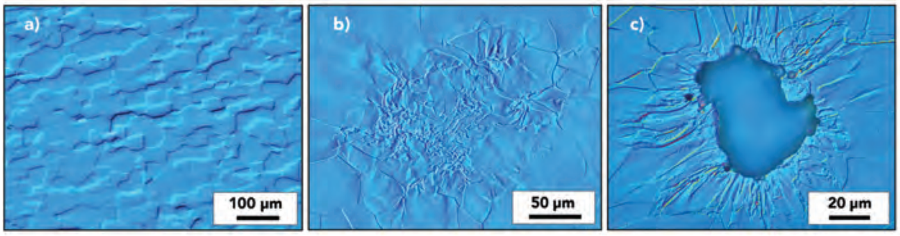


Fig. 1 — Stages in damage development observed experimentally in shocked tantalum: (a) undeformed microstructure, (b) strain localization, and (c) void damage.

Research at Los Alamos National Laboratory (LANL) is aimed at building a coupled experimental and computational methodology that supports the development of predictive damage capabilities by:

- Capturing real distributions of microstructural features from real material and implementing them as digitally generated microstructures in damage model development.
- Distilling structure-property information to link microstructural details to damage evolution under a multitude of loading states.

MICROSTRUCTURE: A 3D CONCEPT

The internal structure of materials is complex and multiscale—and defined by a large number of parameters. Microstructures of materials such as metals are three-dimensional (3D). However, most traditional methods developed to study such materials depend on observations made in 2D sections due to their opaque nature. Increasing demand for modeling and simulation to predict materials properties and to provide more realistic representations of microstructures have increased the need for high accuracy characterization and analysis of microstructures. Predictive representation of ductile damage and failure in materials remains a significant computational challenge. Past quantification efforts to characterize microstructural aspects considered average quantities, which in part were driven by the limited description of microstructure in the models.

Microscopy methods for unbiased descriptions of microstructures have undergone dramatic improvements. The desire for 3D microstructural data is relatively straightforward because 3D data provides access to important geometrical and topological quantities that cannot be determined or are erroneously quantified using classical stereological methods applied to 2D images. However, experimental 3D characterization and quantification techniques still require significantly more development compared with conventional 2D analysis. The state of the art for 3D materials characterization is advancing and is covered in the literature[8-10]. Depending on the area and features of interest, different microscopy methods are used to obtain 3D information. Methods used to obtain 3D statistics from microstructures include stereology[11], serial sectioning with or without electron backscatter diffraction (EBSD)[12] to reconstruct microstructures in 3D, 3D FIB-SEM[13], and high-energy diffraction microscopy[14]. However, because it is not possible to measure all conceivable microstructural features, characterization must have a well-defined scope.

LANL research on generating digital materials models involves DREAM.3D[15], an open source software package designed for the digital reconstruction, instantiation, quantification, meshing, and visualization of microstructures. This package allows creation of synthetic microstructures from automatically generated statistics or from one's own statistics. Reconstructed volumes can be exported in various formats, and statistical analysis can be extracted for further use.

Synthetic microstructures were generated for a rolled and annealed high-purity tantalum material from Cabot Corp. The plate composition was high purity, with ppm contents of <50 O, 10 N, 10 C, and 5 H. EBSD analysis was performed with a step size of 1.0 µm on a Phillips XL30 FEG SEM, using the TSL data collection and analysis software, encompassing tens of thousands of grains, capturing more than 100,000 boundary segments. Grain size, orientation distribution function (ODF), and grain boundary misorientation parameters were determined using the TSL orientation imaging microscopy (OIM) software. Based on statistics collected on the tantalum material including grain size and morphology, and ODF, a statistics file was generated and used within DREAM.3D to generate digital microstructure volumes. An example of digitally generated tantalum material is shown in Fig. 2. A large number of such volumes were created and it was confirmed that the statistics are similar to the starting material from which the experimental data was collected.

The method provides an unlimited supply of digital microstructures, which are statistically representative of the original material. Synthetic volumes are surface meshed to enable moving models into FEM or other simulations. Interpretation of physical behavior is performed by comparing experimental to calculated free surface velocity responses by including hypothesized mechanisms within the theoretical model used to conduct the simulations.

INVESTIGATING DUCTILE DAMAGE

As mentioned previously, nucleation of damage is a statistical process where 3D distribution of sizes and strengths of defects, local heterogeneous polycrystal stress states, and poorly understood atomistic level physical mechanisms of damage nucleation play a fundamental role. Figure 3 shows void damage in a tantalum sample tested in a plate impact gas gun experiment; microstructure characterization indicates that voids nucleate at specific microstructural features.

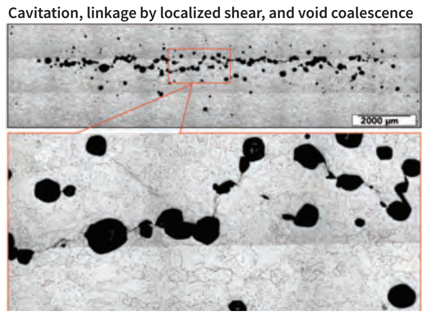


Fig. 3 — Void damage in a tantalum sample tested in a plate impact gas gun experiment.

Serial sectioning and volumetric reconstruction of void-based damage in the sample enables quantification of the true size, shape, and distribution of both individual microstructural features and their local neighborhoods. This reveals hidden connectivity between features (Fig. 4), insight unobtainable from 2D-based stereological approaches. The 3D reconstruction also indicates that the amount of void damage varies from section to section between 3% and 15%. Void fraction variation is assumed to depend on the spatial distribution of damage prone microstructural features in the material.

Optical microscopy reveals material damage such as voids and cracks or retained microstructural features, but it fails to indicate how the rest of the material is affected by the deformation processes. EBSD data can be processed to extract orientation image maps and plots enabling visual representation of orientation related aspects of the deformed microstructure. Local misorientation can be characterized using a kernel misorientation approach. Kernel average misorientation (KAM) maps are now a standard method to indicate relative differences in crystallographic orientation between neighboring points in a sample. KAMs was applied to qualitatively evaluate localized plastic strain in the material. Generally, KAM is higher in deformed regions or grains. For the specimen presented here, KAM was calculated to the 5th neighbor, with a maximum misorientation of 6°. Regions with less than 2° misorientation were considered undeformed. The 3D reconstruction of KAM maps obtained from EBSD (Fig. 5) in shocked tantalum reveals contiguous and complex plastic linkages in 3D. Therefore, the microstructure not only must be viewed as a 3D concept, but the events and features related to deformation and damage also must develop in 3D.

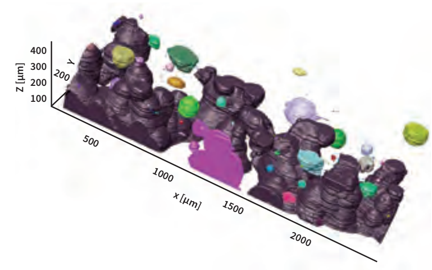


Fig. 4 — 3D reconstruction of void distribution in shocked tantalum.

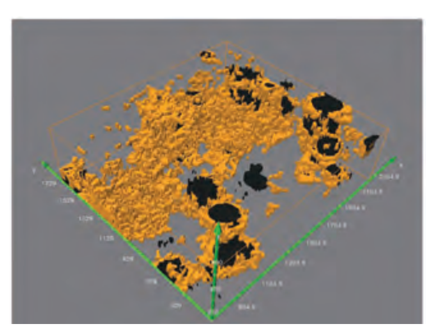


Fig. 5 — 3D reconstruction of kernel average misorientation (KAM) maps in shocked tantalum. Black and orange represent void damage and deformation affected material, respectively.

	Min Diam. [µm]	Max Diam. [µm]	Grains >100µm	µ	σ
Simulated Microstructure	6.3 (4.47-8.05)	168.69 (123.0-226.7)	2.2% (1.4-3.3)	3.5537 (3.51-3.59)	0.5396 (0.49-0.58)
Real Microstructure	5.0	210.00	2.7%	3.55	0.55

Fig. 2 — Comparison of statistics from a digitally generated tantalum microstructure containing 1500 grains to the real material.

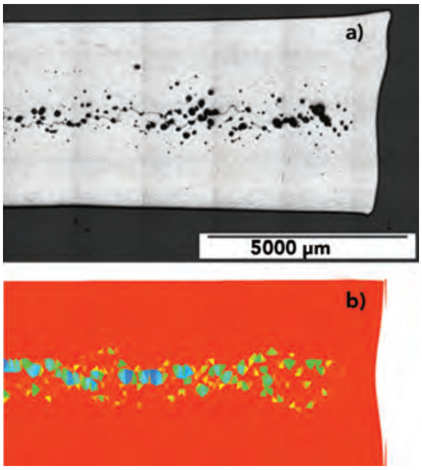


Fig. 6 — Void pattern in (a) recovered specimen and (b) macroscale simulation of the experiment.

PREDICTIVE CAPABILITY FOR MATERIALS RESPONSE

Material structure must be evaluated as a statistically varying quantity for multiscale modeling and simulations of a material's response to loading. Thus, it is necessary to represent many instances of material structure. Digitally generated microstructures using the method described here are ideal for this purpose because they can be easily implemented into the simulations.

Plate impact experiments on tantalum produced a pattern of voids similar to that shown in Fig. 6(a). Figure 6(b) shows that macroscale simulations of the experiments replicate characteristic features of the voids using constitutive material models. However, these lack the underpinnings of polycrystalline mechanics needed to support predictive simulations of material response to loading[16].

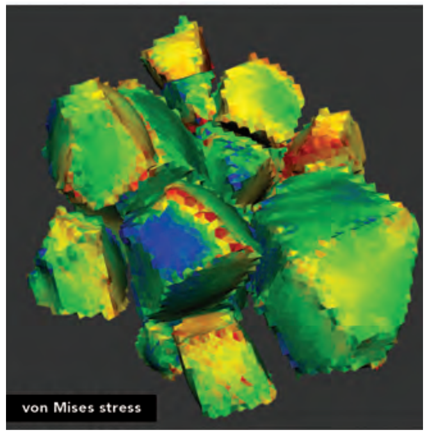


Fig. 7 — Expanded view of simulated von Mises stress on grain surfaces in polycrystalline tantalum; stress hot spots tend to appear on triple points.

Use of a rate-dependent macroscale damage model[16, 17] enabled estimating the time in the experiment at which the macroscale model suggests progression of pore growth begins. Numerical representation of experimental results provides an estimate of the stress state in the sample at this predicted time of void initiation. Calculated stress state can then be applied to mesoscale models of statistically equivalent material structures as discussed previously. Polycrystal simulations of tantalum under loading trajectories that match those in the plate impact spall plane provide first order quantitative estimates of the von Mises stress on grain surfaces in the polycrystal. Figure 7 shows an expanded view of von Mises stress on the surface of individual crystallite grains when maximum principle tensile stress is at its peak. The single crystal model used in these calculations is based on thermally activated motion of dislocations[18].

The long-term goal is to discover reliable phenomenological relationships that relate the time evolving spatial distribution of stress hot spots to loading conditions, material properties, and spatial distributions of grain morphology and texture. Initially, the aim is to predict stress at select points on grain boundaries from several variables including grain boundary area, grain boundary normal relative to shock direction, grain volume, neighbor grain volume, Taylor factor, difference in Taylor factor across the grain boundary, and difference in equivalent elastic strain across boundary. An accurate cross-validated statistical regression model would provide an understanding of which mesoscale features are most important in determining the spatial distribution of stress hot spots. This in turn will lead to more well-founded simulation models to predict macroscale behavior of materials under extreme loadings and, eventually, to a principled understanding of how these materials fail when subjected to shock. **~AM&P**

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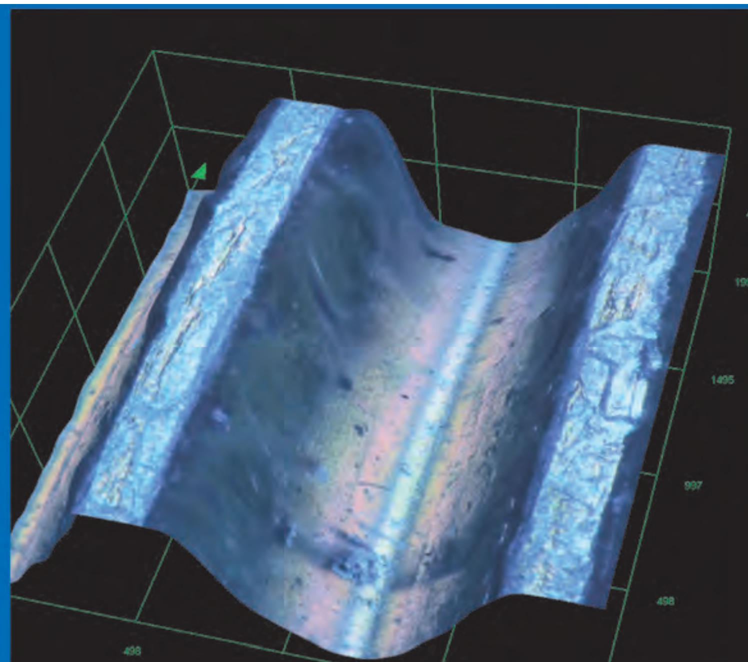

ANALYSIS OF GRAIN SIZE DISTRIBUTIONS

Because the nature of grain size distribution can influence mechanical properties and service behavior, it is important to accurately characterize this parameter.

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Measurement of grain size and distribution can be performed using both manual (ASTM E112) and image analysis (E1382) methods. Standard E112 is designed to measure grain size in specimens with equiaxed grains and a unimodal (normal), or Gaussian, grain size distribution. However, it does not define how to determine if grains in a specimen adhere to this criterion. This article demonstrates how to evaluate grain size distribution, which can be done using either grain-area or intercept-length measurements. The use of grain areas to evaluate distribution is preferred, as the amount of data per field is less, and the calculation of ASTM grain size, G, is a simple and direct matter. Further, the relationship between mean lineal intercept length and grain size is empirical.

Grain structures of some metal specimens have grain distributions other than unimodal or Gaussian distribution. For example, high-alloy and stainless steels and nickel-base superalloys commonly have bimodal grain size distributions in the as-rolled and solution annealed condition—especially if the annealing temperature is below the recommended temperature. A range of distributions can exist between specimens that exhibit unimodal Gaussian distributions and those that clearly exhibit bimodal, or duplex, grain size distributions. Because the nature of grain size distribution can influence mechanical properties and service behavior, it is important to accurately characterize this parameter. The best way to evaluate grain size distribution is to measure grain areas and plot the percentage of grain areas per ASTM G class versus ASTM grain size number (G), while calculating the skew and kurtosis (sharpness of the peak of a frequency-distribution curve) of the measured grain areas. A kurtosis of 3 represents a perfect unimodal, or Gaussian, grain size distribution, while values of >5 indicate non-Gaussian distributions.

ANALYTICAL PROCEDURE

Grain areas can be measured using image analysis (IA) and electron backscatter diffraction (EBSD). A reasonably large number of grains (typically, at least 500 grains) must be measured using randomly selected fields; both methods required excellent metallographic specimen preparation. For IA, grain structure must be fully revealed with minimal missing grain edges between adjacent grains, although this technique can correct for some missing grain boundaries. EBSD requires a specimen with excellent flatness and freedom from deformation-induced subsurface damage, which reduces the percentage of pixels that generate diffraction patterns that can be indexed. If a face-centered-cubic metal specimen exhibits annealing twins, they must be suppressed by the etchant used, removed by the image analysis program, or removed by the orientation differences across the twin boundary by EBSD.

To define a normal distribution, plot the area percentage of grains per ASTM grain size class. The definition of G according to E112 is:

$$N_{AE} = 2^{G-1} \qquad (1)$$

where N_{AE} is the number of grains per square inch at a magnification of 100× and G is the ASTM grain size number. Skew and kurtosis are calculated from the raw measurement data of the grain areas. Calculate the kurtosis of the data using an application such as Microsoft Excel. Next, order grain areas from largest to smallest, then add up grain areas according to how they relate to specific ASTM G values as shown in Table 1. In the table, for a given G class, areas are binned according to the area for a given G value plus or minus the area for G-0.5 to G+0.5. Total grain areas for each G value are summed and divided by the total areas of all measured grains and expressed as a percentage.

ANALYSIS EXAMPLES

Example 1. Figure 1 shows the microstructure of a motor lamination steel with a very low carbon content,

TABLE 1–BINNING OF GRAIN AREAS BY ASTM G CLASS

ASTM G	A max, μm²	A min, μm²
00	365,008	182,504
0	182,504	91,239
1	91,239	45,620
2	45,620	22,810
3	22,810	11,405
4	11,405	5703
5	5703	2851
6	2851	1426
7	1426	713
8	713	356
9	356	178
10	178	89.5
11	89.5	44.6
12	44.6	22.3
13	22.3	11.1
14	11.1	5.57
15	5.57	2.79

*Member of ASM International

tint etched using Klemm's I reagent at a magnification of 100× (the magnification bar was removed to make grain area analysis simpler). Figure 2 shows detection of grain boundaries by IA. Boundaries can be eroded to one pixel width, with the image then inverted to detect grain interiors. Each grain is measured for its area, and the areas are mathematically analyzed for skew and kurtosis. Grain areas are ordered from largest to smallest, and grain areas in each grain size class (as defined in Table 1) are added and divided by the total area of all grains measured and expressed as a percentage (Table 2). A plot of these data (Fig. 3) has a kurtosis of 2.55 (close to a perfect normal Gaussian distribution), and the data cover eight ASTM G classes with an average grain size of ASTM G = 6.66. Due to the nature of the G calculation (Eq. 1), the distribution of % grain areas per G class versus G reveals a normal distribution. By comparison, the x axis in Fig. 4a is a linear scale of grain areas rather than G values, and the distribution is now log-normal. By using seven grain area classes rather than 14 (Fig. 4b), the distribution curve is smoother with less noise.

Example 2. Figure 5a shows the grain structure of E-Brite 26-1,* a ferritic stainless steel, etched electrolytically using aqueous 60% nitric acid at 1 V dc for 20 s. The structure exhibits areas of banding with coarse and finer grains. Figure 5b shows the detected grain areas measured by IA. Table 3 contains measurement data by ASTM G class covering 14 G classes. The skew is 3.59, while the kurtosis is 18.62, well above

Fig. 1 — Ferrite grain structure of a motor lamination steel etched using Klemm's I reagent at a magnification of 100× (magnification bar removed for grain area measurements).

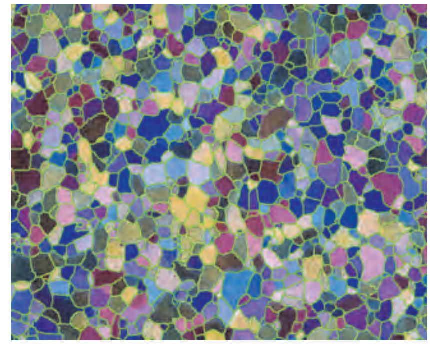

Fig. 2 — Detection of grain boundaries by image analysis.

TABLE 2–BINNING OF GRAIN AREAS BY G CLASS FOR MOTOR LAMINATION STEEL

G	3	4	5	6	7	8	9	10	11
% Area	0	3.19	23.76	42.53	20.25	7.21	2.19	0.76	0.12

No. grains	∑ grain areas, μm^2	Avg. grain area, μm^2	ASTM G	No. of G classes
891	1,158,903	1300.68	6.63	8

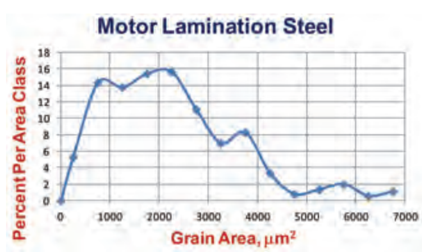

Fig. 4a — Plotting grain areas (covering 14 grain size classes) for the motor lamination steel instead of ASTM grain size (G) on the x axis reveals a log-normal grain area distribution rather than the unimodal Gaussian distribution show in Fig. 3.

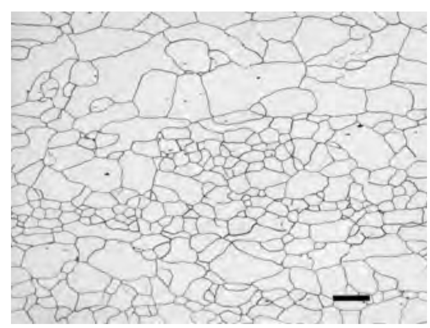

Fig. 5a — Example of non-Gaussian grain size distribution containing regions of coarse and fine ferrite grains.

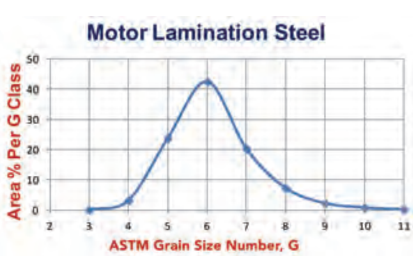

Fig. 3 — Grain size distribution curve for motor lamination steel revealing excellent unimodal, Gaussian grain size distribution with a mean ASTM grain size of 6.63, kurtosis of 2.55, skew of 1.43, and a distribution covering eight grain size classes.

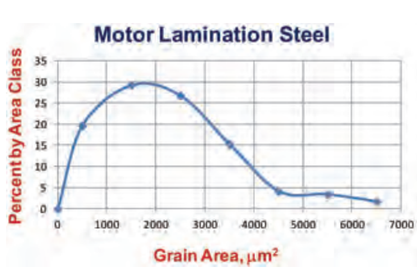

Fig. 4b — Seven grain classes plotted on a linear scale using grain area rather than G.

Fig. 5b — Detection of grain interiors by image analysis.

TABLE 3–BINNING OF GRAIN AREAS BY G CLASS FOR 26-1 FERRITIC STAINLESS STEEL

G	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Area	0	3.5	16.3	24.4	20.6	17.4	10.4	3.7	0.7	0.1	0.08	0.008	0.011	0.004	0.003

No. grains	∑ grain areas, μm²	Avg. grain area, μm²	ASTM G, all grains	No. of G classes
339	804,976.1	2374.6	5.7	14

TABLE 4–BINNING OF GRAIN AREAS BY G CLASS FOR SC-19 AUSTENITIC STAINLESS STEEL

G	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Area	0	28.2	17.3	12.3	6.97	5.08	2.77	2.6	4.19	6.4	6.5	4.29	2.1	0.99	0.38

No. grains	∑ grain areas, μm²	Avg. grain area, μm²	ASTM G, all grains	No. of G classes
3901	578,437.1	148.28	9.77	14

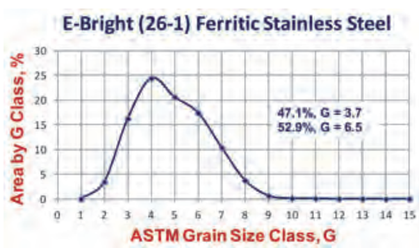

Fig. 6 — Grain size distribution for 26-1 ferritic stainless steel revealing non-Gaussian grain size distribution, but without a clear bimodal, or duplex, grain size distribution. The distribution covers 14 grain size classes with a mean grain size of ASTM G = 5.7, which can arbitrarily be divided into two classes with 47.1% of the grains having a mean grain size of G = 3.7 and the balance with a mean grain size of 6.5. A skew of 3.59 and kurtosis of 18.62 is non-Gaussian.

