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ADVANCED MATERIALS & PROCESSES

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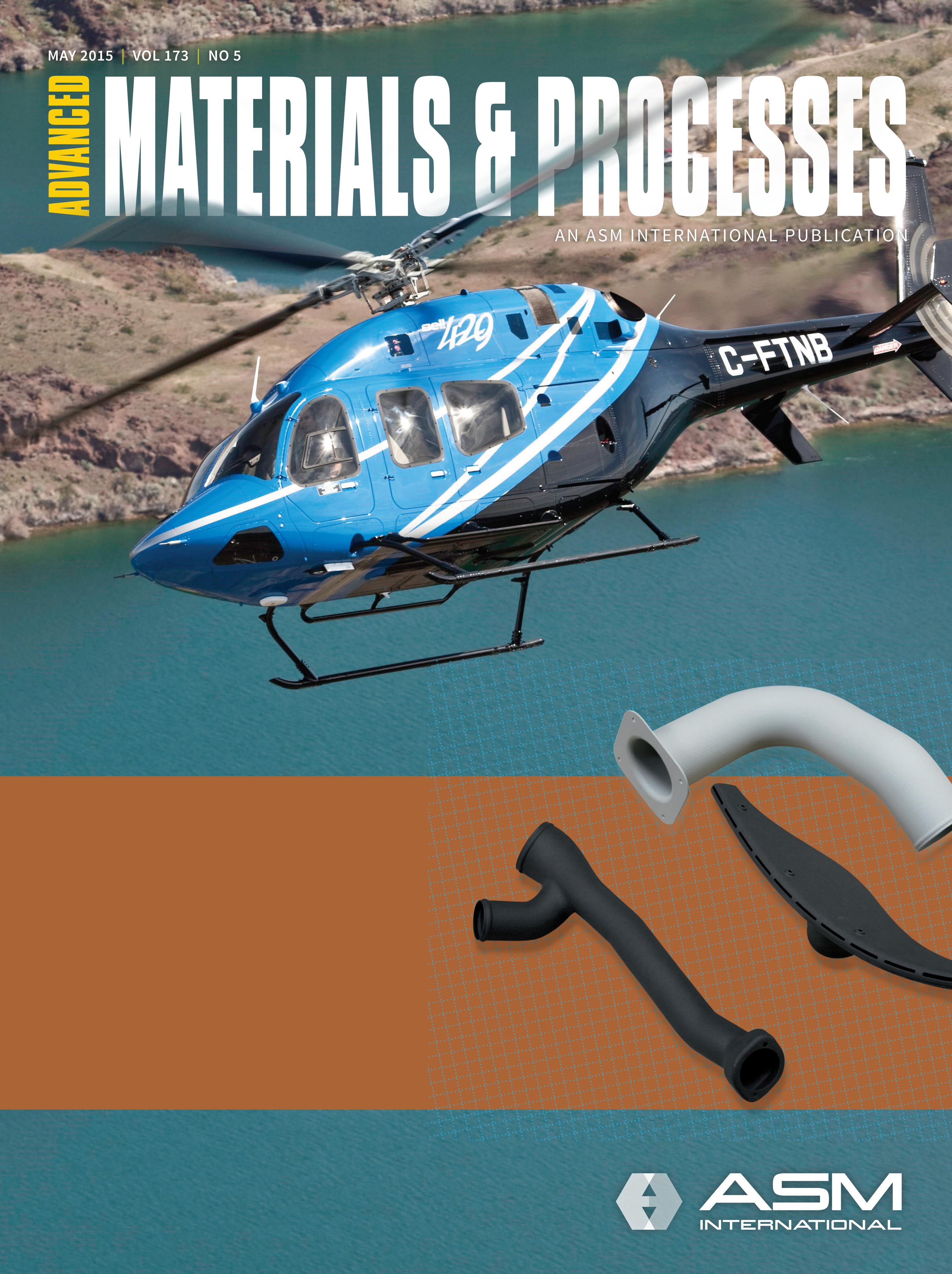

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TECHNICAL SPOTLIGHT

USING 3D PRINTING TO BUILD FLIGHT-CERTIFIED HARDWARE

Additive manufacturing continues to make strides in aerospace parts production.