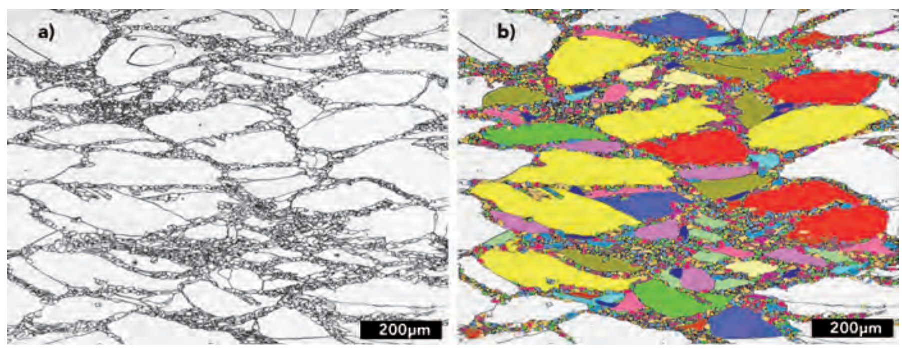

Fig. 7 — SCF 19 austenitic stainless steel with a bimodal necklace-type grain structure due to partial recrystallization after cold working: (a) partially recrystallized grain structure etched using aqueous 60% nitric acid at 1 V dc for 60 s (100×); (b) detection of grain areas by image analysis.

the maximum value of 5 for a normal distribution. The grain size distribution curve with a slight hump to the right of the maximum value is shown in Fig. 6. The mean overall grain size is G = 5.7. The distribution curve is not bimodal, and although not justified, it could be broken into two parts and calculated that 47.1% of the grains have a mean grain size of G = 3.7, while 52.9% have a mean grain size of G = 6.5.

Example 3. Figure 7 shows a bimodal grain size distribution called a necklace distribution in SCF-19* austenitic stainless steel. The specimen was cold reduced 10% in thickness and solution annealed at just 900°C, while the recommended solution annealing temperature is 1180°C. Grain boundaries were selectively electrolytically etched using aqueous 60% nitric acid at 1 V dc for 60 s (annealing twin boundaries are not revealed using this etch and voltage). Table 4 contains the area percentage of grains per G class, covering 14 G classes, for 3901 grains measured. The skew for the distribution shown in Fig. 8 is 16.96 and the kurtosis is 320.04, a very high value. The distribution is clearly bimodal with 71.2% of the grain area having a mean grain size of G = 4 and 28.8% having a mean grain size of G = 11.5. **~AM&P**

**Note: E-Brite 26-1 is a registered trademark of ATI Allegheny Ludlum. SCF-19 is a registered trademark of Carpenter Technology Corp.*

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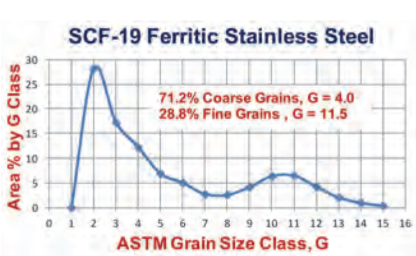

Fig. 8 — Bimodal grain size distribution in partially recrystallized SCF 19 austenitic stainless steel covering 14 grain size classes where the mean grain size of all grains is 9.77, although such a measure is of no value due to the duplex grain size distribution.

A CENTURY OF PROGRESS AT THE MATERIALS AND MANUFACTURING DIRECTORATE

Throughout its 100-year history, the Materials and Manufacturing Directorate (ML) has conducted groundbreaking critical research programs responsible for a multitude of technological advances.

Jaimie S. Tiley, FASM, and Amy Whitney-Rawls*
Air Force Research Laboratory, Wright-Patterson AFB, Ohio

The Materials and Manufacturing Directorate was created in 1917 as the Materials Laboratory at McCook Field in Dayton, Ohio, to provide lighter, stronger, and more reliable materials for the growing aerospace community. Not surprisingly, initial research focused on improving the flexible wood products used in airplane structures. Various metal alloys were also used for engine components, propellers, and landing gear, leading to research efforts in metallurgy, casting, and materials processing. For example, this early research enabled development of a carburized armor plate to protect against armor-piercing ammunition. The material resisted bullets traveling 2200 feet per second—a tremendous improvement over conventional materials of the time. This work provided the foundation for 41xx class steel alloys. The laboratory moved to Wright Field in 1927 and continued groundbreaking research activities, including development of a rotating beam fatigue machine, which enabled uniform loading of material test specimens. The new design revolutionized testing procedures and set the international standard for characterizing fatigue properties.

WARTIME ADVANCEMENTS

The start of World War II necessitated an increased emphasis on materials development and improved processing capabilities. ML provided manufacturing assistance to weapons producers and engineering support to improve aircraft capabilities. In addition, requirements to accelerate weapon systems production and find substitutes for materials that were in short supply created new research directions. For example, innovative materials such as butyl rubber and nylon were developed to replace the natural silks used in parachutes. Radar technologies and lightweight structural components were also developed to meet new military demands. Service issues were targeted as well, including assessments of the B-17 bombers, which were discovered to contain cracks in the wing spars. ML developed steel reinforcement plates that were applied to keep the fleet flying and successfully avoid wing failures.

In 1948, ML launched a fluorocarbon research group sponsored by the Petroleum Product Unit, which grew to become the in-house polymer group (Fig. 1). Research addressed critical needs for advanced polymers, including requirements for stable polyester materials in transparent radomes used in airborne radar applications and development of high stiffness glass fibers. The fibers were used to create lightweight composite materials to structurally compete with aluminum. Successful development of "S glass" was transitioned and used in filament-wound rocket motor cases for the third stage of the Minuteman II intercontinental ballistic missile (ICBM).

Fig. 1 — Early polymer research within the Materials Laboratory, 1948.

SPACE AGE RESEARCH

In the early 1960s, advanced efforts in developing boron filaments, composites, and dispersion hardening alloys were initiated. In addition, the Rare Earth Permanent Magnet Materials Initiative was established to research the high magnetic properties of rare-earth transition element intermetallic compounds. This research led to development of samarium cobalt magnetic

*Member of ASM International

compounds, which still remain important components of the high-end permanent magnet market, used in traveling wave tubes, ion propulsion engines, magnetic memory applications, and numerous motor applications. Similarly, the advanced research on composites provided a new class of materials with excellent strength, stiffness, and density properties to compete with aluminum and steel structures. Early results were transitioned to the F-111 horizontal stabilizer, engine fan blade, reentry vehicle structure, satellite antenna disk, and an OV-10 wing box.

ML pioneered carbon-carbon composites, which were particularly suitable for very high temperature applications over long periods of time. As a result, these composites were transitioned for use in many aerospace applications including aircraft brake disks, solid rocket motor nozzles, space battery sleeves, missile reentry vehicle nose tips, turbine engines, and hypersonic flight vehicles.

High temperature work involving coating technologies also provided solutions to multiple space related issues during the 1960s. The tungsten-silicide coating developed at ML was successfully employed on the second stage engine of the Saturn 1B launch system, and a tin-aluminum coating system successfully protected thrust engines of the Agena target vehicle, leading to the historic first linkup of two orbiting space vehicles. Additional research on ablative materials, including lightweight beryllium heat shields, provided critical technology for manned space reentry capsules, including work on phenolic materials for the heat protection used on the Mercury spacecraft (Fig. 2).

Fig. 2 — (a) Phenolic materials research led to development of the heat shield on the Mercury Spacecraft; (b) high-temperature coatings were also employed on the Saturn 1B launch system.

During the second half of the 1960s, ML invested in pioneering research to improve high temperature materials for turbine engines and hypersonic/supersonic flight. Materials including high strength titanium and improved aluminum alloys were developed and optimized, with results transitioned to numerous flight systems including the SR-71 aircraft. Higher operating temperatures also required research on greases, oils, and hydraulic fluids capable of withstanding the increased weapon system temperatures and improved performance.

Operations in Southeast Asia resulted in severe damage to critical components as a result of the increased speed and performance of aerospace systems. In particular, radomes, antenna covers, wing leading edges, and other structural surfaces were damaged during military operations. To address this issue, ML created elastomeric polyurethanes to provide additional protection for erosion-prone areas. At the same time, they also developed fluorocarbon elastomers and provided thermal flash to protect surfaces during high temperature operations on advanced aircraft. The laboratory moved into its current facilities in the 1980s.

DEVELOPMENTS IN THE 1980s AND 1990s

As sensors and protection devices became more critical in the 1980s and 1990s, ML developed mercury cadmium telluride as a detector material for strategic surveillance and intercept missions (Fig. 3). The material was used extensively in target acquisition and missile guidance. In-house knowledge of high energy radiation interactions also established ML as the dominant international leader in developing protection against laser weapon radiation. The laboratory continues to lead this field, including research on laser-hardened materials to protect satellite and aircraft components, and advanced optics to protect the human eye. Research also developed new and improved radar absorbing materials, which were transitioned to the B-2 bomber and F-117 fighter, as well as critical computer modeling programs designed to provide increased materials casting and deformation capabilities.

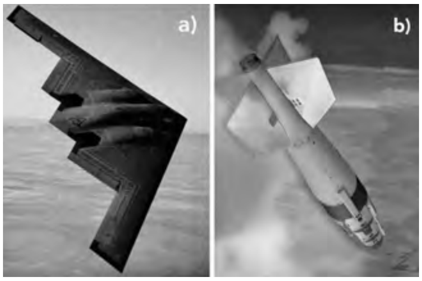

Fig. 3 — a) Advances in radar absorbing materials were transitioned to the B-2 bomber; (b) additional research produced detector materials for use in missile guidance systems.

During the 1980s and 1990s, ML also began extensive research on developing nanotechnology to provide revolutionary advancements in weaponry, providing responsive systems that minimize collateral effects and substantially improve defensive systems. Examples include efficient chemical/biological sensors and lighter-weight armor. Researchers also successfully developed new aluminum-lithium alloys for lightweight structural applications, and high temperature gamma titanium alloys for use in propulsion systems. Considerable advancements in the processing of alpha/beta titanium and precipitation strengthened nickel alloys were successfully transitioned to industry, providing a dramatic increase in materials capabilities. Additional improvements came from development of critical polyimide resins, including the AFR-700-B polymer used on the F-17 trailing edge, and AFR-PE-4 polymer used on turbine engine applications.

Improvements in aluminum structural materials provided new 6092/silicon carbide DRA sheets used for ventral fins on the F-16. The new material increased stiffness by 40%, extending component life by four times and saving $26M in lifecycle costs from reduced maintenance and system downtime. Extruded billet of this material also saved over $100M and improved the resistance to erosion by over seven times when applied to propulsion systems.

In partial response to environmental concerns and growing regulatory restrictions, the 1990s also involved considerable research in replacing hazardous materials. Materials and processes for high velocity oxygen fuel (HVOF) spray systems were optimized to replace cadmium and chrome plating techniques. In addition, multiple coating systems were transitioned, including coating systems that utilize a magnesium rich primer, which are used to replace hazardous chromate coating systems on large aluminum structures. Establishment of the Coatings Technology Integration Office facilitated this research and helped establish ML as a dominant international leader in testing and developing coatings.

RECENT DEVELOPMENTS

The new millennium brought extreme environmental and financial challenges associated with multiple conflicts operating in desert environments. ML responded in part by forming multiple collaborative ML-industry efforts including the Composite Affordability Initiative and the Metals Affordability Initiative (MAI). These programs leveraged commercial and military resources to further accelerate development of new technologies. In particular, they provided tremendous transitions for new materials including thin walled titanium castings for C-17 structures, 718+ nickel alloys for high temperature turbines, Mondaloy nickel alloys for rocket applications, and aluminum beryllium for low density satellite applications and high stiffness optical control structures. The current MAI program continues to provide a vital research link between major equipment manufacturers and government research personnel.

More recent research involves the use of biotechnology to better understand how biological organisms, such as pit viper snakes or melanophilia beetles, sense thermal or infrared energy. Scientists have begun using these biologically inspired systems to develop new materials, including the use of spider silk technology for high strength composite fibers. Further, researchers have successfully developed flexible materials that allow wearers to monitor their physiological response in real time using unique biological sensors. These advances promise to revolutionize personnel assessment capabilities. Flexible electronics and materials have also enabled new solar panel energy technologies and communication devices for satellites and airplanes.

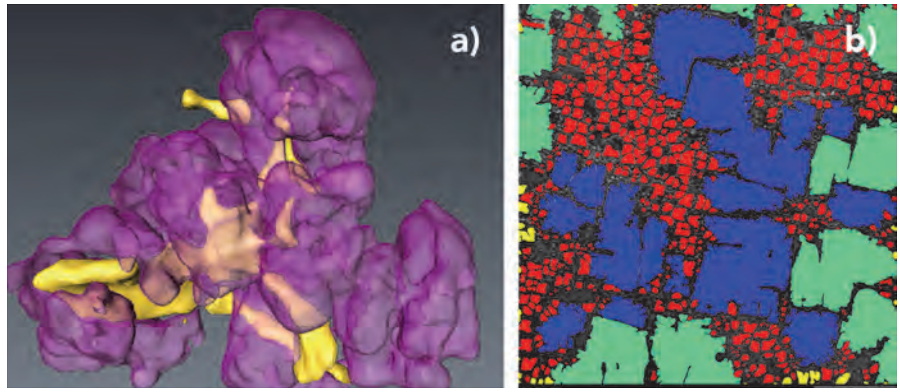

Fig. 4 — Advanced characterization techniques were employed to develop and characterize new microstructures including (a) titanium nitride (yellow) in a graphite matrix (purple), and (b) tertiary γ' evolution in nickel alloys. Different colors represent different structures within each image.

ML is known worldwide for pioneering work on defining the atomic structure of metallic glasses. This fundamental knowledge has accelerated discovery of new bulk metallic glasses and provides a foundation for understanding the unique properties of this class of amorphous materials. ML researchers were the first to use the multi-principle element alloying philosophy to intentionally devise a new family of high entropy alloys (HEAs), based on refractory elements, for high temperature structural materials. Research groups around the world are now studying refractory HEAs and others have followed this lead by defining new HEA families for other applications, including lightweight structural and low cost catalytic varieties.

Many advances in developing complex microstructures have been developed within ML, including work on Mo-Si-B-X alloys for high temperature oxidation applications, metal matrix nanocomposites reinforced with carbon nanotubes and graphite nanoplatelets, titanium carbide reinforced nickel for solid lubricating fracture-resistant composites, and numerous titanium alloys reinforced with boron additions, among others. Two examples are shown in Fig. 4. For example, ML has helped develop and transition oxide/oxide ceramic matrix composites currently in use on turbine engine applications, and high temperature silicon carbide/silicon carbide materials that are nearing certification.

Current research involves precipitation strengthened cobalt alloys for turbine disk applications, improved ceramic and metal matrix composites for potential hypersonic applications, and development and modeling of additive processing techniques, to name a few. Advanced modeling approaches are also being developed to simulate complex microstructure interactions aimed at improving the accuracy of deformation models used to predict mechanical performance and certify new materials for use in aerospace products. For example, Fig. 5 shows a 3D reconstruction

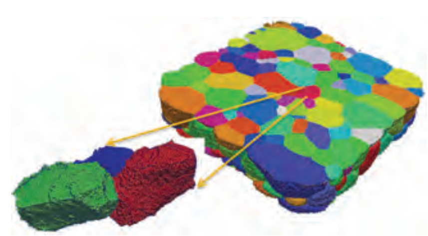

Fig. 5 — 3D reconstruction of metallic material developed using advanced synchrotron techniques to identify individual grains and grain texture information.

of a crystalline material developed for use in crystal plasticity models. Characterization techniques have evolved from standard polishing and imaging processes and serial sectioning techniques to include advanced nondestructive tools such as high energy synchrotron diffraction systems.

SUMMARY

Over the past 100 years, ML researchers have continued a proud legacy of developing and transitioning critical aerospace materials. Although the accomplishments listed here are only briefly detailed, many represent breakthrough advancements in science that have dramatically changed the engineering world.

In addition, ML focuses tremendous resources on the nondestructive evaluation, modeling, characterization, and processing of materials. Every day confirms the belief that discoveries in materials research to date are just the beginning and future breakthroughs will open up limitless materials opportunities. The Air Force Materials Directorate has been—and will continue to be—a vital materials resource for the Air Force and the nation. **~AM&P**

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AFRL SCIENTISTS WIN JACQUET-LUCAS AWARD

The 2016 recipients of the Jacquet-Lucas Award are Vikas Sinha, UES Inc., Sushant Jha, Universal Technology Corp., Adam Pilchak, Reji John, and James Larsen, Air Force Research Laboratory, and William J. Porter, III, University of Dayton Research Institute, for their entry entitled *Quantitative Characterization of Fracture Features in Titanium Alloys.* An abridged version of this article will run in a future issue of *AM&P.* The ASM Metallographic Award was established in 1946 for the best entry in the annual ASM metallographic competition. In 1958, it became known as the Francis F. Lucas Metallographic Award. In 1972, ASM joined with The International Metallographic Society in sponsoring the Pierre Jacquet Gold Medal and the Francis F. Lucas Award for Excellence in Metallography. This award has been endowed by Buehler Ltd. since 1976.

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2017

CONFERENCE AND EXPOSITION

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Plan now to attend the 28th AeroMat Conference and Exposition, the premier aerospace materials conference presented by top leaders in this field. Every year, AeroMat brings together hundreds of aerospace professionals and exhibiting companies to discuss and display the latest advancements in materials and processes for aerospace applications.

With more than 125 presentations on multiple content areas, the technical program of the 2017 conference is one of the top reasons aerospace professionals attend AeroMat. From additive manufacturing and advanced aluminum alloys to integrated computational materials engineering, a wide range of topics will be covered. In addition, daily plenary sessions on the show floor will complement the technical programming and provide attendees with a comprehensive view of the industry.

AEROMAT 2017 SCHEDULE-AT-A-GLANCE

The preliminary schedule included here is subject to change.

Date/Time	Event
Sunday, April 9	
5:00–7:00 p.m.	Registration Open
Monday, April 10	
7:00 a.m.–6:00 p.m.	Registration Open
8:00–10:00 a.m.	Technical Programming
10:00–10:30 a.m.	Refreshment Break
10:30 a.m.–12:00 p.m.	Technical Programming
12:00–1:00 p.m.	Lunch (on own)
1:00–3:00 p.m.	Technical Programming
3:00–3:30 p.m.	Refreshment Break
3:00–7:00 p.m.	Exhibits Open
3:30–5:30 p.m.	Plenary Speakers: Steve Townes and Eric Roegner
5:30–7:00 p.m.	EXPO Networking Reception
Tuesday, April 11	
7:00 a.m.–5:00 p.m.	Registration Open
8:00–10:00 a.m.	Technical Programming
10:00–10:30 a.m.	Refreshment Break
10:00 a.m.–3:30 p.m.	Exhibits Open
10:30 a.m.–12:00 p.m.	Plenary Speakers: Mac Louthan and Kathryn Cook

Date/Time	Event
12:00–1:00 p.m.	Lunch on Exhibit Floor
1:00–3:00 p.m.	Technical Programming
3:00–3:30 p.m.	Refreshment Break
3:30–5:30 p.m.	Technical Programming
7:00–9:30 p.m.	Social Event – USS Yorktown at Patriots Point (transportation included)
Wednesday, April 12	
7:00 a.m.–1:00 p.m.	Registration Open
8:00–10:00 a.m.	Technical Programming
9:00 a.m.–1:00 p.m.	Exhibits Open
10:00–10:30 a.m.	Refreshment Break
10:30 a.m.–12:00 p.m.	Plenary Speakers: Sheila Sharpe and Peter Liaw
12:00–1:00 p.m.	Lunch on Exhibit Floor
1:00–5:00 p.m.	Technical Programming
3:00–3:30 p.m.	Refreshment Break
Thursday, April 13	
8:30 a.m.–12:00 p.m.	Additive Manufacturing Short Course
8:30 a.m.–4:00 p.m.	Titanium Alloys Short Course

PLENARY SPEAKERS

Monday, April 10

Steve Townes
Chairman, SC Aerospace and CEO, Ranger Aerospace LLC
3:30–4:30 p.m.

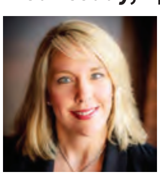
Eric Roegner
Chief Operating Officer, Investment Castings, Arconic Titanium and Engineered Products
President, Arconic Defense
4:30–5:30 p.m.

Tuesday, April 11

Mac Louthan
Savannah River National Laboratory
10:30–11:15 a.m.

Kathryn Cook
Technical Program Manager, Facebook
11:15 a.m.–12:00 p.m.

Wednesday, April 12



Sheila Sharp
Space Launch System, Senior Manager Systems Engineering, Integration & Test, Boeing
10:30–11:15 a.m.

Peter Liaw
Professor, University of Tennessee
11:15 a.m.–12:00 p.m.

EDUCATION SHORT COURSES

Two education short courses will be offered on Thursday, April 13.

Additive Manufacturing
Instructor: Frank Medina
8:30 a.m.–12:00 p.m.

This course deals with various aspects of additive, subtractive, and joining processes to form 3D parts with applications ranging from prototyping to production. Attendees will learn about a variety of AM and other manufacturing technologies, including their advantages and disadvantages for producing both prototypes and production-quality parts. Some of the most important challenges associated with using these technologies will also be covered.

Titanium Alloys
Instructor: Rod Boyer
8:30 a.m.–4:30 p.m.

Titanium and its alloys are a versatile family of metals with applications in many industries. They feature high strength-to-weight ratios, excellent corrosion resistance, and high and low temperature capabilities. Further, they also exhibit compatibility with graphite fibers, which is gaining importance with increased utilization of composites in aircraft structures. This unique combination of physical, mechanical, and chemical properties makes them attractive for aerospace, marine, industrial, biomedical, and other applications. This course provides an overview of titanium alloy processing, from refining ore to machining hardware, and explores how the unique properties of titanium drive applications in various industries.

NETWORKING EVENT

Tuesday, April 11 - 7:00–9:30 p.m.

Attendees will enjoy dinner and entertainment aboard the USS Yorktown at Patriots Point. Transportation is included from the Embassy Suites Hotel.

USS Yorktown

The Charleston Convention Center is conveniently located just two miles from the airport and only minutes away from historic downtown Charleston.

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Solar Manufacturing
SPECTRO Analytical Instruments
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SUGINO
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Wickert Hydraulic Presses USA

Note: Exhibitor list current as of February 1.

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THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

THERMAL SPRAY COATINGS IN AEROSPACE APPLICATIONS

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THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

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EDITORIAL OPPORTUNITIES FOR iTSSe IN 2017

The editorial focus for *iTSSe* in 2017 reflects established applications of thermal spray technology such as power generation and transportation, as well as new applications representing the latest opportunities for coatings and surface engineering.