On The Cover:

Parts of the environmental control system of the Bell 429 commercial helicopter are produced using EOS laser-sintering technology. Courtesy of Bell Helicopter Textron Inc., Fort Worth, Texas. bellhelicopter.com

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METALLURGY LANE

TITANIUM: PART III

Charles R. Simcoe

Titanium's potential was not fully realized until 1956 when metal production reached 5200 tons and sponge production nearly 15,000 tons.

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ASM NEWS

The monthly publication about ASM members, chapters, events, awards, affiliates, and other Society activities.

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AEROSPACE TODAY: COMPOSITES, 3D PRINTING, & A SHOT OF ESPRESSO

Many fascinating developments are taking place in the aeronautics industry, and we hope you enjoy our annual aerospace issue. Composite materials that offer high strength and low weight are one promising area. Just recently, NASA created a special partnership, the Advanced Composites Consortium, to develop composite materials for future aircraft designs. The public-private partnership includes the Federal Aviation Administration (FAA), General Electric Aviation (GE), Lockheed Martin Aeronautics Co., Boeing Research & Technology, a team from United Technologies Corp. led by Pratt & Whitney, and the National Institute of Aerospace, who will manage administrative functions.

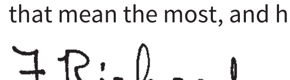
NASA formed the consortium in support of the Advanced Composites Project, part of the Advanced Air Vehicles Program in the agency's Aeronautics Research Mission Directorate. The goal is to reduce product development and certification timelines by 30% for composites used in aeronautics applications. If you're attending AeroMat this month in Long Beach, Calif., be sure to check out the composites sessions, which cover a range of topics from fundamental science and technology to process development and fabrication.

Another important area—also featured in several AeroMat sessions—covers high temperature and turbine materials. Advances in alloys, ceramics, intermetallics, and coatings will be presented, emphasizing how integrated computational materials engineering enables cost-effective, rapid development. Along these lines, be sure to read Mike Nathal's article, in which he makes the case for what appears to be "low-hanging fruit" to replace single crystals as high-pressure turbine blades—oxide dispersion strengthened (ODS) Ni-base alloys (p. 21).

Arguably, the hottest topic in aerospace parts production these days is the vast promise of 3D printing, due to its ability to create intricate components in significantly less time than traditional methods such as casting. Just a few weeks ago, the FAA cleared the first 3D-printed part to fly in a commercial jet engine from GE: It's a fist-sized piece of silver metal, which houses the compressor inlet temperature sensor inside a jet engine. GE Aviation is now working with Boeing to retrofit more than 400 GE90-94B jet engines with the 3D-printed part. In addition, GE also began flight tests with the next-generation LEAP jet engine, which holds 19 3D-printed fuel nozzles. The engine, which will power new narrow-body planes like the Boeing 737MAX and the Airbus A320neo, was developed by CFM International, a 50/50 joint venture between GE Aviation and France's Safran (Snecma).

It would normally take GE several years to design and prototype a part like the sensor housing, but the team was able to shave as much as a year from the process. "The 3D printer allowed us to rapidly prototype the part, find the best design, and move it quickly to production," says Bill Millhaem, general manager for the GE90 and GE9X engine programs. "We could never do this using the traditional casting process, which is how the housing is typically made."

And now for that shot of espresso. The SpaceX Dragon cargo capsule hooked up with the International Space Station in mid-April, delivering groceries, supplies, and an espresso machine. Italy's space agency made it happen: The new machine is the result of collaborations between engineers from the country's aerospace industry and the Lavazza coffee company. It's the little things in life that mean the most, and happy astronauts are likely more productive.