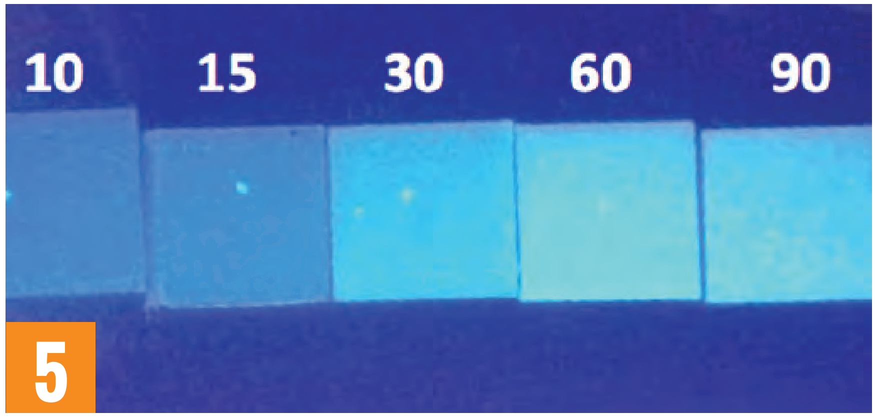
May: Energy & Power Generation

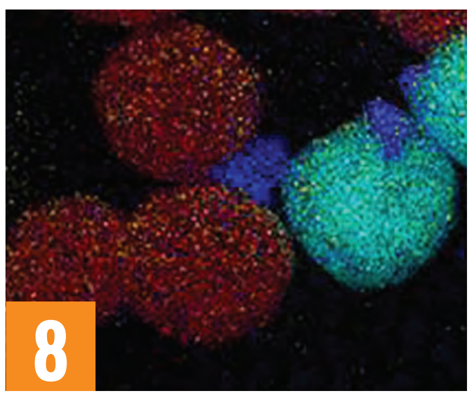
August: Automotive & Industrial Applications

November: Emerging Technologies/Applications & Case Studies

To contribute an article, contact Frances Richards at frances.richards@asminternational.org.

To advertise, contact Erik Klingerman, at erik.klingerman@asminternational.org.





DEPARTMENTS

ABOUT THE COVER

Surface sensitive analytical techniques are imperative for understanding coating degradation. On the cover is a Theta Probe spectrometer used to record x-ray photoelectron spectroscopy (XPS). XPS helps facilitate monitoring of degradative changes, which occur as a function of UV and UV/ozone exposure. Courtesy of Thermo Scientific.

iTSSe | iTSS

EDITORIAL

ITSC 2017 PROMISES THE STARS AND MORE


Kroemmer

The International Thermal Spray Conference and Exposition 2017 (ITSC) is taking place in Düsseldorf, Germany, during June 7-9—now back in Europe after three years. This annual event provides an excellent opportunity for the thermal spray community to meet, exchange information, and conduct business. The program committee did a great job of ensuring that the latest research and development is included to ensure a high level of technical content. In addition, an industrial forum will include presentations from industry about new hardware and product applications. Along with a three-day exhibition and poster session, a comprehensive overview of the field of thermal spray will be presented. The conference will take place at the CCD Congress Centre Düsseldorf, situated on the banks of the Rhine and linked to the Messe Düsseldorf exhibition center. The theme of ITSC 2017 is "Thermal Spray Paves the Way to the Stars."

Conferences such as ITSC are the best way to get up to speed and ensure that our technology remains state of the art and that we continue to work on a competitive basis. This is not only important for company owners, but for everyone developing a technology and looking for new application possibilities. The fact that attendees, presenters, and exhibitors from all over the world participate makes it the best way to share information and enlarge the global market.

Thermal spray is still a growing technology that is able to spur interest in new industrial areas. Automation, productivity, and safety have been key factors over the past few years. New equipment needs to fulfill all of these requirements along with online documentation and process monitoring. Big steps have already been taken in this direction on the equipment side, but now industry needs to carefully plan its investments in order to integrate these developments into production. These issues are key to maintaining interest in our technology and taking it to the next level. In this way, we can create a workplace in which highly trained and motivated employees want to participate.

I'm looking forward to seeing everyone at ITSC—and meeting both well-known and new colleagues. As with all ITSCs, 2017 promises to be an unforgettable event, especially with GTS e.V., the Association of Thermal Sprayers, celebrating its 25th anniversary.

Werner Kroemmer
Linde AG

TSS NAMES COMMITTEE CHAIRS FOR 2016-2017 TERM

The ASM Thermal Spray Society (TSS) board appointed chairs to each of its committees for the 2016-2017 term. **Douglas Puerta,** Portland, Ore., was elected president. **Christian Moreau, FASM, TS-HoF,** Concordia University, Montreal, currently serves as immediate past president and chair of the Nominating Committee. **Richard Chromik,** McGill University, Montreal, continues as chair of the Accepted Practices Committee. **Bob Unger,** Polymet Corp., West Chester, Ohio, was named chair of the Awards Committee. **Shari Fowler-Hutchinson,** Saint-Gobain, Worcester, Mass., serves as chair of the Exposition Committee. **Robert Vassen,** Forschungszentrum Jülich GmbH, Germany, was named chair of the Journal of Thermal Spray Technology Committee and **Jose Colmenares-Angulo** was named chair of the Membership, Marketing and Outreach Committee. **André McDonald,** University of Alberta, Canada, serves as vice president of TSS and chair of the TSS Program Committee. **Fardad Azarmi,** North Dakota State University, Fargo, continues as chair of the TSS Training Committee. If you are interested in serving on an affiliate society committee, contact the respective committee chair or email joanne.miller@asminternational.org.


Puerta


Moreau


Chromik


Unger


Fowler-Hutchinson


Vassen


Colmenares-Angulo


McDonald


Azarmi

THERMAL SPRAY SOCIETY INDUCTS TWO INTO THERMAL SPRAY HALL OF FAME

Two professors and researchers in thermal spray technology will be inducted into the Thermal Spray Hall of Fame in June 2017 at ITSC in Düsseldorf, Germany. The 2017 inductees are:

Robert Vassen, section head, Forschungszentrum Jülich GmbH, Germany, is being recognized "for thermal spray developments for applications in solid oxide fuel cell materials and thermal barrier coatings for gas turbines, as well as mentoring and training of highly skilled professionals."

Petri Vuoristo, FASM, professor, Tampere University of Technology, Finland, is cited "for long-term contributions for the advancement of TS and related deposition technologies through worldwide education and practice."


Vassen


Vuoristo

TSS BOARD SEEKS STUDENT MEMBERS

TSS is seeking applicants for two student board member positions. Nominations are due **April 1.** Students must be a registered undergraduate or graduate during the 2016-2017 academic year and must be studying or involved in research in an area closely related to the field of thermal spray technology. For more information on eligibility and benefits, visit tss.asminternational.org.

KAY HONORED AT AKRON CHAPTER MEETING

Albert Kay, FASM, president, ASB Industries, Barberton, Ohio, was a 2016 recipient of ASM's Distinguished Life Member Award "in recognition of outstanding innovation and early commercialization of emerging thermal spray technologies including high velocity oxy fuel and cold spray; exemplary development of a business model that gained worldwide recognition; and for dedication and unselfishness, unstinting personal effort, and leadership on behalf of the Thermal Spray Society and ASM International." Unable to attend the awards ceremony at MS&T in Salt Lake City, Kay was presented his award by ASM Trustee Roger Jones, during an Akron Chapter meeting in November 2016. Many staff members from ASB Industries were on hand to see their company president honored.


Albert Kay (seated) is surrounded by ASB staff members after receiving the ASM Distinguished Life Member Award.

HYPERACCELERATED DEGRADATION OF AN AEROSPACE COATING

A promising method of testing aerospace coatings could help minimize exposure to hexavalent chromium by understanding coating lifecycles.

Taraneh Bozorgzad Moghim, Marie-Laure Abel, and John F. Watts
University of Surrey, UK

Aerospace coatings are the first form of protection against the extreme environments an aircraft is subjected to. Therefore, a coating must maintain high performance properties throughout its lifetime. A great deal of research is taking place into the replacement of hexavalent chromium—Cr(VI)—a carcinogen currently used within primers and as part of the pretreatment for a coating substrate due to its highly effective anticorrosive and adhesive properties. To minimize exposure to Cr(VI), preventing topcoat degradation should also be a priority. Measures taken to prolong topcoat lifetime or identify when the topcoat is failing will aid in reducing the risks imposed by Cr(VI). However, two main issues must first be resolved. One is determining the degradation mechanism at the molecular scale. This is essential in order to establish the topcoat's failure point. The other is monitoring the topcoat in order to establish where the coating is in its functional lifetime and whether measures should be put in place to aid functionality. This kind of large-scale monitoring requires a simple, cost effective, and nondestructive technique.

First, in order to understand the degradation phenomena, it is essential to examine the interface between the topcoat and the environment. The main causes of degradation include high humidity, extreme temperatures, and UV radiation, which is an acute cause. Many well established testing methods exist within the coatings industry as a means of comparing coatings and meeting application requirements. These include natural exposure and accelerated testing methods such as exposure within a QUV chamber, prohesion chamber, and temperature cycling. However, these methods often require months or even years of exposure to observe degradative effects. Further, as an aircraft crosses the tropopause the level of ozone it is exposed to rises significantly, an issue seldom addressed in the literature but that could play a vital role in determining an aerospace coating's failure mechanism. With this in mind, a novel coating test method called HyperTest was developed, which combines UV and ozone—a technique traditionally used for secondary electron microscopy sample preparation.

The device requires the sample to be placed within a vacuum chamber and then uses a UV lamp light source at wavelengths (λ) of 185 and 254 nm to irradiate the topcoat surface. The long wavelength is also able to photodissociate molecular oxygen into atomic oxygen, which is then able to form ozone. The short wavelength penetrates the coating surface creating

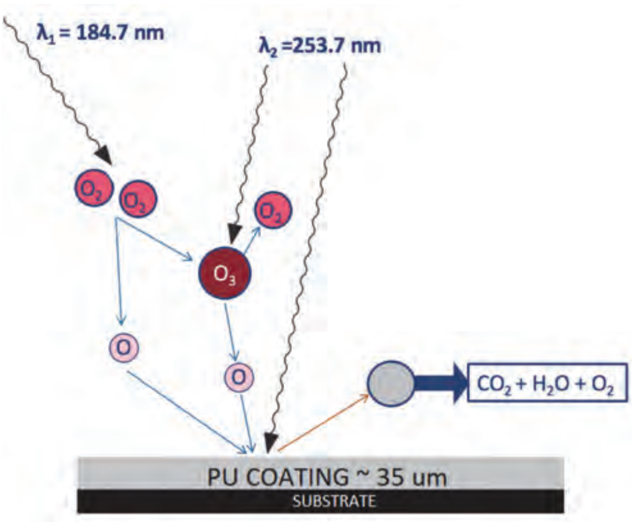


Fig. 1 — Schematic detailing the functionality of the HyperTest method using UV/ozone.

excited molecules or free radicals, which are able to react with ozone to form simple volatile molecules that are released by the vacuum (Fig. 1). Through analysis of the topcoat of the UV/ozone exposed samples, as detailed here, the HyperTest method proves to be hyperaccelerating when compared to samples treated with UV within a QUV chamber.

ANALYZING COATING FAILURES

Surface sensitive analytical techniques are imperative for understanding degradation phenomena. Determining changes occurring to the topcoat surface, particularly during initial degradation, can aid development of a degradation mechanism and subsequently allow identification of the coating's failure point. The main analytical techniques applied in this research include time of flight secondary ion mass spectrometry (ToF-SIMS) and x-ray photoelectron spectroscopy (XPS), recorded using a Theta Probe spectrometer (Fig. 2). ToF-SIMS provides a significant level of elemental and molecular detail of the upper monolayer of the surface, enabling identification of degradation products. XPS is also a highly surface-sensitive technique, offering chemical state information and enabling quantitative analysis. XPS helps facilitate monitoring of degradative changes, which occur as a function of UV and UV/ozone exposure.

Fig. 2 — XPS Theta Probe.

The XPS survey spectrum details all the elements present at their respective binding energies (BE). From Fig. 3a, it is apparent that with no exposure, carbon, oxygen, and nitrogen are dominant, which is to be expected from a polyurethane (PU) base topcoat. After 56 days of exposure to UV, very little change is evident (Fig. 3b). However, after 120 minutes of UV/ozone exposure, the survey spectrum (Fig. 3c) shows a significant rise in inorganic components. These are representative of the filler and pigmentation present within the coating. Observing such a significant increase of inorganic components at the surface suggests the PU has degraded to reveal the bulk inorganic components. However, by comparing the organic components, changes occurring to the PU can be understood and the two testing methods can be compared, overriding the differing time scales.

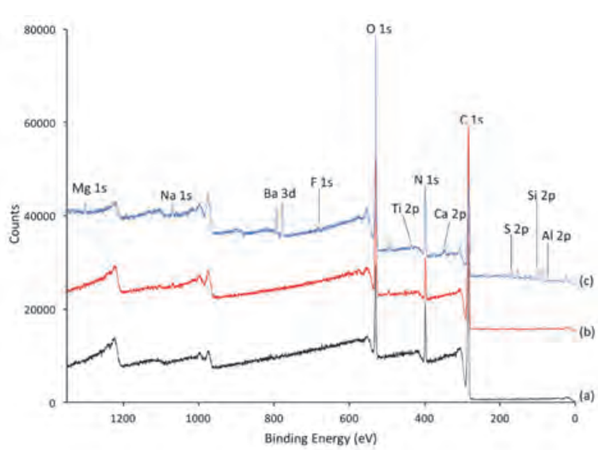


Fig. 3 — XPS survey spectra of (a) unexposed topcoat, (b) UV exposed for 56 days, and (c) UV/ozone exposed for 120 minutes..

Figure 4 shows that with increasing UV/ozone exposure, relative amounts of nitrogen and oxygen generally increase with decreasing carbon. However, with UV exposure from 2 to 56 days there is no clear trend, with data points clustering around the 1-2 minute marks of UV/ozone. This suggests that 56 days within the QUV chamber equates to 1-2 minutes of the HyperTest method. Additionally, the high-resolution spectrum of the carbon 1s peak exhibits a rise in the carbonyl component at BE 288.2 eV and a drop in the aliphatic carbon at BE 285.0 eV suggesting the oxidation of the topcoat with UV/ozone exposure (Fig. 5a). In contrast, after 56 days of UV exposure, the C 1s spectrum (Fig. 5b) resembles that of an unexposed topcoat (Fig. 5c). The additional detail that can be provided by ToF-SIMS, although complex, is vital in aiding a more detailed mechanistic understanding. By examining the organic peaks of the spectra and putting them through principle component analysis (PCA), it was possible to ascertain dominant peaks that increased with increasing UV/ozone exposure, thus enabling identification of the azo compound, a product of degradation.

Unifying all of the detailed analysis enables a comprehensive understanding of chemical changes occurring to the coating upon UV/ozone exposure. It is proposed that UV radiation is able to penetrate the coating and break the weakest bond of the PU backbone through chain scission. This creates free radicals that further decompose, forming amino radicals that react to form the azo product, while additionally forming simple volatile molecules such as CO_2. The presence of ozone accelerates this process by providing a greater flux of oxygen to oxidize the surface, thereby creating an etching effect.

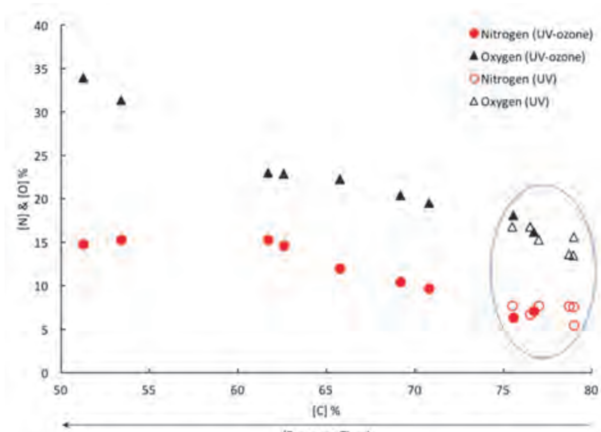


Fig. 4 — Relative concentrations of oxygen (triangular) and nitrogen (circular) against the relative concentration of carbon for UV exposed samples and UV/ozone exposed samples. Increasing exposure time is suggested from right to left along the x axis.

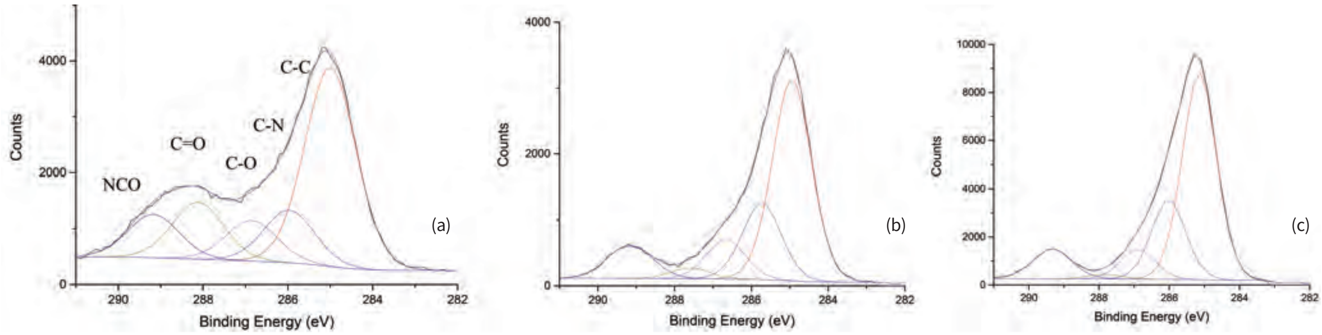


Fig. 5 — Carbon 1s high resolution spectra of (a) UV/ozone exposed for 120 minutes, (b) UV exposed for 56 days, and (c) unexposed topcoat.

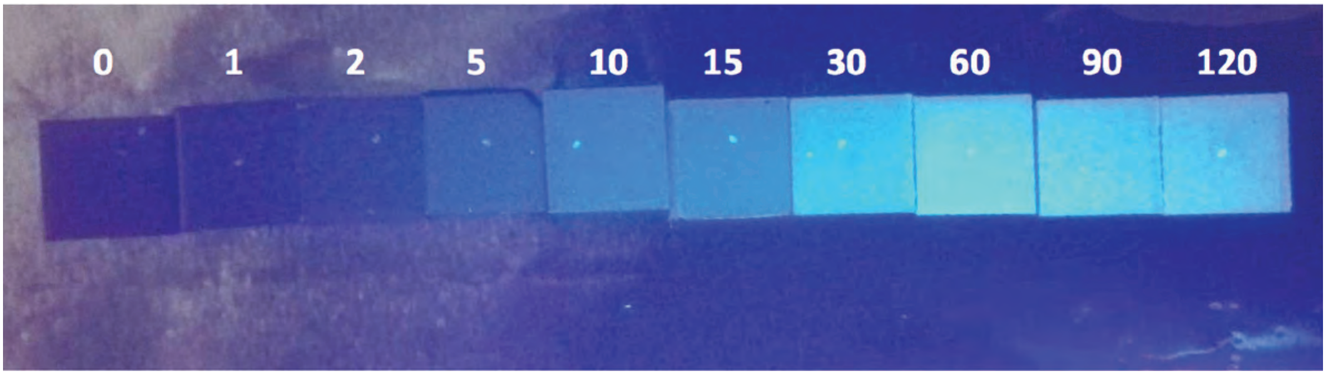


Fig. 6 — UV lamp irradiated samples exposed to UV/ozone from 0 to 120 minutes.

SUMMARY

Through this study, it was possible to identify both the degradation product and the increase in the carbonyl components. However, monitoring changes to the topcoat on a mass scale is a greater challenge. Due to the nature of the changes, a UV lamp was used to irradiate the samples to examine if changes to the fluorescence could be observed. Figure 6 depicts drastic changes to the fluorescence with increasing exposure time. Using the luminescence values of the images provides an isolated degradation scale, which could be used as a way of assessing coating lifetime. HyperTest has proven to be a highly efficient way of testing topcoat degradation and UV irradiation is a seemingly simple, cost effective way of monitoring the topcoat used within this study. Nevertheless, more research is currently being undertaken to explore the possibilities of this technique and its potential for wider application. **~iTSSe**

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Reference

T.B. Moghim, et al., A Novel Approach to the Assessment of Aerospace Coatings Degradation: The Hypertest, *Prog. Org. Coat.*, http://dx.doi.org/10.1016/j.porgcoat.2016.11.008.

COLD SPRAY: ADVANCED CHARACTERIZATION METHODS—SCANNING ELECTRON MICROSCOPY

This article series explores the indispensable role of characterization in the development of cold spray coatings and illustrates some of the common processes used during coatings development.

Dheepa Srinivasan, GE Power, GE India Technology Center, Bangalore

Scanning electron microscopes are often used to view features that exceed the resolution of optical microscopes. Images can be magnified up to 100,000 times and typically require only minimal sample preparation. Several key aspects of scanning electron microscopy (SEM) distinguish it from other analytical techniques, including the equipment's depth of field and the ability to obtain chemical composition information using energy-dispersive x-ray spectroscopy (EDS) or wavelength-dispersive spectroscopy (WDS).

The microscope has a lateral resolution of 1 to 50 nm in the secondary electron mode. EDS provides rapid multi-element analysis for Z > 11, with a detection limit of ~200 ppm. WDS is based on the phenomenon of Bragg diffraction of x-rays incident on a crystal and yields a more precise quantitative estimate of elements. SEM is uniquely able to image in both secondary electron (SE) mode and backscattered electron (BE) mode. Figure 1 shows a comparison of EDS and WDS spectra from a complex multi-element glass.

In cold spray characterization, SEM analyzes feedstock powders for particle size, distribution, shape, and chemical composition prior to spraying. Figures 2 (a) and (b) show representative scanning electron micrographs with two types of WC-Co feedstock powders used for cold spray, with an acicular and a spherical shape. SEM is used prior to spray to assess powder cross-section (Fig. 2 c, d) and particle size distribution (Fig. 2 e, f).

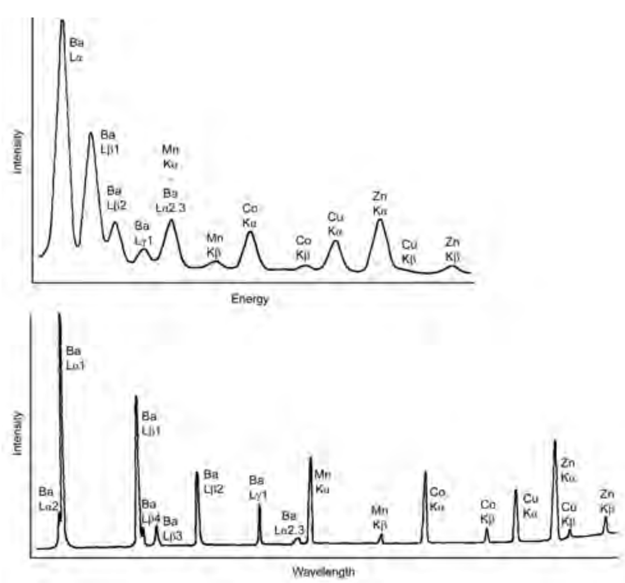


Fig. 1 — Comparison of EDS and WDS spectra from a complex multi-element glass.

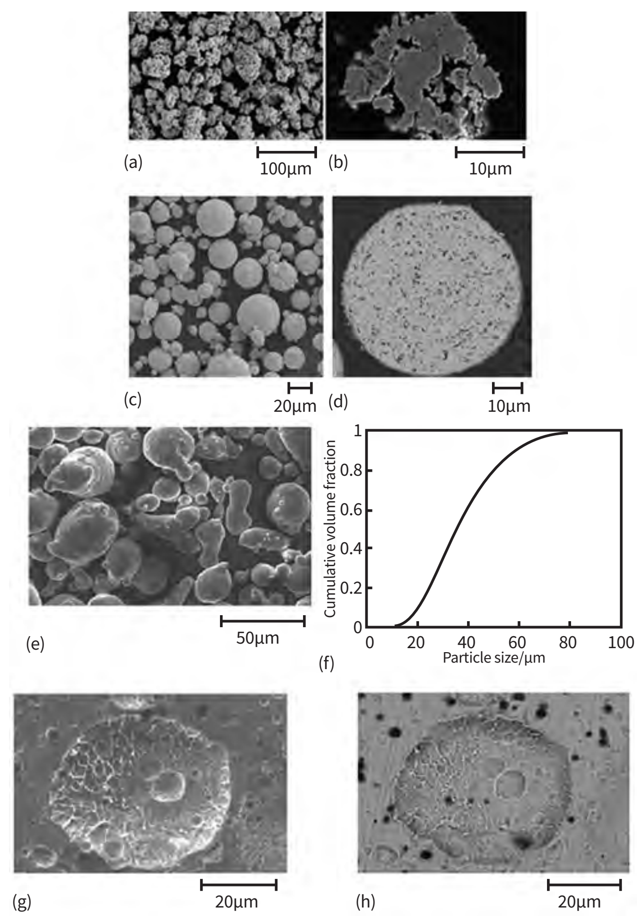


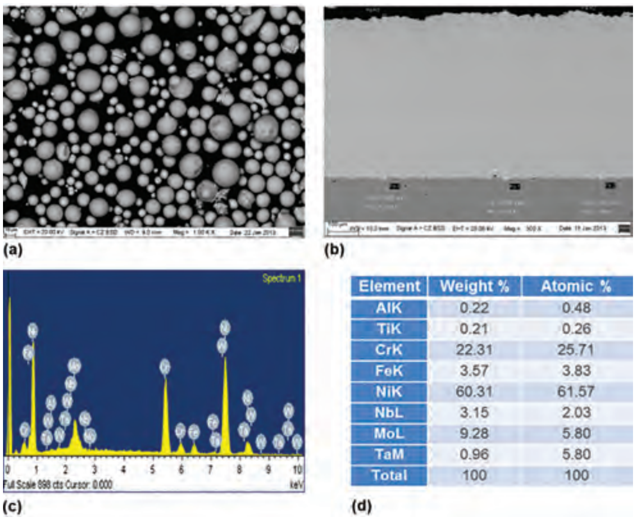
Fig. 2 — SEMs show powder morphology and cross-sectional structure from: (a, b) two different feedstocks of WC-Co powders, (c, d) powder cross-section, (e) morphology and (f) size distribution of aluminum feedstock powder, and (g, h) secondary electron image and backscattered image of an aluminum coating.

Imaging can be done in either the SE or BE mode, as shown in Fig. 2 (g) and (h), respectively, taken from an aluminum coating. SE imaging typically reveals topography, while

BE imaging reveals atomic number contrast to illustrate coating phases. Spray angle and deposition efficiency effects are analyzed using SEM microstructures of etched samples. For example, nozzle erosion sometimes occurs during cold spray, especially for hard materials such as MCrAlY or Inconel powders. The eroded material could end up embedded in the coating and distinguished as an artifact.

SEM is used extensively to characterize coating chemistry via EDS. Figures 3 (a) to (d) show SEM micrographs of IN625 feedstock powders and a cold spray coating, along with the corresponding energy-dispersive x-ray analysis pattern from the powder, and coating chemistry. Elemental mapping is often done on powders prior to spray in order to evaluate the level of segregation in the chemistry, as shown in Fig. 4 (a) to (d) on two types of MCrAlY powders. Coating porosity characterization provides feedback to achieve optimum thickness for a dense coating (Fig. 5) such as titanium. Coating porosity evolution with different feedstock powders and powder surface topography is also shown in Fig. 5.

Coating thickness and interface contour can be characterized in a manner that makes SEM an indispensable and versatile tool for evaluating coating integrity in the as-sprayed condition, as well as in developing an understanding of bonding to the substrate. Substrate hardness helps achieve good coating deposition. Figures 6 (a) and (b) show the interface of a



Element	Weight %	Atomic %
AlK	0.22	0.48
TiK	0.21	0.26
CrK	22.31	25.71
FeK	3.57	3.83
NiK	60.31	61.57
NbL	3.15	2.03
MoL	9.28	5.80
TaM	0.96	5.80
Total	100	100

Fig. 3 — SEMs show: (a) IN625 powder morphology and (b) as-sprayed coating, and (c) energy-dispersive x-ray analysis pattern and (d) listing of the elements from the spectrum in the coating.

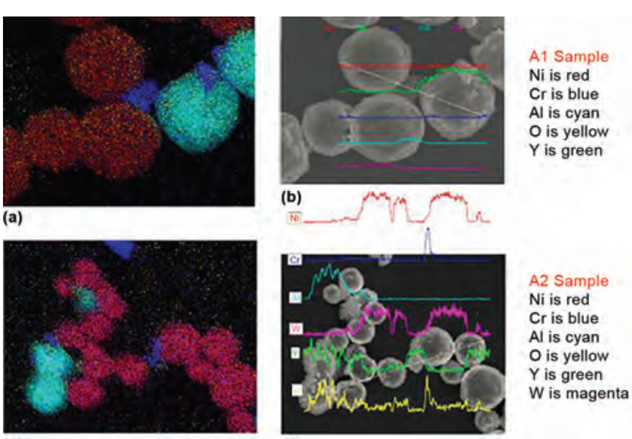


Fig. 4 — Energy-dispersive x-ray analysis mapping along with SEMs taken from an MCrAlY cold spray coating illustrate elemental segregation in the powders: (a, b) Powder type A and (c, d) Powder type B.

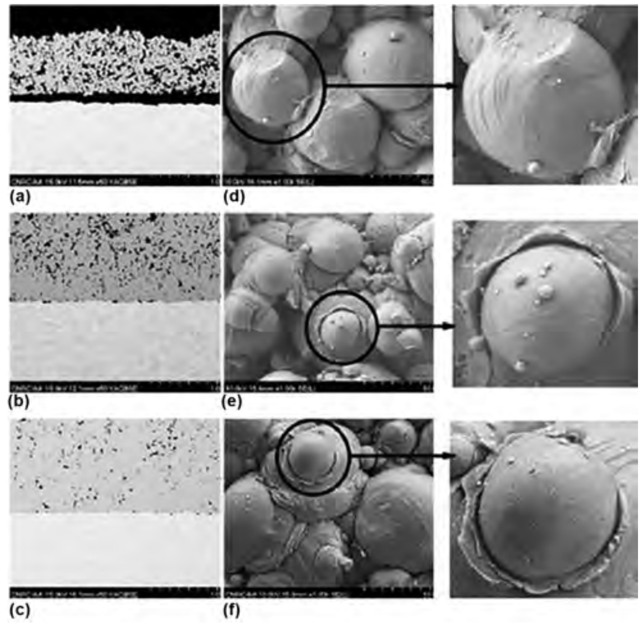


Fig. 5 — SEMs show powder morphology and cross-sectional structure from two different feedstocks of WC-Co powder.

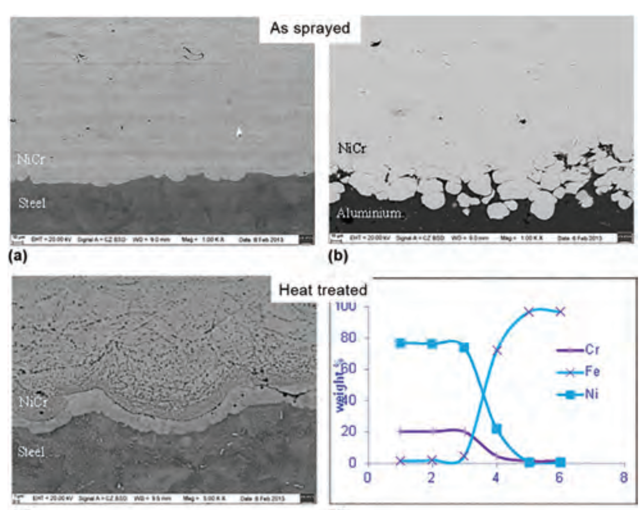
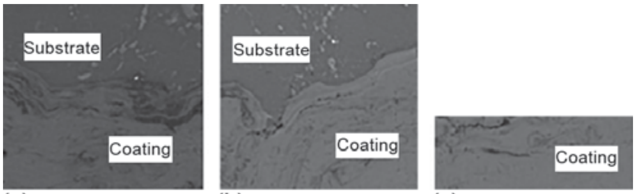


Fig. 6 — SEMs from a NiCr cold spray coating (using helium gas) on (a) AISI 4130 steel, (b) aluminum substrate, and (c) coating-substrate interface after heat treatment, revealing an interdiffusion zone; (d) composition across the interface taken by EDS.



(a) (b) (c)

Fig. 7 — SEMs of aluminum cold spray coating on magnesium substrate: (a) without heat treatment, air cooled; (b) 250°C (480°F), 1 h holding time, air cooled; (c) 300°C (570°F), 1 h holding time, air cooled.

Ni-20Cr coating on an AISI 4130 steel versus an aluminum substrate. The softer aluminum substrate does not provide any resistance to the particles that impinge on it at high velocity, as shown by the first layer of particles, which undergo little or no deformation (Fig. 6 b), compared to the steel substrate (Fig. 6 a). In each case, upon heat treatment, a thin diffusion layer forms along the interface, as shown in the scanning electron micrograph in Fig. 6 (c). The nature of the interdiffusion layer is established by EDS analysis of the chemistry, as shown in Fig. 6 (d). Similarly, SEM is also used extensively to study the intersplat coating characteristics in the as-sprayed versus heat treated condition, as shown in Fig. 7 (a) to (c). **~iTSSe**

For more information: Dheepa Srinivasan is a principal engineer at GE Power, GE India Technology Center, Bangalore, dheepa.srinivasan@ge.com, www.ge.com. This article series is adapted from *Chapter 5, Cold Spray—Advanced Characterization,* in High Pressure Cold Spray—Principles and Applications, edited by Charles M. Kay and J. Karthikeyan (ASM, 2016).

INTERNATIONAL THERMAL SPRAY CONFERENCE AND EXPOSITION 2017

June 7-9, Düsseldorf, Germany

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TSS Thermal Spray Society ASM INTERNATIONAL

Plan now to attend the 2017 International Thermal Spray Conference and Exposition (ITSC), the premier annual event for the global thermal spray community to meet, exchange information, and conduct business. This outstanding conference presents the latest advancements in application, research, and development in the field of thermal spray. The theme of ITSC 2017 is *Thermal Spray Paves the Way to the Stars.* To complement the technical program, a three-day exhibition, featuring an industrial forum as well as a poster session, will take place.

The conference will be held at the CCD Congress Center Düsseldorf, which is set on the banks of the Rhine River and linked to the Messe Düsseldorf exhibition center. Düsseldorf is located in western Germany and is known for its fashion industry and art scene. It is divided by the Rhine, with its Altstadt (Old Town) on the east bank and modern commercial areas to the west.

CONFERENCE HIGHLIGHTS

Comprehensive Technical Programming

Wednesday, June 7 through Thursday, June 9

Attendees will learn about the latest research and development in their field while gaining a global perspective from leading scientists and engineers from around the world.

Young Professionals Session • Wednesday, June 7 • 3:40 p.m.

This session features the ITSC Best Paper Awards, the René Wassserman Prize, as well as the Oerlikon Metco Young Professional Award.

Exhibitor Reception • Wednesday, June 7 • 5:40 p.m.

All registrants are invited for appetizers and beverages.

Networking Event • Thursday, June 8 • 7:30 p.m.

Each year, ITSC offers a wide variety of networking opportunities for attendees and exhibitors. This year, the conference features a barbecue in Düsseldorf's Football Arena. Enjoy food, drinks, and music while the TSS Hall of Fame, TSS President's Award, the JTST Best Paper Award are presented. Included with complete registration.

Show Floor • Wednesday, June 7 through Friday, June 9

The ITSC show floor offers an unparalleled exposition featuring the world's largest gathering of thermal spray equipment suppliers, consumable and accessory suppliers, vendors, and service providers. Visitors will find information about equipment for thermal spray, research and specialist institutes, applied research, and the latest innovations conveniently located in one venue.

Industrial Forum • Thursday, June 8 • 9:00 a.m. – 5:00 p.m.

The forum takes place at the CCD Congress Center Düsseldorf, Stadthalle, Hall 12. Invited companies will give presentations on industry-related topics and products during conference and exposition hours. All talks are given in English and limited to 20 minutes including questions and answers. Visit www.dvs-ev/itsc2017 for more information.

EXHIBITION HOURS*

Wednesday, June 7 • 12:00 – 6:00 p.m.

Thursday, June 8 • 9:00 a.m. – 6:00 p.m.

Friday, June 9 • 9:00 a.m. – 4:00 p.m.

**Exposition hours are subject to change.*

EXHIBITOR LIST*

Company
Air Products AMT AG
ARTEC S.p.A. I Turbocoating S.p.A.
Beijing United Coatings
BGRIMM Advanced Materials Science & Technology Co. Ltd.
C&M Technologies GmbH
Chengdu Huarui Co. Ltd.
Coherent (Deutschland) GmbH
DeWAL Industries Inc.
Diamant Metallplastic GmbH
Eastcoat Oberflachentechnologie
Castolin Eutectic
Flame Spray Technologies BV
Fraunhofer Institut für Werkstoff- und Strahltechnik (IWF)
Fujimi Inc.
Global Tungsten & Powder Corp.
Grillo-Werke AG
GSI - Gesellschaft für Schweisstechnik International mbH NL SLV München
GTS - Gemeinschaft Thermisches Spritzen e. V.
GTV Verschleissschutz GmbH
H.C. Starck GmbH
Hoganas Sweden AB
IBEDA Sicherheitsgerate & Gastechnik GmbH & Co. KG
Imerys Fused Minerals Murg GmbH
Impact Innovations GmbH

Company
Kermetico Inc.
Linde AG, Gases Division
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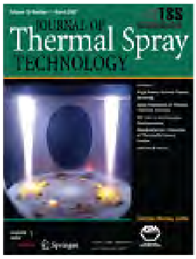
MBN Nanomaterialia S.p.A.
Metallizing Equipment Co. Pvt. Ltd.
Millidyne Oy
Mogul Metallizing GmbH Northwest
Mettech Corp.
Oerlikon Metco AG
OSEIR Ltd.
Polymet Corp.
Praxair Surface Technologies
Saint Gobain
Seram Coatings AS
Sewon Hardfacing Co. Ltd.
SMS Group GmbH
TECNAR Automation Ltd.
Thermal Spray Centre (CPT)
Thermico GmbH & Co. KG
Treibacher Industrie AG
TSS/ASM International, DVS
Wall Colmonoy Ltd.
Wisdom Consumables
Zierhut Messtechnik GmbH

**Exhibitor list current as of January 10, 2017.*



The *Journal of Thermal Spray Technology (JTST),* the official journal of the ASM Thermal Spray Society, publishes contributions on all aspects—fundamental and practical—of thermal spray science, including processes, feedstock manufacture, testing, and characterization. As the primary vehicle for thermal spray information transfer, its mission is to synergize the rapidly advancing thermal spray industry and related industries by presenting research and development efforts leading to advancements in implementable engineering applications of the technology. Articles from the January issue, as selected by *JTST* Editor-in-Chief Armelle Vardelle, are highlighted here. This issue will feature papers based on presentations at ITSC 2016. In addition to the print publication, *JTST* is available online through springerlink.com. For more information, visit asminternational.org/tss.

THERMAL CYCLING BEHAVIOR OF QUASI-COLUMNAR YSZ COATINGS DEPOSITED BY PS-PVD

Jiasheng Yang, Huayu Zhao, Xinghua Zhong, Fang Shao, Chenguang Liu, Yin Zhuang, Jinxing Ni, and Shunyan Tao

Columnar-structured thermal barrier coatings, due to their high strain tolerance, are expected to substantially extend turbine lives and improve engine efficiencies. In this paper, a plasma spray-physical vapor deposition (PS-PVD) process was used to deposit yttria partially stabilized zirconia (YSZ) coatings with quasi-columnar structures. Thermal cyclic tests on burner rigs and thermal shock tests using a heating and water-quenching method were applied to evaluate the thermal cycling and thermal shock behaviors of structured thermal barrier coatings (TBCs). Evolution of the microstructures, phase composition, residual stresses, and failure behaviors of quasi-columnar YSZ coatings before and after thermal tests was investigated. The quasi-columnar coating obtained had an average life of around 623 cycles when the spallation area reached about 10% of the total coating surface during burner rig tests with the coating surface temperature of ~1250°C. Failure of the coating is mainly due to the break and pullout of center columnar segments (Fig. 1).

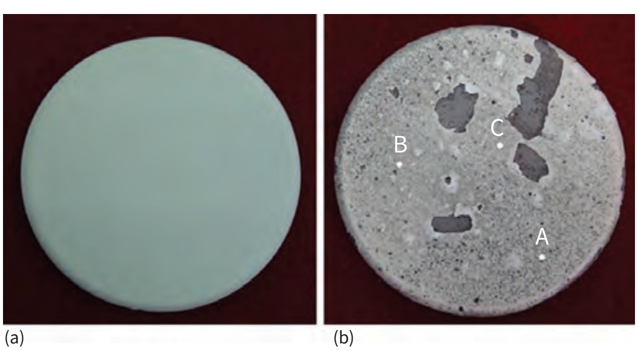


Fig. 1 — Photographs of YSZ TBCs (a) before and (b) after thermal cycling for 623 cycles.

HOT CORROSION MECHANISM IN MULTILAYER SUSPENSION PLASMA SPRAYED GD2ZR2O7/ YSZ THERMAL BARRIER COATINGS IN THE PRESENCE OF V_2O_5 + NA_2SO_4

Krishna Praveen Jonnalagadda, Satyapal Mahade, Nicholas Curry, Xin-Hai Li, Nicolaie Markocsan, Per Nylén, Stefan Björklund, and Ru Lin Peng

This study investigates corrosion resistance of two-layer $Gd_2Zr_2O_7$/YSZ, three-layer dense $Gd_2Zr_2O_7$/ $Gd_2Z_{r2}O_7$/ YSZ, and a reference single-layer YSZ coating with a similar overall top coat thickness of 300-320 µm. All coatings were manufactured by suspension plasma spraying resulting in a columnar structure except for the dense layer. Corrosion tests were conducted at 900°C for 8 h using V_2O_5 and Na_2SO_4 as corrosive salts at a concentration of approximately 4 mg/cm^2. SEM investigations after the corrosion tests show that $Gd_2Zr_2O_7$-based coatings exhibited lower reactivity with the corrosive salts and the formation of gadolinium vanadate ($GdVO_4$) accompanied by the phase transformation of zirconia was observed. It is believed that the $GdVO_4$ formation between the columns reduced the strain tolerance of the coating. Further, due to the fact that $Gd_2Zr_2O_7$ has a lower fracture toughness value, this made it more susceptible to corrosion-induced damage. In addition, presence of a relatively dense layer of $Gd_2Zr_2O_7$ on the top did not help reduce corrosion-induced damage. For the reference YSZ coating, the observed corrosion-induced damage was lower, probably due to a combination of more limited salt penetration, the SPS microstructure, and superior fracture toughness of YSZ (Fig. 2).

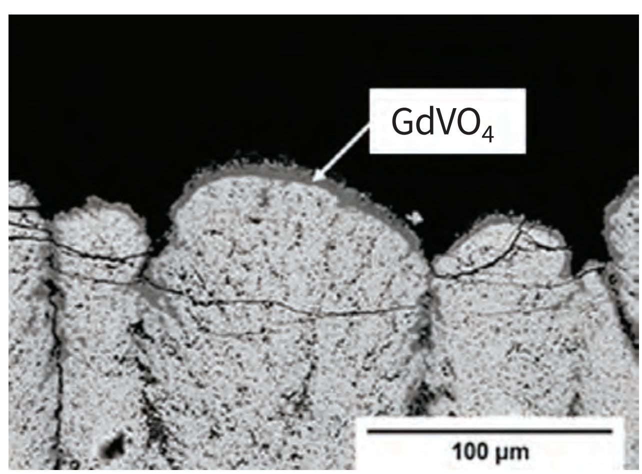


Fig. 2 — Cross-section of two-layer gadolinium zirconate coatings showing $GdVO_4$ on the top surface.

INVESTIGATION ON THE TRIBOLOGICAL BEHAVIOR OF ARC-SPRAYED AND HAMMER-PEENED COATINGS USING TUNGSTEN CARBIDE CORED WIRES

W. Tillmann, L. Hagen, and P. Schröder

Due to their outstanding properties, WC-W_2C iron-based cermet coatings are widely used in the field of wear protection. Regarding commonly used WC-W_2C reinforced coating systems, it has been reported that their tribological behavior is mainly determined by the carbide grain size fraction. Although the manufacturing route for arc-sprayed WC-W_2C cermet coatings is in an advanced state, there is still a lack of knowledge concerning the performance of cored wires with tungsten carbides as filling material and their related coating properties when post-treatment processes are used, such as machine hammer peening (MHP). A major objective was to characterize WC-W_2C FeCMnSi coatings deposited with different carbide grain size fractions as a filling using cored wires, with respect to their tribological behavior. Moreover, deposits derived from cored wires with a different amount of hard phases are investigated. According to this study, polished MHP surfaces are compared to as-sprayed and polished samples by means of metallographic investigations. With the use of ball-on-disk and dry rubber wheel tests, dry sliding and rolling wear effects on a microscopic level are scrutinized. It has been shown that the MHP process leads to a densification of the microstructure formation. For dry sliding experiments, the MHP coatings obtain lower wear resistances, but lower coefficients of friction than the conventional coatings. With regard to abrasion tests, the MHP coatings possess improved wear resistance. Strain hardening effects at the subsurface area were revealed by the mechanical response using nanoindentation. However, the MHP process caused a cracking of embedded carbides, which favor breakouts, leading to advanced third-body wear (Fig. 3).