frances.richards@asminternational.org

MARKET SPOTLIGHT

REPORT ASSESSES CRITICALITY OF ALL METALS ON PERIODIC TABLE

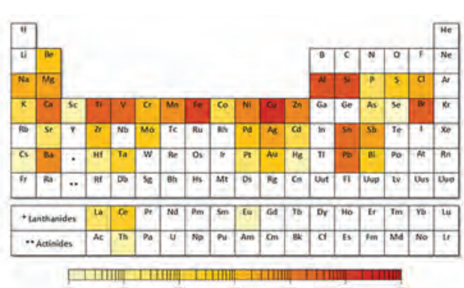
In a new report, researchers from Yale University, New Haven, Conn., assess the criticality of all 62 metals on the periodic table, providing key insights into which materials might become more difficult to find in the coming decades, which ones will exact the highest environmental costs, and which ones cannot be replaced as components of vital technologies. Many of the metals traditionally used in manufacturing, such as zinc, copper, and aluminum, show no signs of vulnerability. But other metals critical to the production of newer technologies like smartphones may be harder to obtain in coming decades, says Thomas Graedel, professor of industrial ecology at the Yale School of Forestry & Environmental Studies. The study represents the first peer-reviewed assessment of the criticality of all of the planet's metals and metalloids.

"The metals we've been using for a long time probably won't present much of a challenge," says Graedel. "But some metals that have been deployed for technology only in the last 10 or 20 years are available almost entirely as byproducts. You can't mine them specifically and they don't have any decent substitutes."

According to researchers, criticality depends on more than geological abundance. Other factors include the potential for finding effective alternatives in production processes, the degree to which ore deposits are geopolitically concentrated, the state of mining technology, regulatory oversight, geopolitical initiatives, regional instabilities, and economic policies. In order to assess the state of all metals, researchers looked at supply risk, environmental implications, and vulnerability to human-imposed supply restrictions.

Supply limits for many metals critical to the emerging electronics sector (including gallium and selenium) are the result of supply risks. Environmental implications of mining and processing present the greatest challenges with platinum-group metals, gold, and mercury. For steel alloying elements (including chromium and niobium) and elements used in high-temperature alloys (tungsten and molybdenum), the greatest vulnerabilities are associated with supply restrictions.

Among the factors contributing to criticality challenges are high geopolitical concentration of primary production, lack of available substitutes, and political instability. For example, a significant portion of tantalum, widely used in electronics, comes from the war-ravaged Democratic Republic of the Congo. *For more information, visit environment.yale.edu.*



Concentrations (in parts per million) of elements on a printed circuit board. Courtesy of Thomas Graedel, et al.

FEEDBACK

You say ALUMINUM, I say ALUMINIUM

I recently read the two historical articles on the Hall-Heroult process used to make aluminium ("Metallurgy Lane," September and October 2014). It was particularly interesting to read about Charles Hall's developmental work and the evolution of the appropriately named Pittsburgh Reduction Co. I did a literature search several years ago and found that the word for the element stems from its presence in the mineral alum. Refining of the ore produced a derivative of its name—alumina. The reduction process resulted in what was initially called aluminum.

Then, in the late 19th century, an agreement was reached with the predecessor of the International Union of Pure and Applied Chemistry to add the letter "i" to its name to bring its spelling into line with the other elements, e.g., helium, lithium, and sodium. The icing on the cake to the "Metallurgy Lane" articles would have been to answer the question of why the American Chemical Society, in 1927, reverted to the 19th century name for aluminium, i.e., aluminum.

Tony Wells, Australia

[Attention metal history buffs: If you have a theory or an answer to this naming puzzle, please drop us a line.—Eds.]

We welcome all comments and suggestions. Send letters to frances.richards@asminternational.org.

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The first and largest lab-grown diamond is 3.04 carats, shown in comparison to a 1.0-carat stone.

WORLD'S LARGEST LAB-GROWN DIAMOND SHINES BRIGHT

Pure Grown Diamonds, New York, announced a scientific breakthrough with what is said to be the world's largest laboratory-cultivated white diamonds, which are indistinguishable from mined diamonds, even under a microscope, yet cost 30% to 40% less. The first and largest lab-grown diamond is 3.04 carats. These lab-cultivated diamonds have the identical chemical composition, physical properties, and optical features of earth-mined diamonds, according to the International Gemological Institute. They also mature within six to 10 weeks, are eco-friendly, and conflict-free.

The process begins with a diamond seed placed inside a low-pressure microwave chamber. Hydrogen and methane gases are introduced while a microwave generator pumps energy into the chamber, igniting a glowing plasma ball. Carbon molecules then rain on the seed and crystallization begins. *puregrowndiamonds.com.*

USING PASTA TO EXPLAIN RING-SHAPED POLYMERS

A bowl of anelloni, consisting of ring-shaped spaghetti made from linguine, which researchers used to explain a mystery in polymer physics.

Two physicists from the University of Warwick, UK, took to the kitchen to explain the complexity of what they say is one of the final puzzles to be solved in polymer physics. As a way of demonstrating the complicated shapes that ring-shaped polymers can adopt, researchers created a new type of ring-shaped pasta, dubbed *anelloni* ("anello" is Italian for "ring"). With just two eggs and 200 g of plain flour, Davide Michieletto and Matthew Turner created large loops of pasta that, when cooked and thrown together in a bowl, get very tangled up, in much the same way that ring-shaped polymers become massively intertwined with each other.

When faced with a bowl of traditional spaghetti, it is easy to suck or pull a single strand out. Yet it is much harder to extract a single piece of pasta from a pile of anelloni. "The thing about ring-shaped polymers is that they're poorly understood—in fact, they're one of the last big mysteries in polymer physics," say researchers. While the new kind of pasta is just for fun, the real work involves carrying out computer simulations of ring-shaped polymers, which show that if molecules are long enough, they are likely to get so tangled up that that they would appear frozen in place. *For more information: Davide Michieletto, d.michieletto@warwick.ac.uk, www2.warwick.ac.uk.*

MAGNETIC GEAR REDUCER

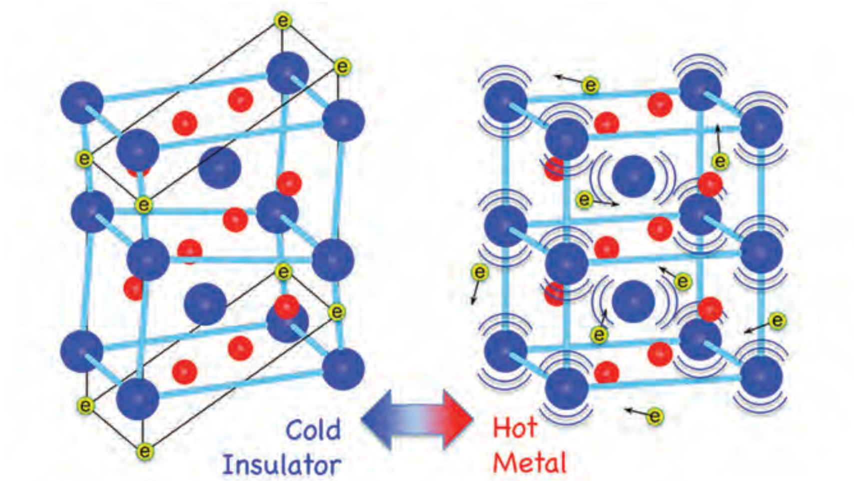
MAGDRIVE, a European research project coordinated by Professor José Luis Pérez Díaz, from the UC3M Instituto Pedro San Juan de Lastanosa, Spain, aims to develop a magnetic gear reducer—a mechanism that transforms speed from an input to an output axle, such as a bicycle chain. Unlike conventional gear reducers, the magnetic design's transmission is produced without contact between pieces.

"The operating life of these devices can be much longer than the life of a conventional gear reducer with teeth, and can even work in cryogenic temperatures," says Efrén Díez Jiménez of UC3M. "If the axle is blocked, parts simply slide among themselves, but nothing breaks." In addition, it is quieter, vibration is reduced, and through-wall transmission is achievable. Although the main goal of the MAGDRIVE project is to build a prototype that can be used in the extreme conditions of space, another version that can be used at room temperature was also developed. *www.uc3m.es/Home.*

Researchers at UC3M are developing a new transmission mechanism with no touching parts, based on magnetic forces that prevent friction and wear, eliminating the need for lubrication.

Are you working with or have you discovered a material or its properties that exhibit OMG - Outrageous Materials Goodness?
Send your submissions to Julie Lucko at julie.lucko@asminternational.org.