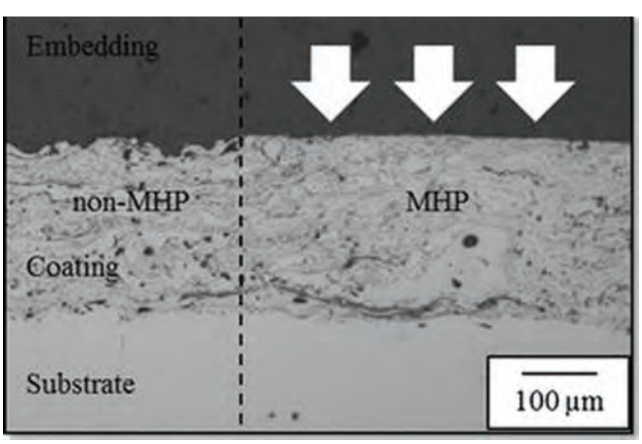


Fig. 3 — Cross-sectional images taken by light microscopy showing the coating morphology across the non-MHP and MHP area at sample (2,0).

ANTI-ICING BEHAVIOR OF THERMALLY SPRAYED POLYMER COATINGS

Heli Koivuluoto, Christian Stenroos, Mikko Kylmälahti, Marian Apostol, Jarkko Kiilakoski, and Petri Vuoristo

Surface engineering shows increasing potential to provide a sustainable approach to icing problems. Icing reduces safety, operational tempo, and productivity, as well as the reliability of logistics, industry, and infrastructure. Currently, several passive anti-icing properties adaptable to coatings are known, but further research is required to proceed into practical applications. An icing wind tunnel and centrifugal ice adhesion testing equipment can be used to evaluate and develop anti-icing and icephobic coatings for potential use in various arctic environments, e.g., in wind power generation, oil drilling, mining, and logistic industries. The present study deals with evaluation of icing properties of flame-sprayed polyethylene (PE)-based polymer coatings. In laboratory-scale icing tests, thermally sprayed polymer coatings showed low ice adhesion compared with metals such as aluminum and stainless steel. The ice adhesion strength of the flame-sprayed PE coating was found to have approximately seven times lower ice adhesion values compared with metallic aluminum, indicating promising anti-icing behavior (Fig. 4).

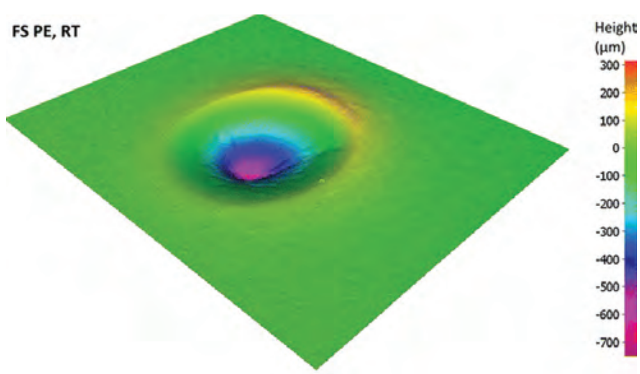


Fig. 4 — 3D optical profiles of impact craters of flame-sprayed PE coatings after high-velocity impact test at room temperature (RT).

CAN THERMALLY SPRAYED ALUMINUM (TSA) MITIGATE CORROSION OF CARBON STEEL IN CARBON CAPTURE AND STORAGE (CCS) ENVIRONMENTS?

S. Paul and B. Syrek-Gerstenkorn

Transport of CO_2 for carbon capture and storage (CCS) uses low-cost carbon steel pipelines due to their negligible corrosion rates in dry CO_2. However, in the presence of liquid water, CO_2 forms corrosive carbonic acid. In order to mitigate wet CO_2 corrosion, use of expensive corrosion-resistant alloys is recommended; however, the increased cost makes such a selection economically unfeasible. Therefore, new corrosion mitigation methods are sought. One such method is the use of thermally sprayed aluminum (TSA), which has been used to mitigate corrosion of carbon steel in seawater, but there are concerns regarding its suitability in CO_2-containing solutions. A 30-day test was carried out during which carbon steel specimens arc-sprayed with aluminum were immersed in deionized water at ambient temperature bubbled with 0.1 MPa CO_2. The acidity (pH) and potential were continuously monitored, and the amount of dissolved Al^{3+} ions was measured after completion of the test. Some dissolution of TSA occurred in the test solution leading to a nominal loss in coating thickness. Potential measurements revealed that polarity reversal occurs during the initial stages of exposure, which could lead to preferential dissolution of carbon steel in the case of coating damage. Thus, one needs to be careful while using TSA in CCS environments (Fig. 5).

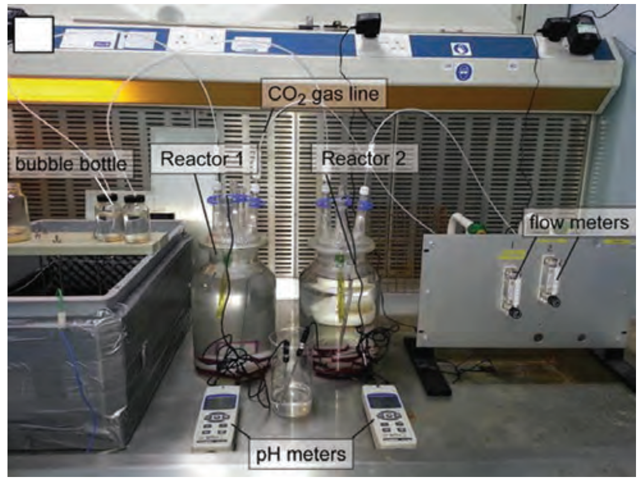


Fig. 5 — Experimental setup showing the arrangement of reactors.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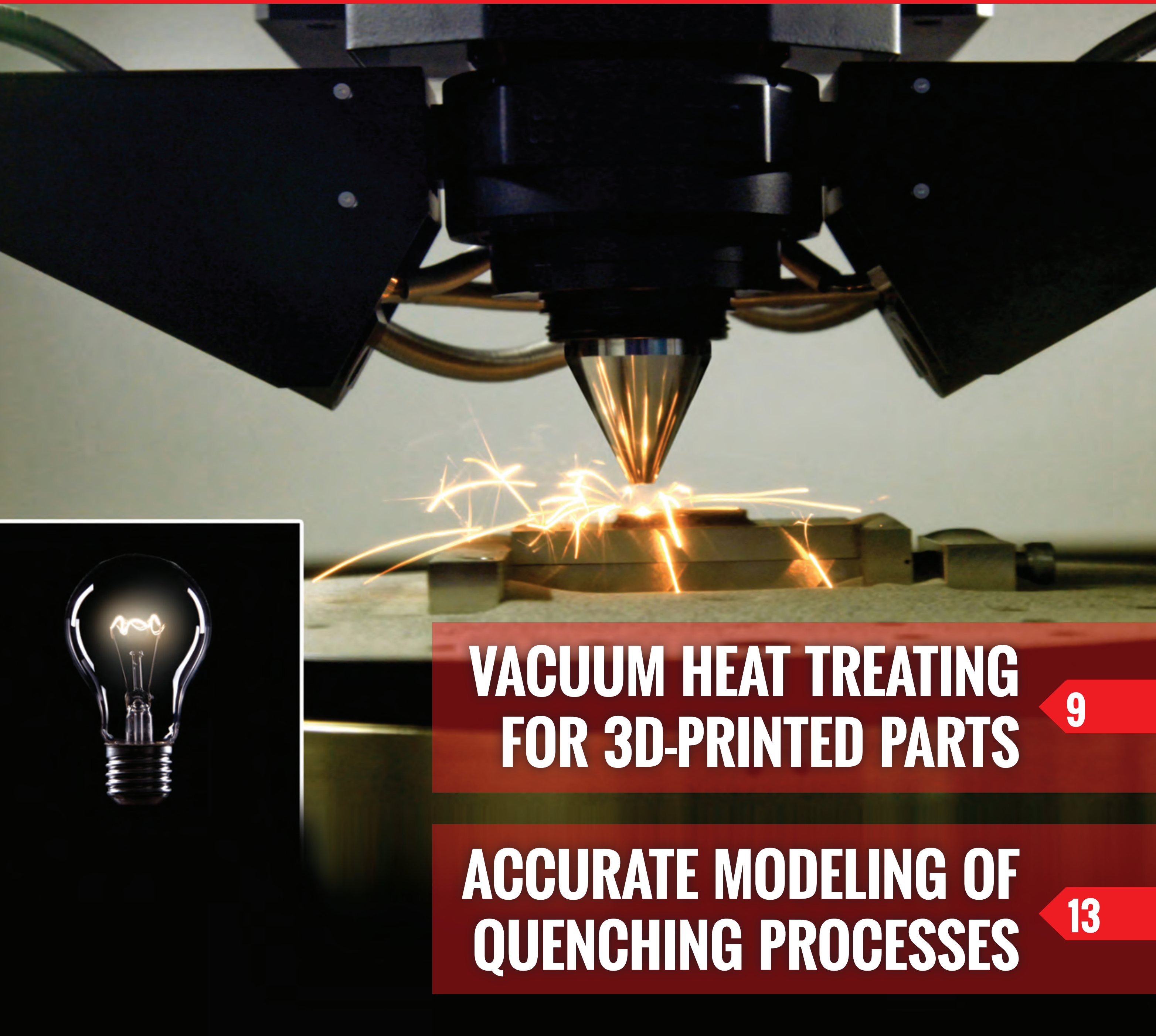

VACUUM HEAT TREATING FOR 3D-PRINTED PARTS 9

ACCURATE MODELING OF QUENCHING PROCESSES 13

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Ignacio Castro, Arbomex SA de CV

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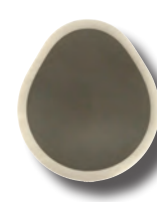

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BUSINESS AND TECHNOLOGY FOR THE HEAT TREATING PROFESSIONAL

DEPARTMENTS

ABOUT THE COVER

Just as light bulb technology has incrementally improved over time, so has additive manufacturing (AM). Heat treatments of AM parts are constantly evolving as designs and process controls are developed to suit this new metallurgy. Courtesy of Solar Atmospheres Inc., solaratm.com.

EDITORIAL OPPORTUNITIES FOR HTPro IN 2017

The editorial focus for *HTPro* in 2017 reflects some key technology areas wherein opportunities exist to lower manufacturing and processing costs, reduce energy consumption, and improve performance of heat treated components through continual research and development.

June Testing and Process Control
September Thermal Processing in On/Off Highway Applications
November Atmosphere/Vacuum Heat Treating

To contribute an article to one of the upcoming issues, contact Frances Richards at frances.richards@asminternational.org.

To advertise, contact Erik Klingerman at erik.klingerman@asminternational.org.

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CHANGE CREATES CHANGE

Cars and airplanes. Two different modes of transportation, two essential products undergoing radical design changes that demand new results from heat treating providers in terms of both equipment technology and process capabilities.

Airplanes are undergoing radical redesigns to improve fuel efficiencies by 15-20% or lengthen range. Whether it is a new geared turbofan engine or metallic components throughout the aircraft and landing gear, use of smaller metal parts and gears demands improved longevity and lighter weight.

Automobiles are going through exhaustive redesign every year to meet government fuel targets and customer-driven expectations for higher MPG. Every metallic part in the engine, drivetrain, frame, and safety and exhaust systems is being revised to minimize weight and optimize critical mechanical properties and residual stress distribution. It often seems that designers do not bother to consider the practicalities involved in heat treating these parts—as they add hole after hole, reduce cross sections, and use "crazy" shapes and exotic alloys.

These new challenges push heat treaters to demand innovation from equipment suppliers to deliver products that can perform. In the induction heat treat world, the past few years have seen advancements in use of multiple frequencies, dual frequencies, computer-aided coil designs, and FEA analysis to take the "Black Art" out of induction heat treating. Going forward, a new power supply technology will provide an even higher level of capability by enabling independent, stepless, and instant adjustment of frequency and power during the heat cycle. This technology may be the biggest change in the induction heat treat industry since motor generators and tube oscillators.

State-of-the-art power supply technology allows the physics and reference depth data of electromagnetic induction to be coupled with innovative computer programs to "map out" the exact output necessary for precise heat treating along vastly changing component geometries. For example, precise heat treating specifications for gears and half shafts will be able to be programmed, rather than taking a trial and error approach.

With these new tools being offered to induction heat treaters, we say to component designers, "Bring it on!"

Gary A. Doyon
President/CEO, Inductotherm Group
Chairman/CEO, Inductoheat Inc.

NOMINATIONS SOUGHT FOR ASM HTS/ SURFACE COMBUSTION EMERGING LEADER AWARD

The ASM HTS/Surface Combustion Emerging Leader Award was established in 2013 to recognize an outstanding early-to-midcareer heat treating professional whose accomplishments exhibit exceptional achievements in the heat treating industry. The award was created in recognition of Surface Combustion's 100-year anniversary in 2015.

The award acknowledges an individual who sets the "highest standards" for HTS participation and inspires others around him/her to dedicate themselves to the advancement and promotion of vacuum and atmosphere heat treating technologies. Rules for submitting nominations:

- Candidates must be a member and active participant in ASM and HTS.
- Nominees must be 40 years of age or younger and employed full time in the heat treating industry for a minimum of five years.
- Candidates must be submitted by an ASM or HTS member.
- Three letters of recommendation must be submitted with the nomination form. Nominations should clearly state the nominee's impact on the industry and/or service in dedication to the future of the HTS.
- The award shall be presented to one recipient every two years at the General Membership Meeting at the HTS Conference and Exposition.
- **Recommendations must be submitted to ASM Headquarters no later than April 1.**

The winner receives a plaque and $4000 cash award funded by Surface Combustion. For complete rules and nomination form, visit the Heat Treating Society website at hts.asminternational.org and click on Membership & Networking, then Society Awards. For additional information or to submit a nomination, contact Joanne Miller at 440.338.5151 ext. 5513, joanne.miller@asminternational.org.

Olga Rowan, (center) senior engineer, Caterpillar Inc., received the 2015 ASM HTS/Surface Combustion Emerging Leader Award from HTS past president Roger Jones, FASM, (left) and Bill Bernard, Jr., FASM, (right), president and CEO of Surface Combustion.

HTS SEEKS STUDENT BOARD MEMBER APPLICATIONS

HTS is continuing its successful Student Board Member Program and is looking for Material Advantage student members to provide insight and ideas to HTS. Opportunities include:

- All expenses to attend meetings paid for by the Society.
- Take an active role in shaping the future of your professional Society.
- Actively participate in your professional Society's board meetings.
- Gain leadership skills to enhance your career.
- Add a unique experience to your resume.
- Represent Material Advantage and speak on behalf of students.
- Work with leading professionals in the field.

Student Board Members are required to attend two board meetings (October 23 during the HTS Conference & Exposition and spring 2018) and participate in three teleconferences. The term begins in September 2017. **Application deadline is April 1.** Visit asminternational.org/students/student-board-member-programs for complete form and rules.

"I pursued the Heat Treating Society Student Board Member position as a resume-building and networking opportunity. The connections I made landed me a job in the heat treating industry and ultimately convinced me to stay active in the Society, where I currently serve on the HTS Membership Committee. Looking back, I can wholeheartedly say that I came for the experience and I stayed for the people."

Lee M. Rothleutner, HTS Student Board Member, 2014-2015

HTS COMMITTEE CHAIRS NAMED FOR 2016-2017 TERM

The ASM Heat Treating Society Board appointed chairs to each of its committees for the 2016-2017 term. **Stephen G. Kowalski,** president, Kowalski Heat Treating Co., continues to serve as president of HTS. **Roger A. Jones,** corporate president, Solar Atmospheres Inc., is currently serving as HTS immediate past president, as well as chair of the HTS Awards & Nominations and the HTS Finance Committees. **Michael J. Schneider, FASM,** senior technologist, R&D materials (retired), The Timken Co., continues as chair of the HTS Education Committee. **Michael A. Pershing,** senior technical steward, Caterpillar Inc., was named chair of the HTS Research & Development Committee. **Andrew Banka,** vice president, Airflow Sciences Corp., was appointed chair of the HTS Technology & Programming Committee. **JoAnne Bruning,** business development manager, Bluewater Thermal Solutions, was named chair of the HTS Membership Committee. **Chuck Faulkner,** marketing manager, Heat Treatment, Houghton International, continues as chair of the HTS Expositon Commtitee. If you are interested in serving on an HTS committee, contact the respective committee chair or email joanne.miller@asminternational.org.


Kowalski


Jones


Schneider


Pershing


Banka


Bruning


Faulkner

CHTE RESEARCHERS TACKLE REAL-WORLD HEAT TREAT PROBLEMS

Eighteen years ago, the Center for Heat Treating Excellence (CHTE) was founded with the goal of bringing the industrial sector and university researchers together to find solutions to real-world problems. Today, CHTE—located at Worcester Polytechnic Institute (WPI) in Massachusetts—has 19 members from all areas of industry working together with WPI researchers to improve both heat treat and thermal processing methods worldwide.

The organization has an impressive body of work. It has completed more than 20 projects that cover everything from induction tempering, thermal processing, and distortion to gas and oil quenching, energy efficiency determination, furnace modeling, alloy life extension, gas and vacuum carburization, and more.

DISTORTION AND RESIDUAL STRESS RESEARCH

CHTE's latest project is called "Guidelines for Assessing Distortion and Residual Stress." According to Richard Sisson, George F. Fuller Professor of Mechanical Engineering and CHTE technical director, this is an area of huge concern; companies spend millions of dollars scrapping parts that become distorted during the heat treat process, in either the heating or cooling period. Further, some materials have stored residual stress, which causes distortion and compromises part integrity.

Steve Ferdon, director of engineering technology in the fuel systems business at Cummins Inc., and current chair of CHTE's board of directors, is excited about this project. "Because residual stress and heat treat distortion are recurring frustrations for the industrial membership, we have had a truly open and collaborative effort to develop the scope of work for this project," says Ferdon. "Global players in the aerospace, industrial equipment, transportation, automotive, heat treat equipment, and integrated computational materials engineering (ICME) industries are engaged and will provide technical guidance and resources throughout the project. The expected outcome will be development of precompetitive data, process design practices, and analytical tools that will have a real, practical, and immediate benefit to members' bottom lines."

Key project objectives include:

1. Determining the most important heat treating process parameters that impact residual stress and distortion in industrial parts.
2. Developing a ranking of these processing parameters based on their impact.

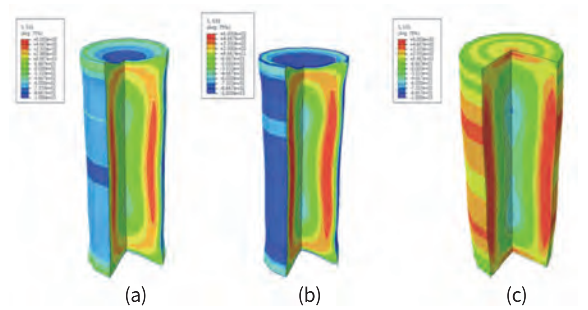

Fig. 1 — Cylinders of several steel grades were austenitized and quenched in water. The residual stress in hoop direction as predicted by DANTE, (a) Pyrowear53, (b) AISI 4140 steel, and (c) AISI 52100 steel. Compressive stress in the hoop direction developed in the exterior part for Pyrowear53 and AISI 4140 steel. Tensile stress developed in the 52100 steel. Variation is due to differences in martensite start temperature.

3. Providing processing guidelines to control residual stress and distortion.

This is a big undertaking for CHTE. The center is now compiling a list of parameters to start putting boundaries on the project, which will further refine the scope. Currently, the project is in the modeling and simulation phase with the expectation that research testing will begin in June (Fig. 1).

RESEARCH OF INTEREST

What makes CHTE unique from other collaborative efforts is that members select the research projects. In December 2016, CHTE and WPI researchers met to determine the direction of additional studies. Based on their input, the project selection committee determined that many companies are facing similar areas of concern, thus defining key topic areas that the center is considering for future research:

- **Processing modeling and data validation** is of key importance. This aligns well with the ATC TMI road map that was sponsored by NIST and ASM International and published in 2015. In this roadmap, a significant focus is developing tools for simulation. CHTE has two member companies—Thermo Calc and DANTE Solutions—that both focus on ICME, and this is becoming more important as a tool to understand complex material systems before investing in expensive physical models, prototypes, or processes. Many of the CHTE studies will contribute to the datasets available for ICME studies.
- **Bainite** is an emerging topic of interest among the membership. OEMs desire a better understanding

Fig. 2 — CarbTool is an effective model to predict carbon concentration profiles during low-pressure and gas carburizing.

of the potential strength toughness and cost benefits of bainitic steels over martensitic steels. Furnace manufacturers and commercial heat treat shops, in order to satisfy customer requirements, must quickly acquire knowledge and experience in the design, validation, and control of heat treating processes devised to produce bainitic microstructures in steel alloys. According to Ferdon, "The unique benefit that CHTE brings to applied research is the collective knowledge, experience, material characterization tools, and manufacturing resources that lie within the materials science organizations of its member companies."

- **Additive manufacturing** is another hot area, and as the technology improves to a point of reliably printing metal products, it is important to understand how heat treatments can be used in these processes.

RECENT PROJECTS

Following is a snapshot of some of the projects CHTE is now completing:

CarbTool – Predicting Microhardness and Carbon Concentration Profiles. Researchers at CHTE are perfecting carbon concentration profile predictions through enhancements to CarbTool, its simulation software. This software successfully predicts the carbon concentration profiles of steel parts in both low-pressure carburization, also referred to as vacuum carburization, and gas carburization. The models being developed can be used to optimize industrial carburizing parameter processes, eliminating much of the trial and error currently happening in the industry. This in turn is saving heat treaters significant time and money (Fig. 2).

Studying Properties of Induction and Furnace Tempered Parts. For the past two years, CHTE researchers have been working on a one-of-a-kind research project aimed at better understanding the mechanical properties and microstructural features of steels that have been gas tempered and induction tempered. This comparative, precompetitive research aims to help heat treaters better understand the optimal technology they should use, especially because tempering requires a balance between specified hardness and tensile strength, while increasing toughness and maintaining a uniform microstructure (Fig. 3).

Additive Manufacturing – Researching the Behavior of Metals and Alloys. The growing field of additive manufacturing (AM) allows manufacturers to create more complicated and lighter weight parts with less wasted materials. Yet questions abound about how these materials will behave in their environment. Will the materials be durable? Will corrosion be a problem? How will the part withstand stress? Understanding the processing, structure, property, and performance relationship in the AM field is why WPI researchers are spending significant time and energy on this work.

Alloy Life Extension Project. Goals include finding ways to extend the service life of parts and fixtures, and reducing the energy associated with these processes. Recently, much of the center's focus has been on assessing the benefits of alumina forming alloys, which excel in high temperature applications, as they oxidize more slowly than chromia formers and are a barrier to carbon uptake.