METALS | POLYMERS | CERAMICS



Changes in the crystal structure and electronic properties of VO_2 occur during its insulator-to-metal phase transition (V blue; O red). Above 67°C (right), large-amplitude, nonlinear lattice vibrations (phonons) lead to a tetragonal crystal structure with mobile electrons (yellow) indicating that the vanadium dioxide is a metal. At lower temperatures (left), the electrons are localized in the atomic bonds in the distorted monoclinic crystal structure indicating that the vanadium dioxide is an insulator. Courtesy of ORNL.

SOLVING A 50-YEAR-OLD VANADIUM DIOXIDE MYSTERY

At the transition temperature, vanadium dioxide's electrical conductivity abruptly increases by a factor of 10,000 and the atomic lattice rearranges from a monoclinic to a tetragonal structure. A fundamental description of the physical and electronic properties during the transition in VO_2 has remained controversial for more than 50 years. Now, researchers at Oak Ridge National Laboratory, Tenn., are using advanced neutron and x-ray scattering experiments at DOE facilities, coupled with large-scale first-principles calculations with super computers, to determine the detailed mechanism for the transition.

Their studies reveal that the thermodynamic force driving the insulator-to-metal transition is dominated by the lattice vibrations (phonons) rather than electronic contributions. In addition, a direct, quantitative determination of the phonon dispersions was achieved, as well as a description of how changing occupancies in the atomic orbitals participate in the phase transition. The low-energy phonons change the bonds between atoms (i.e., electron orbitals), allowing some electrons to travel freely at higher temperatures leading to a metallic state. This research demonstrates that anharmonic lattice dynamics play a critical role in controlling phase competition in metal oxides, and provides the complete physical model vital for the predictive design of new materials with unique properties. *ornl.gov.*

COOKING UP ANTIBACTERIAL PLASTIC FOR HEALING

Bioplastics made from protein sources such as albumin and whey show significant antibacterial properties, findings that could eventually lead to their use in medical applications such as wound healing dressings, sutures, catheter tubes, and drug delivery, according to a recent study by the University of Georgia College of Family and Consumer Sciences, Athens. Researchers tested three nontraditional bioplastic materials—albumin, whey, and soy proteins—as alternatives to conventional petroleum-based plastics that pose risks of contamination. In particular, albumin, a protein found in egg whites, demonstrates tremendous antibacterial properties when blended with a traditional plasticizer such as glycerol. *uga.edu.*

BRIEF

A new mountaineering shoe called the Edging Chassis from **Salomon,** France, uses the high-performance, bio-based EcoPaXX polyamide from **Royal DSM,** the Netherlands. EcoPaXX enables production of a chassis with an intricate design that is light and flexible yet rigid, retains its properties at low temperatures, and has reduced moisture uptake, despite being a polyamide. The material is suitable for injection molding and certified as carbon neutral. *ecopaxx.com.*

Image courtesy of DSM Engineering Plastics.

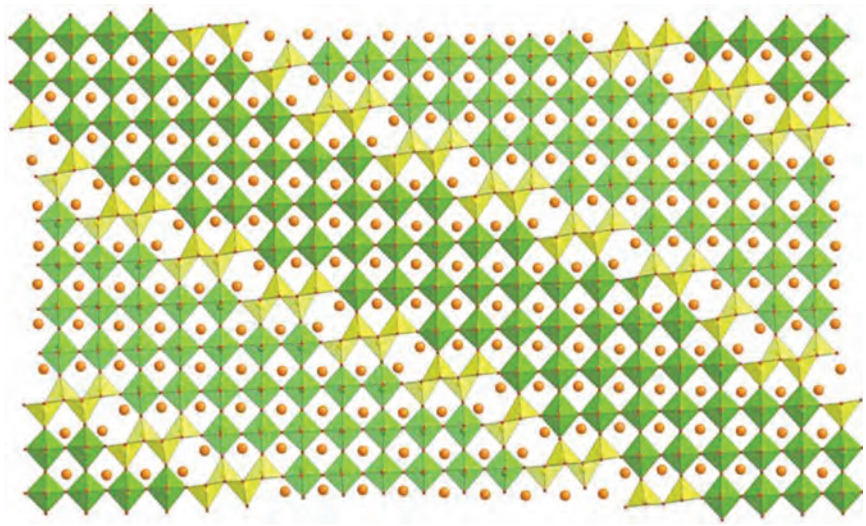
SMART GLASS COULD POWER CELL PHONES

Researchers at the Georgia Institute of Technology, Atlanta, produced a color-changing glass that creates enough electrical charge to power a smartphone. The team developed several types of smart glass by subjecting materials to rain and wind. Their objective was to find a way to coat windows to facilitate triboelectrics, the process of harnessing energy in static electricity that happens when two materials meet. Two layers of solution achieved the desired effect: One was used to harness the energy found in raindrops while the other was to do the same for wind. Researchers created nanosized generators for the first layer that use the positive charge in raindrops. This occurs when the water droplets rub against air as they fall to the earth and make contact with the windshield of a car.

Georgia Tech researchers discovered a new type of color-changing glass that harnesses static charges from wind and raindrops. The electricity produced could power mobile devices. Courtesy of Jenny Downing/Flickr.

The second layer involves sandwiching two charged plastic sheets with small springs. As the car accelerates, wind pressure builds up, pushing the sheets against each other. This produces the electric current needed for the experiment. By combining the two layers, researchers were able to create a type of glass that is initially clear but then becomes blue in tint. The process also produces around 130 mW of electricity per square meter of the glass, enough to power a smartphone battery. *gatech.edu.*

TESTING | CHARACTERIZATION



Refined structure of $(Pb,Bi)_{1-x}Fe_{1+x}O_{3-y}$. Courtesy of Batuk, et al.

COMBINED METHODS OFFER BEST OF BOTH WORLDS

Electron crystallography is routinely used to solve otherwise intractable structures. Now, combining powder diffraction data with electron crystallography offers a clearer view of modulated structures. When performed in an aberration-corrected microscope and combined with spectroscopic techniques, it can offer unprecedented detail down to sub-angstrom resolution.

"The result of all this progress is that electron crystallography provides answers to more and more questions that used to be the domain of x-ray or neutron diffraction, and is especially useful when the x-ray or neutron experiment needs to be performed on a powder material, which limits the diffraction information available," says Lukas Palatinus of the Czech Academy of Sciences in Prague.

Palatinus points out that when confronted with modulated structures, in which every atomic position is perturbed from one unit cell to the next by a modulation function, the construction of the structure model is much more complicated than for nonmodulated materials. While existing techniques can solve this problem from single crystal diffraction data, another approach is needed for powder diffraction data, which is where the work of Dmitry Batuk and colleagues come in. Batuk has shown how electron crystallography tools can be used to sidestep the limitations of powder diffraction and complement the structure analysis of modulated structures by powder diffraction. The team investigated a series of anion-deficient perovskites to demonstrate proof of principle. In these materials, modulation arises as a consequence of the presence of crystallographic shear planes that have an average periodicity that is not in synchrony with the materials' basic periodicity. In addition, given the advent of research into perovskites for solar panels and semiconductor applications, new information about their structures and properties is increasingly important.

However, electron crystallography is unlikely to make x-ray or neutron diffraction redundant any time soon, says Palatinus, because many materials are too short lived under the degrading eye of the electron beam. Further, electron techniques generally cannot be applied in situ in chemical reaction environments nor under pressure, instead requiring near vacuum conditions. "The key to success lies in exploiting the synergy between various methods," he adds. *www.cas.cz.*