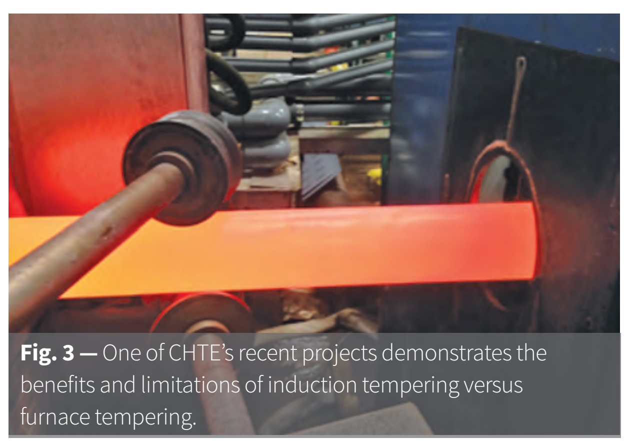

Fig. 3 — One of CHTE's recent projects demonstrates the benefits and limitations of induction tempering versus furnace tempering.

CHTE MEMBERSHIP

CHTE members include furnace and heat treat equipment manufacturers, commercial heat treat shops, OEMs, professional and technical institutions, and heat treat tool and supply providers. Current members include ALD Vacuum Technologies GmbH, Amsted Rail, ASM International, Bodycote, Caterpillar Inc., Cummins, DANTE Solutions, Deere & Company, Fiat Chrysler Automotive, General Electric Power, GKN Sinter Metals, H.C. Starck, Ipsen, Pratt & Whitney, Sikorsky Aircraft, Surface Combustion Inc., Thermatool, Thermo-Calc Software, and The Timken Company. For more information about CHTE, email Rick Sisson at sisson@wpi.edu.

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VACUUM HEAT TREATING FOR ADDITIVE MANUFACTURING

Heat treaters are discovering new opportunities in the rapidly expanding field of additive manufacturing.

Robert Hill, FASM,* Solar Atmospheres of Western PA, Hermitage, Pa.

The impact of additive manufacturing (AM) on industry is undeniable and doubts about its staying power have all but disappeared. For heat treaters, the big question now is whether or not they are willing to embrace change. Additively manufactured parts present unique challenges, but the rapid growth of this technology is a powerful incentive to confront and overcome them. Some heat treaters have already started down this path and are blazing a trail that others can follow.

DEVELOPMENT OF AM

The invention of the incandescent light bulb and the development of additive manufacturing share many similarities. One overriding theme, however, perhaps most significant and easiest to miss, is that neither of these transformative technologies arose from a single stroke of genius overnight. Much to the contrary, both were decades in the making, driven by efforts and insights from dozens of people stoking a process of incremental improvement that continues on both fronts to this day (Fig. 1).

The practice of heat treating AM parts, as might be expected, is on a similar course. Here as well, many are contributing to the progress—designers, materials scientists, process engineers, equipment builders, and others. Together they are driving advancements and establishing best practices to meet production demand for full density, crack-free parts. This is good news for the heat treating industry, where the pipeline of jobs associated with AM parts is rapidly being filled from both ends of the manufacturing spectrum. On one end, fueling demand, prime contractors such as General Electric Aviation, Lockheed Martin, Boeing, and Airbus are in an all-out sprint to incorporate AM components into new designs. Meanwhile, on the supply side, small and mid-size machine shops are staging a build-up of capacity, and discovering in the process that having a 3D printer on the shop floor can open new doors, especially with medical device OEMs (Fig. 2). Like aircraft manufacturers, medical device manufacturers consider AM a critical pathway to future design improvements, which for heat treaters, makes it a convenient pathway to growth.

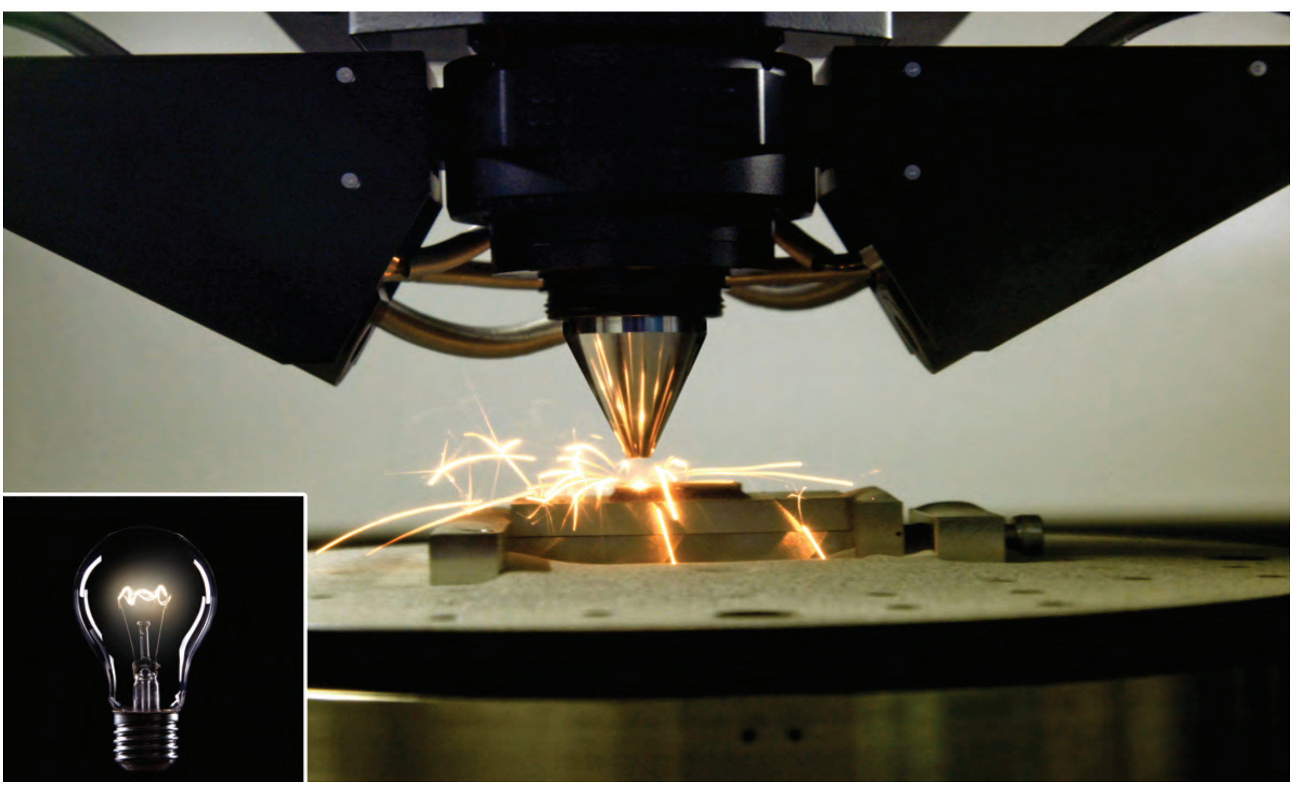

Fig. 1 — Additive manufacturing, like the light bulb, is the result of decades of improvements and has the potential to reshape industry and the world.

*Member of ASM International

Fig. 2 — 3D printers are becoming a common sight in CNC and tool and die shops as more manufacturers embrace AM technology.

VACUUM FURNACES

The rapid spread of additive manufacturing is not its only appeal, however, at least not for the heat treating industry. As heat treaters are learning, AM work originates high in the value chain and the majority of it has similar, although challenging, processing requirements. Under such circumstances, a little knowledge, experience, and knowhow can go a long way.

Most AM components being processed today have complex geometries and are made to near net shape. This makes them highly susceptible to defects caused by surface contamination and thermally induced stress. Achieving the necessary processing conditions requires a vacuum furnace that can hold a vacuum somewhere between 10^{-5} and 10^{-6} Torr while maintaining a uniform temperature of ±2°F throughout the heat zone (Fig. 3). In addition, heating and cooling cycles as well as soaks must be tightly controlled to prevent fractures and optimize part densities. This requires unambiguous and accurate feedback that can be obtained only from direct sensor contact with the part. Not all furnace designs allow for that.

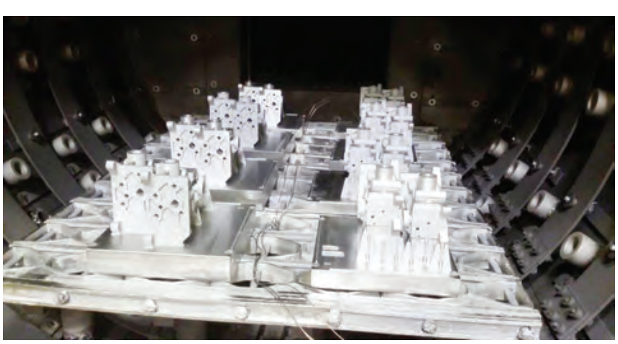

Fig. 3 — Heat treaters have found an ally in vacuum furnaces when it comes to processing intricate, near net shape AM parts.

Fig. 4 — These cracks indicate that parts were formed on a base plate too thick relative to the printed features.

DESIGN PITFALLS

Besides having the right equipment and knowing how to operate it, heat treaters must also know how to recognize common design pitfalls that can doom a process from the start. Any geometrically complex part with dissimilar cross sections or non-radii surfaces, for example, will be difficult to process, especially if liquid quenching alloys are involved. The same goes for parts made from non-air-hardenable powder or wire because it compromises strength and ductility due to crack susceptibility.

Another common but easily avoidable pitfall is the use of mismatched build plates. Particularly for parts made by direct metal laser sintering (DMLS) or electron beam melting (EBM), all build plates should be as thick as the thickest cross section being printed. Quite often, however, designers will print complex parts on extremely thick backer plates in order to reuse the plates after sectioning away the part. The thickness mismatch invariably causes cracking and other defects in the printed part (Fig. 4).

Parts with unvented internal cavities represent another common design oversight. Cooling passages and cavities that are not properly ducted are subject to differential pressures during vacuum processing, often causing them to deform or fracture. By the time such parts get to heat treaters, it is usually too late to address the problem. Another feature designers often forget to incorporate into their designs is printed thermocouple holes in parts made on DMLS or EBM systems (Fig. 5). Once the part is made, it will be extremely difficult to heat treat because the only accessible surface, the backer plate, is not thermally representative of the co-joined, intricate printed parts.

Measuring and controlling temperature is critical to the success of heat treating AM parts, and an area where many process improvements originate. One especially clever improvement harnesses the power of AM itself to minimize temperature differences across fragile printed

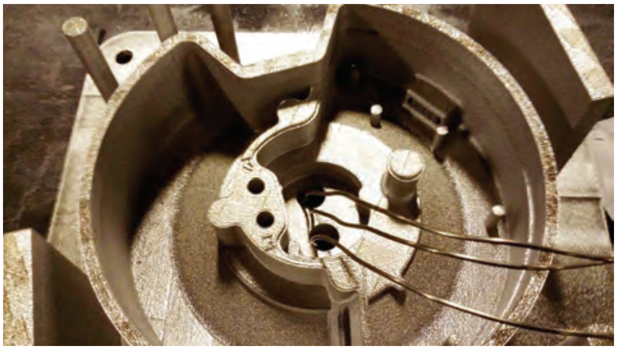

Fig. 5 — AM components often include holes to give thermocouples direct contact with part surfaces, where they can obtain precise temperature measurements.

parts. The method is based on printing a "negative" of the outer surface of the AM part undergoing treatment. The printed cover, which is placed over the work piece, promotes uniform heating and cooling. It also provides access for direct thermocouple attachment to the part. The result: high quality, crack-free parts that could not be achieved without this ingenious adaptation.

CONCLUSION

As the AM community continues making progress, it will find answers to many lingering questions regarding production readiness, quality standards, equipment certification, repeatability, and other matters. At that point, it is a safe bet that heat treaters will be vacuum processing far more near net shape finished components than raw materials.

They will also help bring about the next big innovation, the ability to print different materials at different locations within a 3D space. Consider, for instance, what this could mean for a carburized gear. Through selective application of materials, the pitch of each tooth could be imbued with high hardness, gear tooth flanks with improved wear resistance, ductility in the core, and improved corrosion resistance everywhere else.

Being able to synthesize substrates and structures from multiple materials would have a far reaching effect, offering a single new approach to many processes such as brazing and thermal spray. Instead of joining complex assemblies made of different thicknesses of cast or wrought metals, for example, manufacturers could print one assembly from a single base metal and then add dissimilar metals in layers as needed.

Another post AM process that will continue to increase in importance is hot isostatic pressing. Many printed components are required to be in a final state that is fully dense with zero porosity. Only hot isostatic pressing can achieve these properties, and will continue to be refined along with other critical processes. ~HTPro

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This video walks you through the step-by-step process for performing a leak check, from calibrating the helium mass spectrometer to determining which part of the furnace is the source of the leak.

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When choosing between all-metal or graphite hot zones, it's important to consider your processes, materials, temperatures, ramp rates and uniformity ranges.

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ACCURATE MODELING OF QUENCHING PROCESSES USING CFD AND A FLOW BOILING DATABASE

Experimentally derived surface heat flux rate data and CFD software are helping researchers more accurately simulate liquid quenching processes.

Andrew L. Banka* and Jeffrey D. Franklin,* Airflow Sciences Corp., Livonia, Mich.

Computational analysis, a tool that has helped optimize many heat treating processes, has yet to have an extensive impact on liquid quenching. Quenching in a vaporizable liquid is a critical production step for many metal parts, but the complexity of the physics make it a difficult process to simulate. Rigorous physics-based boiling models can yield good results, but are impractical for cases of industrial interest. An alternative, data-driven approach presented here holds promise, however, and is scoring well when tested under realistic conditions.

A MODELING DILEMMA

Heat treat processes incorporating a liquid or gas quenching step are essential to the quality of manufactured metal components. The rapid cooling that occurs during quenching largely determines phase distribution, microstructure, residual stress, and distortion in the as-quenched part. Manufacturers, naturally, would like to better control these pivotal material properties, and are looking to numerical analysis tools for the necessary leverage.

Numerical methods and tools have been used to gain a better understanding of many heat treating operations, leading to significant process improvements. But their use in the area of liquid quenching has been much less extensive. Simulating the process of quenching has been a persistent challenge because of the difficulty in predicting surface heat flux rates due to boiling of the vaporizable quenchant.

Materials scientists confronting this issue will often conduct instrumented tests on the part in question, then use "inverse analyses" to extract surface heat flux values from the measured internal temperatures. This approach is time consuming, expensive, and subject to non-unique solutions. Further, the resulting heat flux values are only applicable to the specific part and quenching environment. If a change will be made in processing conditions, the experiment must be repeated.

A purely computational approach—one that predicts the explosive formation of vapor and release of bubbles based on the underlying physics—is theoretically possible, but it would be impractical in applications of industrial interest because length scales and time frames differ by orders of magnitude across the working domains.

An alternative approach, and the focus of this article, incorporates both experimental and computational methods, benefiting from the combination of strengths. Elusive surface heat flux rates are determined experimentally in a precisely controlled flow boiling test system. This data is then used to build computational fluid dynamics (CFD) models that are proving to be quite accurate in quenching process simulations.

FLOW BOILING DATA COLLECTION

As part of an Air Force Research Laboratory sponsored SBIR study, a group of investigators developed an experimental facility to collect flow boiling heat flux data for vaporizable quenchants. In the heart of the system, as shown in Fig. 1, a test coupon embedded in the wall of a flow channel is exposed to quenchant circulating at controlled speeds. The heat source, a bank of cartridge heaters with an output

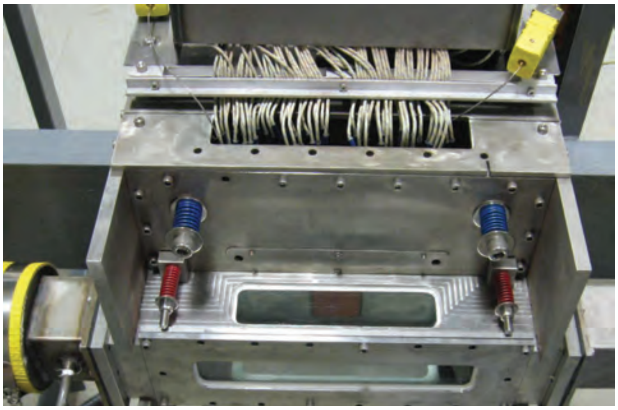

Fig. 1 — Flow channel for measuring flow boiling surface heat flux rates.

*Member of ASM International

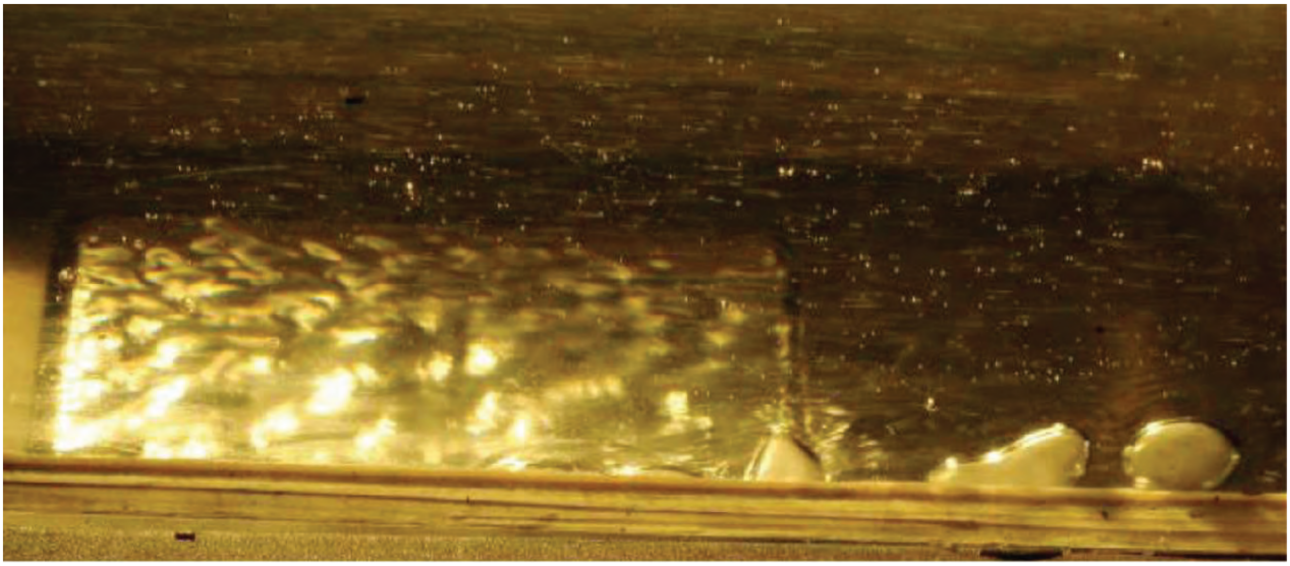

Fig. 2 — Film boiling on side surface at low velocity and high temperature. Flow is from left to right. Vapor film is thick and uneven, and vapor bubbles are being shed.

of 27 kW, is capable of heating the coupon surface to 1600°F, achieving a maximum surface heat flux of 10.8 MW/m^2.

Data collection begins when the coupon is at its maximum temperature and stable film boiling is established at the desired quenchant flow rate and temperature. Collection continues as the heaters reduce the surface temperature of the coupon at a controlled rate of 20°F/minute. This slow cooling approach provides a well-defined relationship between surface temperature and surface heat flux during pseudo-steady-state conditions. Figure 2 shows the vapor-liquid interface on the test coupon during film boiling at a relatively low flow rate. The test procedure is then repeated for each flow velocity, quenchant temperature, and surface orientation of interest.

The raw data collected are temperature values obtained from thermocouples inserted below the surface of the copper coupon. The values are used to derive surface temperature and heat flux rate. The procedure may seem similar to the inversing processes typically used in quench trials, although there are a few key differences. First, all data are collected in near steady-state conditions, eliminating the complexities inherent in transient cooling processes. Second, two thermocouples are used at each surface location, placed at different depths, allowing for advanced extrapolation techniques to the surface of the coupon[1]. And finally, because surface heat flux data are linked to surface temperature, quenchant temperature, quenchant velocity, and surface orientation, they can be applied to any surface under the same conditions.

QUENCH TESTING, SIMULATION AND VALIDATION

To validate the method, quenching data were collected on a generic turbine disk shape made of Inconel 718. Nearly two dozen thermocouples were inserted into the part at critical locations. Most of the thermocouples were placed 0.100 in. from the surface, while five were buried deeper into the part. Near the rim of the disk, the near-surface thermocouple was repeated at 60° intervals to assess the circumferential uniformity of the quenching operation.

In quench tests performed at the Wyman-Gordon research facility in Houston, the disk was soaked at 1800°F, then quenched in Houghton 3420 quenchant under both still and agitated conditions. Temperature data were collected at 10 Hz during both the heating and quenching cycles.

The quenching operation was simulated with ANSYS-Fluent version 16, using a 0.1 second time step. For the still oil quenching simulation, radial symmetry of the part allowed for a 2D model, and 17,557 cells were used to represent both the disk and quench tank in cross section. Simulating a quench of 1500 seconds required about five hours of processing time on a 3.5-GHz Linux workstation with eight processors.

Boiling functions constructed from the flow boiling database were incorporated into a Fluent User Defined Function (UDF) that adjusted the surface heat transfer coefficients (HTCs) on an iterative basis for each surface

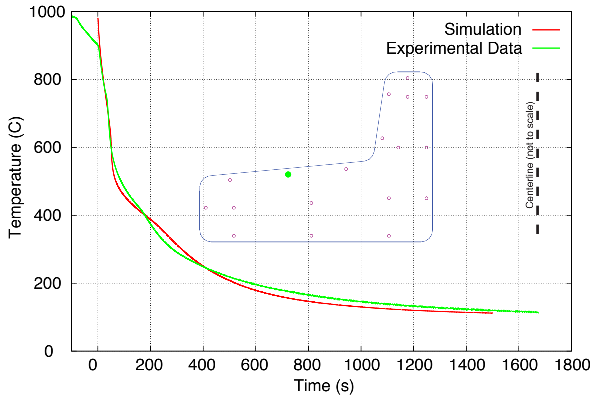

Fig. 3 — Location with best correlation for still oil generic turbine disk.

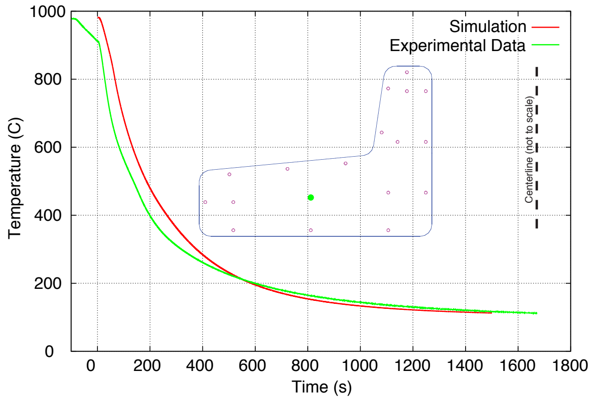

Fig. 4 — Location with poorest correlation for still oil generic turbine disk.

face within the computational domain. Each computational face is thus treated as a separate heat transfer zone with the HTCs based on local conditions. Temperature-dependent properties were used for both Inconel 718 and Houghton 3420.

Temperature data were recorded during the simulation process at each thermocouple location to compare against experimentally measured values. The degree of correlation at each location was based on the average difference between the simulated and measured temperatures over 1500 seconds of simulated time. This is essentially the integrated area between the simulated and measured cooling curves divided by total simulation time.

For the still oil case, average temperature deviations ranged from 14.9° to 28.5°C, indicating that the simulation provides a good representation of the actual quenching behavior. For the thermocouples on the rim of the part, the average spread of temperature data was 27.3°C, while the average deviation between simulated temperature and the mean of the six rim thermocouples was just 22.2°C. In other words, the correlation of the simulation was within the variation band for the actual process.

Cooling curves for locations with the least and greatest average deviations are shown in Figs. 3 and 4. The curves in Fig. 3 are in close agreement over the entire cooling range. The agreement in Fig. 4 is not as good, but it still predicts overall cooling behavior fairly well. The location of the greatest deviation in a buried thermocouple is curious, and may suggest a difference between simulated and actual thermal properties of Inconel 718.

CONCLUSION

A method has been developed combining carefully collected flow boiling heat flux data with CFD simulations to provide accurate simulations of quenching operations. A comparison of simulated and experimentally measured cooling rates for a non-trivial geometry has shown good correlation, indicating that this tool provides a practical method of assessing and improving industrial quenching operations. The level of correlation shown in the example indicates that the experimental database is not limited to the original test conditions (as with typical quench trials), but rather has broad applicability. **~HTPro**

Acknowledgments

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Reference

1. Edward B. Coy, Measurement of Transient Heat Flux and Surface Temperature Using Embedded Temperature Sensors, *Journal of Thermophysics and Heat Transfer,* Vol 24, No. 1, 2010.

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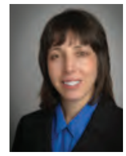
ASMNEWS

AFFILIATE SOCIETIES NAME COMMITTEE CHAIRS FOR 2016-2017 TERM

The Boards of the Electronic Device Failure Analysis Society (EDFAS), Failure Analysis Society (FAS), Heat Treating Society (HTS), International Metallographic Society (IMS), and Thermal Spray Society (TSS) have appointed chairs to each of their committees for the 2016-2017 term. Chairs for ASM Society and General Committees and Councils appeared in the January 2017 issue of *ASM News.* The purpose of each committee is stated on the ASM website, asminternational.org. Click on Membership and Committees, followed by Committee Involvement, and then Affiliate Committees.


Wang


Hartfield


Xie


Moore


Moyal


Beaudoin


Subramanian


Goh


Akyuz


Ulvan


Hanke


Aliya


Shipley


Stevenson


Vitry

Electronic Device Failure Analysis Society (EDFAS)

Zhiyong Wang, executive director, Maximum Integrated, was elected president of EDFAS.

Cheryl Hartfield, product manager/marketer, CDH Consulting, serves as immediate past president and chair of the EDFAS Nominating Committee.

Mayue Xie, engineering TD manager, Intel Corp., continues as chair of the Education Committee.

Tom Moore, FASM, president, Waviks Inc., continues as chair of the EDFAS Membership Committee. **Efrat Moyal,** cofounder, LatticeGear LLC, serves as co-chair.

Felix Beaudoin, functional characterization engineer, GlobalFoundries, is chair of the *Electronic Device Failure Analysis* Editorial Board.

Sam Subramanian, principal engineer, NXP Semiconductors, was named chair of the Events Committee and is general chair of ISTFA 2017.

Szu Huat Goh, manager product diagnostic, GlobalFoundries, Singapore, was named chair of the International Growth Committee.

Failure Analysis Society (FAS)

Burak Akyuz, team lead–metallurgy and failure analysis, Applied Technical Services Inc., continues to serve as FAS president.

Erhan Ulvan, manager–engineering and laboratories, Acurn Group Inc., serves as immediate past president and chair of the FAS Nominating Committee.

Larry Hanke, FASM, principal engineeer, Materials Evaluation and Engineering Inc., was named chair of the Awards Committee.

Debbie Aliya, president, Aliya Analytical Inc., serves as chair of the Education Committee.

Roch Shipley, FASM, principal engineer, Professional Analysis and Consulting Inc., serves as chair of the FAS Finance Committee.

Michael E. Stevenson, president, ESI, continues as chair of the *Journal of Failure Analysis and Prevention* Editorial Committee.

Veronique Vitry, senior research and teaching associate, UMONS, Belgium, serves as chair of the International Relations Committee.

Aaron Slager, engineer IV, Bell Helicopter Textron, was named chair of the FAS Membership Outreach Committee.

In This Issue

ASM INTERNATIONAL

Submit news of ASM and its members, chapters, and affiliate societies to Frances Richards, editor, ASM News | ASM International
9639 Kinsman Road | Materials Park, OH 44073 | P 440.338.5151 ext. 5563 | F 440.338.4634 | E frances.richards@asminternational.org
Contact ASM International at 9639 Kinsman Road, Materials Park, OH 44073 | P 440.338.5151 ext. 0 or 800.336.5152 ext. 0 (toll free in U.S. and Canada) | F 440.338.4634 | E MemberServiceCenter@asminternational.org | W asminternational.org


Slager


Flury


Havics


Miller

Margaret Flury, senior materials engineer, Medtronic, serves as chair of the Rules for Government Committee.

Andrew Havics, director, pH2 LLC, continues to serve as chair of the FAS Programming Committee.

Brett Miller, FASM, continues to serve as the chair of the Publications Committee.

International Metallographic Society (IMS)

Jaret J. Frafjord, technical director, IMR Test Labs, serves as president of IMS.

Richard Blackwell, FASM, appplications specialist, Precision Surfaces International Inc., continues to serve as IMS immediate past president and chair of the IMS Nominating Committee.

James E. Martinez, materials scientist, NASA, serves as IMS vice president and chair of the Publications Committee.

Gabe Lucas, metallographer, Scot Forge Co., was named chair of the IMS Awards Committee.

Laura Moyer, lab manager, Lehigh University, continues to serve as chair of the IMS Education Committee.

Michael Covert, senior metallographer, Ellwood Group, continues as chair of the International Metallographic Society's Membership Committee.


Frafjord


Blackwell


Martinez


Lucas


Moyer


Covert

Heat Treating Society (HTS)

See page 3 of *HTPro* in this issue for the HTS committee chairs.

Thermal Spray Society (TSS)

See page 3 of *iTSSe* in this issue for the TSS committee chairs.

If you are interested in serving on an Affiliate Society committee, contact the respective committee chair directly or email joanne.miller@asminternational.org.

SMST Announces New Officers and Board Members

In accordance with their rules of governance, the International Organization on Shape Memory and Superelastic Technologies (SMST) completed its elections for officers and board members for 2017. **Jeremy Schaffer,** engineer, Fort Wayne Metals, was appointed president of SMST, while **Othmane Benafan,** materials research engineer, NASA Glenn Research Center, was appointed vice president/finance officer. **Aaron Stebner,** assistant professor, Colorado School of Mines, remains on the board as immediate past president. Officers serve a two-year term. The SMST membership reelected **Michael R. Mitchell,** of Mechanics & Materials Consulting LLC, as a director serving a three-year term.


Schaffer


Benafan


Stebner


Mitchell

ASM, FAS, HTS, IMS and TSS Seek Student Board Members

We're looking for Material Advantage student members to provide insights and ideas to the ASM, FAS, HTS, IMS, and TSS Boards. We are pleased to announce the continuation of our successful Student Board Member programs. Each Society values the input and participation of students and is looking for their insights and ideas.

- An opportunity like no other!
- All expenses to attend meetings paid for by the respective Society
- Take an active role in shaping the future of your professional Society
- Actively participate in your professional Society's board meetings
- Gain leadership skills to enhance your career
- Add a unique experience to your resume
- Represent Material Advantage and speak on behalf of students
- Work with leading professionals in the field

Opportunities specific to each Society:

ASM International

- Attend four board meetings (June 26-28, October 8-11 during MS&T17, March and June 2018)
- Term begins June 1

ASM Failure Analysis Society

- Attend two board meetings (fall 2017 and spring 2018)
- Participate in two teleconferences
- Term begins in September

ASM Heat Treating Society

- Attend two board meetings (October 23 during HTS Conference & Exposition and spring 2018)
- Participate in three teleconferences
- Term begins in September

ASM International Metallographic Society

- Attend one board meeting (October 2018)
- Participate in monthly teleconferences
- Term begins in August

ASM Thermal Spray Society

- Attend one board meeting in the second half of 2017
- Participate in two teleconferences
- Receive a one-year complimentary membership in Material Advantage
- Term begins in October

Application deadline is **April 1.** Visit asminternational.org/students/student-board-member-programs for complete form and rules.

RAVINDRAN TO CHAIR 2017 NOMINATING COMMITTEE


Ravindran

Members of the 2017 Nominating Committee have been selected and **Prof. C. Ravi Ravindran, FASM,** professor of advanced materials, Ryerson University, Toronto, was elected to serve as chair by the ASM Board of Trustees. Ravindran has been a member of ASM International since 1970 and served as ASM president in 2013-2014. He is also a past chair of the ASM Canada Council and is the founding chair of the ASM Materials Camps Canada. Ravindran is a Distinguished Life Member of Alpha Sigma Mu and has been honored with the ASM Allan Ray Putnam Service Award. He has been involved with metal casting for more than 40 years, a unique combination of industrial (19 years) and academic experience (25+ years). He was elected an ASM Fellow in 1994. In addition to his many contributions through committee service, Ravindran served the Manitoba Chapter in all positions including chair and is a past chair of the ASM Canada Council. Ravindran is also a past president of the Canadian Academy of Engineering.

ASM Officers Appoint Members

In accordance with the ASM International Constitution, ASM president **Dr. William E. Frazier, FASM,** vice president **Dr. Frederick E. Schmidt, Jr., FASM,** and immediate past president **Mr. Jon D. Tirpak, P.E., FASM,** appointed nine members to the Nominating Committee from among candidates proposed by chapters, committees, councils, and ASM Affiliate Society boards. The committee is responsible for selecting a nominee for vice president-trustee (one-year term) and for nominating three trustees (three-year terms). Members do not select a candidate for president of the Society, because Article IV, Section 3 of the Constitution states that the office of president shall be filled for a period of one year by succession of the vice president. The 2017 Nominating Committee's nominee for vice president will serve as ASM's president in 2019.

2017 Nominating Committee Members Include:

Rodney Boyer, FASM, RBTi Consulting, Bellevue, Wash. (nominated by AeroMat Committee); **Michael Hahn,** engineer, Northrop Grumman Corp., Redondo Beach, Calif. (nominated by Los Angeles Chapter); **Mark Hineman,** senior consultant, Engineering Systems Inc., Aurora, Ill. (nominated by Chicago Regional Chapter); **Robert Hyers,** professor, University of Massachusetts, Amherst (nominated by Boston Chapter); **Arun Kumar,** Flow Serve, Irving, Texas (nominated by North Texas Chapter); **Khinlay Maung,** director of engineering, Air Industries Corp., Irvine, Calif. (nominated by the Columbus Chapter and Chapter Council); **Philip Maziasz, FASM,** distinguished research scientist, Oak Ridge National Laboratory, Tenn. (nominated by Oak Ridge Chapter); **B.S. Murty, FASM,** professor, Indian Institute of Technology, India (nominated by Chennai Chapter); **Erhan Ulvan,** manager–Eng. & Labs, Eastern Canada, Acuren Group Inc., Mississauga (nominated by Ontario Chapter, Canada Council, Failure Analysis Society).

The Nominating Committee will meet on April 26-27 and its recommended slate of officers will be published in the May/June issue of *ASM News.*

ASM Seeks Vice President and Board of Trustees Nominations

ASM is seeking nominations for the position of vice president as well as three trustees. The Society's 2017-2018 vice president and trustee elects will serve as a voice for the membership and will shape ASM's future through implementation of the ASM Strategic Plan.

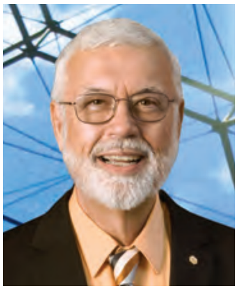
Qualifications: Members must have a well-rounded understanding of the broad activities and objectives of ASM on a local, Society, and international level, and the issues and opportunities that ASM will face over the next few years. Further, they must also have a general appreciation for international trends in the engineered materials industry.

Duties: The duties of board members include various assignments between regular meetings. Trustees also assume the responsibility of making chapter visits and serving as a board liaison to ASM's various committees and councils.

Guidelines: Nominees for vice president must have previously served on the ASM Board and those selected to serve as trustees should be capable of someday assuming the ASM presidency.

Deadline for nominations is March 27. For more information, visit asminternational.org/vp-board-nominations or contact Leslie Taylor, 440.338.5151 ext. 5500, or leslie.taylor@asminternational.org.

FROM THE PRESIDENT'S DESK
The ASM Renewal


Frazier

I want to thank you on behalf of ASM's vice president Frederick Schmidt, the Board of Trustees, our new managing director William Mahoney, and the ASM staff for continued strong support of the ASM Renewal. Our shared beliefs that ASM International is a society of professionals who have come together to accomplish great works for the common good that cannot be achieved independently, and that our values of transparency, integrity, technical excellence, diversity, and constancy of purpose continue to guide our strategy.

Working together with 50 ASM thought leaders drawn from our membership, chapters, affiliate societies, councils, FASMs, past presidents, and industry, we have developed an ASM Strategic Plan and Operating Plan. A preliminary version is available at www.asminternational.org/about/strategicplan. The final version of the plans will be published in the next issue of *AM&P*. Central to these plans is the belief that ASM's maximum value to society can be achieved by working at the intersection of design/engineering, manufacturing, and materials (Fig. 1).

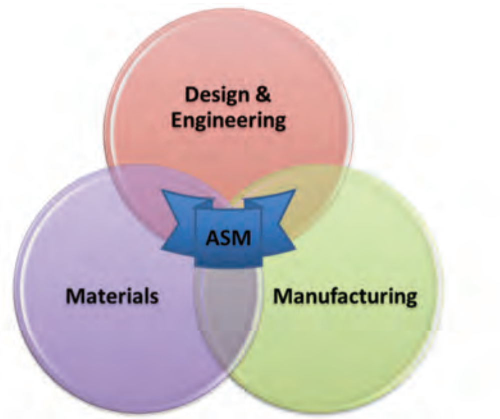


Fig. 1 – ASM binds, connects, and enables materials design, engineering, and manufacturing.

For our continued success and growth, ASM must excel in three fundamental areas—technical excellence, increased membership, and strategic partnerships/collaborations. ASM's plan systematically addresses these in a carefully thought out, time-phased manner. Further, in order to achieve our vision, four trustee led task forces have been established to explore in-depth the following critical areas: education, committee structure, digital workforce, and enhancing student membership. We wish to greatly expand our educational offerings in community colleges and chapters. We also wish to organize our committees to better facilitate content generation and delivery. We recognize that ASM must deliver digital content in the manner desired by tomorrow's workforce. Lastly, we also recognize that students are the seed corn from which our Society will prosper and that we must cultivate and engage them.

ASM's future is bright! Thank you for making the ASM Renewal possible and permitting me to make the journey with you.

William E. Frazier, FASM
President of ASM International
frazierwe@gmail.com

2017 ASM International Student Paper Contest

Deadline April 1

The ASM International Student Paper Contest is designed to increase interest and awareness in materials science and engineering, and provide recognition for outstanding student efforts in the field. The contest is open to all Material Advantage student members who are enrolled at a college or university offering courses in materials science and engineering. The winner will receive a cash prize of $500, plus up to $500 toward travel expenses to attend MS&T17. In addition, a full set of ASM Handbooks (or an online Handbooks subscription) will be presented to the school or student chapter of the winning entry. For contest rules, past recipients, and a sample form, visit asminternational.org/membership/awards/nominate. To submit a nomination, contact christine.hoover@asminternational.org for a unique nomination form link.

2017 Bradley Stoughton Award for Young Teachers

Winner receives $3000

Deadline April 1

This award recognizes excellence in young teachers in the fields of materials science, materials engineering, design, and processing. Do you know a colleague who:

- Is a teacher of materials science, materials engineering, design, processing, or related fields
- Has the ability to impart knowledge and enthusiasm to students
- Is 35 years of age or younger by May 15 of the year in which the award is made
- Is an ASM member

Nominate a colleague for the 2017 award!

Jennifer Carter receives the 2016 Bradley Stoughton Award for Young Teachers from Jon Tirpak, ASM immediate past president.

Engineering Materials Achievement Award

Deadline April 1

This award recognizes an outstanding achievement in materials or materials systems related to the application of knowledge of materials to an engineering structure or to the design and manufacture of a product. Do you know of an innovative, cutting-edge scientific achievement that has distinctly impacted industry, technology, and society within the past 10 years? If so, consider submitting a nomination for the 2017 award. View sample forms, contest rules, and past recipients at asminternational.org/membership/awards/nominate. To submit a nomination, contact christine.hoover@asminternational.org for a unique nomination form link.

Representatives from Oak Ridge National Laboratory accept the 2016 Engineering Materials Achievement Award.

Canada Council Award Nominations due April 30

ASM's Canada Council is seeking nominations for its 2017 awards program. These prestigious awards include:

G. MacDonald Young Award–The ASM Canada Council established this award in 1988 to recognize distinguished and significant contributions by an ASM member in Canada. This award consists of a plaque and a piece of Canadian native soapstone sculpture.

M. Brian Ives Lectureship–This award was established in 1971 by the ASM Canada Council to identify a distinguished lecturer who will present a technical talk at a regular monthly meeting of each Canadian ASM Chapter who elects to participate. The winner receives a $1000 honorarium and travels to each ASM Canada Chapter throughout the year to give their presentation with expenses covered by the ASM Canada Council.

John Convey Innovation Awards–In 1977, the Canada Council created a new award to recognize sustaining member companies that contribute to development of the Canadian materials engineering industry. The award considers a new product and/or service directed at the Canadian or international marketplace. Two awards are presented each year, one to a company with annual sales in excess of $5 million, and the other to a company with annual sales below $5 million. Award rules, past recipients, and sample nomination forms can be found at asminternational.org/membership/awards/nominate.

FROM THE FOUNDATION

Elementary Education Initiatives


Anderson

The goal of the ASM Educational Foundation's kindergarten to sixth grade (K-6) initiative is to reach a larger, more diverse population of students at an earlier age than that reached with the Foundation's other programs. As these students experience materials science and engineering and grow older, they can dive deeper and funnel into other successful educational programs such as the ASM Materials Camp and many of the new educational materials being developed for dissemination on the internet.

Most teachers work very hard to engage students by bringing real-world relevance into their classrooms. These dedicated teachers are particularly supportive of hands-on experiences that support the next-generation science standards they are implementing in their classrooms. One of the more successful educational methodologies for deeply engaging students in a meaningful way is project-based learning (PBL). Fortunately, materials science and engineering is a hands-on profession that typically moves new and exciting materials into society through projects. Materials are therefore in the "sweet spot" of PBL. Based on this understanding, the Foundation is developing short, hands-on projects where students can:

1. Touch and feel in a supportive, informal class room environment.
2. Take something home to stimulate discussion with siblings and parents.
3. Understand the relevance of what they learned the minute they leave the classroom.

These projects can be independently taught by teachers, but it is even more desirable for ASM members to enter the classroom as subject matter experts and run the projects with our nation's teachers. Students remember when "real world" people come into their classrooms. To make a difference in a child's life, while ensuring the future of our profession, don't hesitate to contribute to a meaningful project experience at your local school.

Kevin Anderson, FASM
ASM Materials Education Foundation Trustee

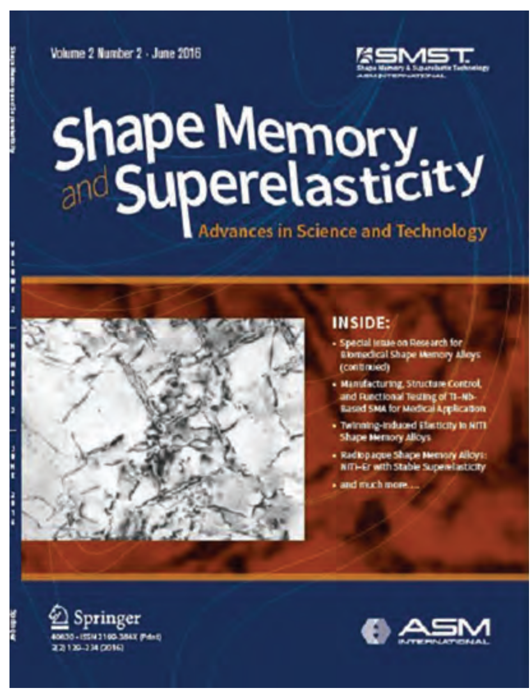
ASM-IIM Visiting Lecturer Program Seeks Applicants

Deadline April 1

The cooperative Visiting Lecturer Program of ASM International and the Indian Institute of Metals (IIM) is seeking applicants for 2017. View rules, past recipients and criteria at asminternational.org/membership/awards or contact christine.hoover@asminternational.org for more information.

Shape Memory and Superelasticity Journal Names 2015 Best Paper

"Composition Dependences of Entropy Change, and Transformation Temperatures in Ni-rich Ti–Ni System" by K. Niitsu, Y. Kimura, X. Xu, and R. Kainuma was selected as the Best Paper of 2015 by the editor and associate editors of *Shape Memory and Superelasticity.* For the 2015 papers, there was a small margin between the scores for the Best Paper winner and the next three papers that tied for second place. Due to this exceptional situation, there will be Honorable Mentions awarded to the three tied papers. For more information, visit http://bit.ly/2mcBZcD.



MD CORNER

Message to our Membership

From time to time, through both direct letters and regular updates in *AM&P,* I will regularly inform the ASM membership on overall developments as well as discrete milestones and outcomes, as the organization presses forward to execute the ASM Renewal. I am pleased to initially report that the 2017 ASM Operating Plan, which includes views of both 2018 and 2019 and which operationalizes the 2016 Strategic Plan, was unanimously approved by the ASM Board and its Finance Committee in January. A link to a summary document is on the ASM website at www.asminternational.org/about/strategicplan.


Mahoney

One of the earliest and most important deliverables in 2017 is our Digital Transformation Program—including a complete replacement of our membership management system along with an upgrade of our website to a commercial-grade transaction portal. The existing membership management system, although a market leader at the time of its installation over a decade ago, was poorly maintained. Similarly, our web toolset was poorly implemented. These conditions have directly contributed to the frustration expressed by many of you for several years at not only the inability to execute straightforward transactions, but also the loss of records, receipt of duplicate magazines, and many other member satisfaction issues.

By Q2 2017, our web toolset will be upgraded to a full commercial platform. While not changing the look and feel of our website, this milestone should provide members with improved transaction capability and reliability and improved tablet and mobile device compatibility. This upgrade will be followed by a replacement of the membership management system with a full Salesforce CRM/association management suite, which will roll out in stages concluding in Q3 2017. By then, members should be experiencing improved service levels and support capabilities.

If you would like more information about this important ASM Renewal project, please contact me. Thank you for your consideration and best regards.

William T. Mahoney, ASM Managing Director
bill.mahoney@asminternational.org

EPC CORNER

Emerging Professionals Committee Spotlight

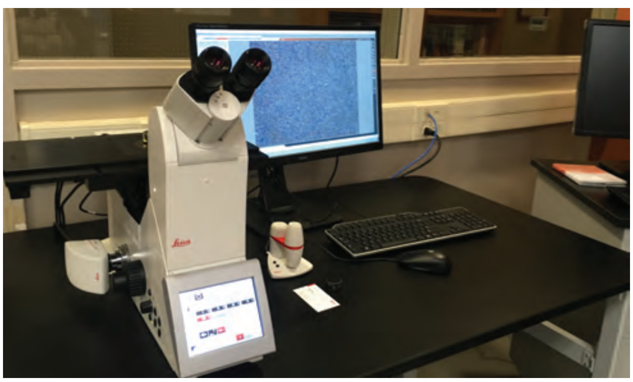
The Emerging Professionals Committee (EPC) participates in a variety of ASM activities. One of the most visible is the Emerging Professionals Symposium held each year at MS&T. Other, more behind-the-scenes initiatives include supporting local chapters and new member conversion/retention. But what is the EPC and why does it exist? The EPC is a volunteer group of young professionals committed to the materials community. Their purpose includes developing a new generation of ASM volunteers and helping ASM transition from one generation of volunteers to the next. This means engaging with young professionals in the materials community, getting them involved in materials education and volunteering, and cultivating the sense of camaraderie, fellowship, and professionalism present within ASM that leads to lifelong membership and active participation. Like any other organization, ASM does not exist without its people.

The EPC is divided into three subcommittees, each focused on a different aspect of engaging young professionals in the materials community: event programming/content, local chapter support, and new member/conversion. The main task of the Event Programming/Content Subcommittee is coordinating the annual EPC Symposium at MS&T. Organizing speakers, panelists, and presenters is no small task. Other functions include writing EPC Corner articles for *AM&P* and developing and maintaining a Facebook page for sharing ASM and EPC events and news.

The Local Chapter Support Subcommittee focuses on EPC's relationship with ASM chapters across the country. Committee members work to match new graduates with chapters in their area and provide ideas, strategies, and best practices for engaging young professional members. The Local Chapter Support Subcommittee also organizes related ASM awards such as the Bronze Award. Finally, the New Member/Conversion Subcommittee works on recruiting young professionals into ASM, converting Material Advantage members into ASM members, and managing marketing campaigns aimed to recruit new EPC members. The EPC is always looking for more ways to engage the young professional community, so please let us know how we can serve you better! For more information, email drew.fleming@asminternational.org.

ASM and Leica Microsystems Announce Educational Partnership

ASM International and Leica Microsystems, Buffalo Grove, Ill., recently announced a new educational partnership. ASM will host classroom programs using inverted and digital microscopes for inspection and analysis in metallography, manufacturing, and materials research through this partnership. These programs will rely on sophisticated equipment from Leica Microsystems, including the Leica DMi8 modular inverted microscope system for materials science and the Leica DMS300 digital microscopy system, as well as Leica LAS X advanced measurement and image analysis software. The partnership will provide learning opportunities for new imaging and inspection techniques.

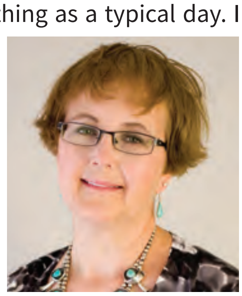


WOMEN IN ENGINEERING

This profile series introduces leading materials scientists from around the world who happen to be females. Here we speak with Janet Sater, FASM, research staff member at the Institute for Defense Analyses (IDA).

What does your typical workday look like?

I don't know if there is such a thing as a typical day. I work in the science and technology division (STD) of a not-for-profit, federally funded research and development center chartered to work only for the Department of Defense (DoD) and its associated agencies. STD provides objective, independent analyses of science and technology issues related to national security for our DoD sponsors. The range of topics on which we work is very broad and includes energy, optics, materials and armor, robotic systems, training, and human factors, among others. We also work with other divisions in our company that are focused on system and operational testing, cost analysis, and so forth. I might work on multiple, widely different projects on any given day.



Sater

What part of your job do you like most?

I love that I am continually learning something new. My graduate school research efforts were focused on aspects of aluminum metallurgy. Since I started working at IDA, however, my efforts have barely touched on aluminum. My work has focused on numerous other materials and structures including polymer composites for spacecraft; high-temperature metal matrix composites for turbine engines; smart materials, devices, and structures for space, air, and underwater systems; robotics; advanced manufacturing processes; biological materials for camouflage; and material supply chains and more. Pretty cool for a metallurgist, but also challenging and fun.

What attracted you to engineering?

I began my college career in biology with the intent of becoming a marine biologist. Because I like working with my hands and am very practical, I changed majors to engineering, but I wondered which field? My father, an electrical engineer, worked for a company that employed all kinds of engineers, and he arranged several meetings for me. Metallurgical engineering seemed most interesting to me. I am visually-oriented, and the idea that I could mix up some elements and chemicals to create a metal and then look at it under a microscope and know why it looked that way was very appealing. I never looked back. I finished my undergraduate degree in three and a half years including an honors research project, and then headed to graduate school at Purdue University for master's and Ph.D. degrees. I've been very happy with my choices.

What are you working on now?

I always have several projects going at the same time. I recently finished a study on the supply chain for a particular metal for a defense agency and I am currently completing a survey of best practices by government and industry for international technology exchange and transfer.

If a young person approached you for career advice about pursuing engineering, what would you tell them?

Take all the math and science you can take in high school. Those fundamentals will serve you well whatever engineering field you choose. Find your passion. Be fearless in exploring the new and different. Develop good communication skills, both oral and written. Ask questions. Listen thoughtfully and with an open mind. Network—and not only electronically. Get involved in relevant professional societies. Find good mentors, including peers, advisors, bosses, and people you admire.

Hobbies?

Cooking, crafts (especially sewing, quilting, and beading), photography, reading, travel.

Last book read?

Candice Millard's "The River of Doubt: Theodore Roosevelt's Darkest Journey."

Would you like to be featured in an upcoming Women in Engineering profile? Contact Vicki Burt at vicki.burt@asminternational.org.

Pittsburgh Enjoys All-Clad Tour and Trustee Visit

On a 7°F evening this past December, Pittsburgh Chapter members visited the All-Clad Metalcrafters LLC facility in Canonsburg, Pa. The tour progressed through the company's operational departments of cladding, forming, rotary, and assembly. Questions from various ASM contingents were revealing, if not amusing: At the cladding operation, where aluminum and stainless steel are sandwiched together, those who work with aluminum asked solely about the aluminum and those who work with stainless steel asked solely about the stainless steel. Process people asked about both, plus furnace temperatures. Everyone asked, "What size pot would that make?"

In January, at the Chapter's National Officers Night, ASM trustee Larry Hanke, FASM, gave a presentation on forensic materials engineering for product liability litigation. Close to 50 members enjoyed the invited talk.

Pittsburgh Chapter members tour the All-Clad facility.


From left, Chapter chair Nate Eisinger, trustee Larry Hanke, and Chapter vice chair Piyamanee Komolwit.

Alamo Hosts Trustee Seal

ASM trustee Sudipta Seal, FASM, enjoyed a visit to the Alamo Chapter (San Antonio) in February. The day started with a tour of Baker Risk, a materials consulting firm, followed by a visit to Southwest Research Institute (SwRI), and a Chapter board meeting. Points of discussion included ideas to increase membership, such as partnering with University of Texas at San Antonio and St. Mary's University, and getting more Material Advantage students involved to ensure the Chapter's long-term health.


Sudipta Seal, back row with blue tie, enjoys a visit to the Alamo Chapter.

San Fernando Valley Holds Nanomaterials Meeting

In February, Sarah Allec, a graduate student in the department of materials science and engineering at the University of California, Riverside gave a talk to the San Fernando Valley Chapter on the electronic properties of nanomaterials from a quantum mechanical perspective. The meeting was held at California State University, Northridge. Since moving the meeting location to the university campus, the Chapter has seen an increase in student involvement and attendance.


From left, Ray Engelhardt, Chapter chair, with guest speaker Sarah Allec.

MEMBERS IN THE NEWS

George Named ORNL-UT Governor's Chair

Easo George, FASM, an authority on advanced alloy development and theory, was named the 15th Governor's Chair at the DOE's Oak Ridge National Laboratory (ORNL) and the University of Tennessee (UT). George has been a professor of materials design and director of the Center for Interface Dominated High Performance Materials since November 2014 at Ruhr-University Bochum, Germany. Prior to that, he worked for nearly 30 years at ORNL where he was a distinguished research staff member and head of the Alloy Behavior and Design Group. He was also a professor of materials science and engineering at UT since 2002.


George

George's research areas include high-entropy alloys; small-scale mechanical behavior of crystalline and amorphous materials; refractory and precious metals for space power applications; mechanical behavior at extremes of temperature and strain rate; and environmental effects on microstructure and mechanical properties.

Kumar Earns Joint Appointment at LLNL and WSU


Kumar

Lawrence Livermore National Laboratory (LLNL) staff scientist **Mukul Kumar** from the materials engineering division will now serve a joint position with both LLNL and Washington State University (WSU). This is only the third joint appointment for LLNL. Kumar will train and collaborate with students, postdoctoral fellows, and other faculty members in WSU's Institute for Shock Physics (ISP) in dynamics of materials and the nuances of shock compression experiments. The opportunity allows a deeper level of collaboration and training than he would have been able to accomplish as a faculty staff scientist solely focused on programmatic work.

Anderson Joins National Inventors Hall of Fame


Anderson

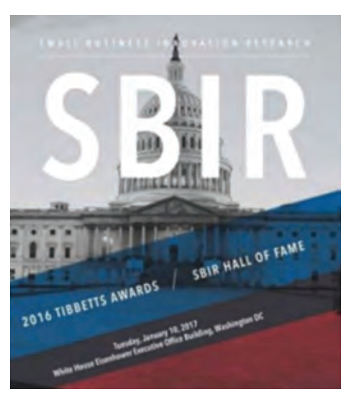
The National Inventors Hall of Fame, in partnership with the U.S. Patent and Trademark Office, announces that **Iver Anderson, FASM,** has joined the 2017 class. Anderson is one of 15 inductees selected this year, all of whom contribute to society in meaningful ways through groundbreaking, patented innovations. Anderson, a scientist at Ames Laboratory, Iowa, was selected for his role in the creation of lead-free solder. As a result of Anderson's discovery, it is estimated that well over 50,000 tons of lead per year will no longer be released into the environment.

National Academy of Engineering Honors ASM Members

In February, the National Academy of Engineering (NAE) elected 84 new members and 22 foreign members. Among the inductees are several ASM members and their citations: **Aziz Asphahani, FASM,** QuesTek Innovations LLC, for executive leadership in STEM education, integrated computer design of materials, and invention and production of corrosion-resistant alloys; **Dianne Chong, FASM,** Boeing Co. (retired), for advances in process and production technologies for composites in large commercial aerospace vehicles; **George Gray III, FASM,** Los Alamos National Laboratory, for contributions to the understanding of the dynamic and shock-loading deformation and damage response of materials; **Reiner Kirchheim,** University of Göettingen, Germany, for contributions to the thermodynamics and kinetics of hydrogen behavior in metals and solute/defect interactions in other materials; **Jagdish Narayan, FASM,** North Carolina State University, for contributions in heteroepitaxial film growth by laser ablation in large misfit systems and new materials; and **Jon Schaeffer,** GE Power & Water, for contributions to the development and implementation of advanced materials in industrial gas turbine engines. Election to NAE is among the highest professional distinctions accorded to an engineer. Academy membership honors those who have made outstanding contributions to engineering research, practice, or education. An induction ceremony will be held on October 8 at NAE's annual meeting in Washington.

QuesTek Employees Earn Tibbetts Award

Employees of **QuesTek Innovations LLC,** Evanston, Ill., were invited to the White House in early January to accept the U.S. Small Business Administration (SBA) 2016 Tibbetts Award. This award is presented to small businesses and individuals that have demonstrated excellence in leveraging Small Business Innovation Research (SBIR) funding to generate measurable impact through technological innovation, technology transfer, business impact, and product commercialization. QuesTek was recognized for unique contributions to the field of Integrated Computational Materials Engineering (ICME) and the Materials Genome Initiative. QuesTek received its first SBIR-funded project in 2001, and has since been awarded over $30 million across a total of 93 projects, all of which have focused on the modeling and design of novel materials.



IN MEMORIAM

Stephen Kenneth Tarby passed away on November 2, 2016, at age 82. After receiving his B.S., M.S., and Ph.D. in metallurgical engineering from Carnegie Institute of Technology, and serving in the U.S. Army Corp of Engineering Nuclear Power Program at the Atomic Energy Commission, he taught at Lehigh University for 41 years. During that time, he served as interim chair twice, in addition to 20 years as associate chair in the department of materials science and engineering. Tarby's leadership was recognized by his appointment to the R.D. Stout Professorship in 1995. In 1984 and 1998, his dedication to teaching and his positive and caring influence on his students were acknowledged by receiving the College of Engineering Teaching Excellence Award. He retired as Professor Emeritus in 2002. He also served on ASM's Journal of Phase Equilibrium Committee from 1991-1994.

Merle L. Thorpe, Jr., FASM, passed away on January 13 at age 87. He grew up in rural New York, attending a one-room schoolhouse and graduating high school in Kingston. He worked his way through Dartmouth College earning a degree in physics and a master's in engineering science and mechanical engineering. His Dartmouth education helped him break the family's poverty cycle engendered by the Great Depression and a three-year stint at Union Carbide's Linde Laboratory helped him realize that he needed to work for himself. He returned to Dartmouth's Thayer School of Engineering as an assistant professor of engineering and physics. While serving as assistant dean of Thayer in 1956, he co-founded his first business, Thermal Dynamics. This risk involved cutting his salary, borrowing money, working long days, and traveling internationally. He built a number of international companies in arc metal cutting, high temperature chemical and ceramic production, high temperature research tools, and thermal spraying of metals and ceramics. These included Thermal Dynamics Corp., Thorpe Corp., Ionarc Smelters, Humphrey's Corp., Arc Corp., and TAFA Inc., all based in New Hampshire. He was a Fellow and trustee of ASM, received The Rotary International Paul Harris Fellow Award, was inducted into the first class of ASM's Thermal Spray Hall of Fame, was awarded the NH Council High Tech Entrepreneur Award in 1989, and received ASM's William Hunt Eisenman Award in 1999.

Calvin R. Cupp, FASM, died on January 4 at age 92. He was born in Toronto and educated at Wilkinson Public School and Riverdale Collegiate before joining the Canadian Army in 1943 at age 18. He served in the United Kingdom and Northwest Europe in the 11th Field Regiment, Royal Canadian Artillery. He returned home in June 1946, and studied metallurgy at the University of Toronto from 1946-1950. In 1953, he completed his Ph.D. in metal physics. After graduation, Cupp worked for many years at International Nickel Co., where, among other things, he introduced x-ray fluorescence as an industrial analytical tool. From 1957 to 1961, he was seconded to Atomic Energy of Canada at Chalk River, where he worked with W. Bennett Lewis conducting studies in radiation damage to high-temperature alloys—research critical to nuclear submarine safety. After retirement, Cupp and an army comrade helped create the Canadian-Netherlands Memorial Park in Groesbeck, Holland, and shared the dedication of the park with Princess Margriet of the Netherlands on May 5, 1998.

ADVANCED MATERIALS & PROCESSES

EDITORIAL PREVIEW

April 2017

Materials Testing & Characterization

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- Six Sigma Materials Selection
- Antibacterial Materials
- SMST Show Preview

Bonus Distribution:
SMST
May 15-19, San Diego

Advertising closes March 6

MAY/JUNE 2017

Materials for Automotive/Energy/ Power Generation

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- Additive Manufacturing Standards
- ITSC Show Preview

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Bonus Distribution:
ITSC
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AD INDEX

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STRESS RELIEF

NEW APP GETS REAL ABOUT NEUTRINOS

Not long ago, observing fundamental particles was reserved for scientists with complex equipment. A new app plans to change all that. VENu is a free smartphone app designed by Oxford University scientists to help future physicists see neutrino activity. The app is comprised of data gathered by scientists from the Microboone experiment, which was launched to detect and understand neutrinos—subatomic particles that only very rarely interact. Neutrinos are notoriously difficult to capture, but state-of-the-art detectors like Microboone are now recording their interactions. A 3D platform, VENu works with Google Cardboard and is designed to exhibit both virtual and augmented reality features. The personal virtual reality viewer allows users to understand many complexities of the Microboone experiment and to learn more about neutrinos. The platform also includes video game features to challenge users. VENu is free to download from both the App Store and Google Marketplace. *venu.physics.ox.ac.uk.*

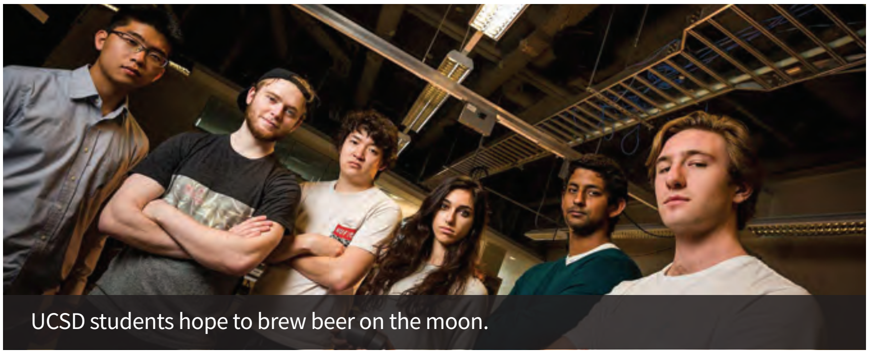
VENu works with Google Cardboard and exhibits both virtual and augmented reality features, enabling users to learn more about neutrinos. Courtesy of Oxford University.

GRAPHENE ENHANCES LITTLE BLACK DRESS

A new evening dress showcases one of the future uses of graphene, incorporating it into fashion for the first time. The project between intu Trafford Centre, wearable tech company Cute Circuit (dressmaker for Katy Perry and others), and the National Graphene Institute at The University of Manchester, UK, uses graphene in a number of innovative ways to create the world's most high-tech little black dress. The dress is complete with a graphene sensor that captures the wearer's breathing rate via a contracting graphene band around the waist; a micro LED attached across the bust on translucent conductive graphene responds to the sensor, causing the LED to flash and change color based on breathing rate. A 3D-printed graphene filament shows the intricate structural detail of graphene in raised diamond-shaped patterns and features flashing LED lights. The high-tech dress can be controlled by "The Q" app created by Cute Circuit to change the way the garment illuminates. *www.manchester.ac.uk.*

STAY THIRSTY, MY ENGINEERING FRIENDS

A team of University of California, San Diego (UCSD) engineering students aims to find out if beer can be brewed on the moon. The students are finalists in the Lab2Moon competition being held by TeamIndus, one of four teams with a signed launch contract to send a spacecraft to the moon as part of the Google Lunar XPRIZE challenge. Understanding how yeast behaves on the moon is not just important for brewing beer in space: It's also important for developing pharmaceuticals and yeast-containing foods like bread. The team is among 25 finalists selected from a pool of 3000 to compete for a spot aboard the TeamIndus spacecraft, which is planned for launch on December 28. If the UCSD team is selected, not only will they be the first to brew beer on the moon, the students believe they will be the first to brew beer in a fermentation vessel the size of a soda can. "Our canister is designed based on actual fermenters," says team leader Srivaths Kaylan. "It contains three compartments—the top will be filled with unfermented beer, and the second will contain yeast. When the rover lands on the moon with our experiment, a valve will open between the two compartments, allowing them to mix. When the yeast has done its job, a second valve opens and the yeast sink to the bottom and separate from the now fermented beer." *ucsd.edu.*



UCSD students hope to brew beer on the moon.

3D PRINTSHOP

SIEMENS PRINTS AND TESTS TURBINE BLADES

Siemens, Germany, achieved a breakthrough by finishing its first full load engine tests for gas turbine blades completely produced using AM technology. The company successfully validated multiple 3D-printed turbine blades with a conventional blade design at full engine conditions. Components were tested at 13,000 revolutions per minute and temperatures above 1250°C. Siemens also tested a new blade design with an improved internal cooling geometry manufactured using AM technology. The team worked with blades manufactured at Materials Solutions, its newly acquired 3D printing facility in Worcester, UK. Tests were conducted at the Siemens testing facility in the industrial gas turbine factory in Lincoln, UK. *siemens.com.*

Siemens finished its first full load engine tests for conventional and newly designed gas turbine blades produced using AM technology.

QUESTEK WINS SIX SBIR/ STTR AWARDS

QuesTek Innovations LLC, Evanston, Ill., was recently awarded six separate projects from the U.S. Navy and U.S. Army to develop technologies and design new alloys specifically tailored to the unique processing conditions and materials-related challenges of additive manufacturing. These include one Small Business Innovation Research (SBIR) Phase II project, two SBIR Phase I projects, and three Small Business Technology Transfer (STTR) Phase I projects focused on aluminum, titanium, and steel systems. The combined funding contract value exceeds $2 million. *questek.com.*

ARIZONA STATE LAUNCHES NEW AM CENTER

To stay at the forefront of the additive manufacturing industry, Arizona State University's (ASU) Ira A. Fulton Schools of Engineering recently launched the Manufacturing Research and Innovation Hub. Located on the Polytechnic campus, the 15,000-sq-ft space is the largest AM research facility in the Southwest. The new center features $2 million in state-of-the-art plastic, polymer, and metal 3D printing equipment along with advanced processing and analysis capabilities. Honeywell Aerospace, Concept Laser Inc., Phoenix Analysis & Design Technologies Inc., and Stratasys Ltd. partnered with the Fulton Schools to establish the new facility. *asu.edu.*

CARPENTER TECHNOLOGY TO ACQUIRE PURIS

Carpenter Technology Corp., Philadelphia, will purchase Puris LLC, Bruceton Mills, W.Va., a producer of titanium powder for additive manufacturing and advanced technology applications, for $35 million. The assets to be acquired include Puris' titanium powder operations and business, additive manufacturing assets, patents, and related intellectual property. As a result of the transaction, Carpenter will enter the titanium powder market significantly earlier than previously planned. Operations will continue at the existing Puris site, which is well positioned for future expansion and will operate as a functional unit of Carpenter Powder Products, complementing Carpenter's existing portfolio of powder metallurgy offerings. *cartech.com.*

ASU faculty at the January opening of the Manufacturing Research and Innovation Hub.