BRIEFS

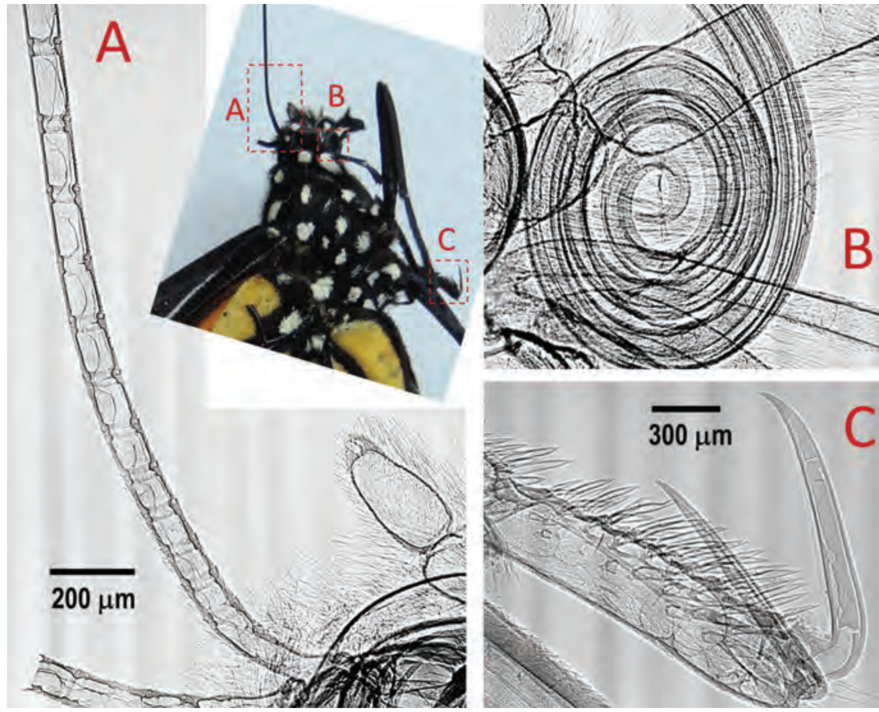
NASA has partnered with five organizations to provide in-depth knowledge on composite materials that could be used to boost aircraft efficiency. Partners include **Boeing Research & Technology,** St. Louis; **Lockheed Martin Aeronautics Co.,** Palmdale, Calif.; **General Electric Aviation,** Cincinnati; the **Federal Aviation Administration,** Romulus, Mich.**;** and a team from United Technologies Corp. led by **Pratt & Whitney,** Hartford, Conn. The consortium was formed in association with the Advanced Composites Project, part of the Advanced Air Vehicles Program in NASA's Aeronautics Research Mission Directorate. *nasa.gov.*

Westmoreland Mechanical Testing & Research Ltd. opened a new materials testing facility in Oxfordshire, UK. The site is triple the size of the previous location, Nadcap certified, and UKAS ISO 17025 accredited. The facility offers additional fatigue and tensile testing capabilities and enhanced composites testing. It also features an upgraded metallography lab, enhanced machining capabilities, and a new lab information management system. *www.wmtr.co.uk.*

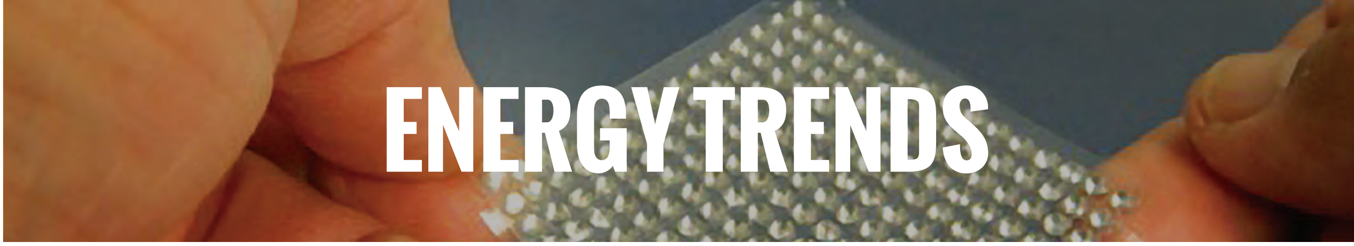
NSLS-II PRODUCES INAUGURAL IMAGES

At the National Synchrotron Light Source II (NSLS-II) at DOE's Brookhaven National Laboratory, Upton, N.Y., scientists working at the Hard X-Ray Nanoprobe (HXN) produced the facility's inaugural x-ray images. Their striking renderings of a monarch butterfly demonstrate the synchrotron's ability to generate extremely detailed images. After the beamline components and optics were aligned, monochromatic x-rays were sent from the first optical enclosure to the experimental station. Next, the images were taken using a high-resolution CCD camera with an optically coupled scintillation screen. The group used an imaging resolution of 1.5 microns per pixel. Test images were produced using x-rays only one-thousandth of the maximum power of NSLS-II.

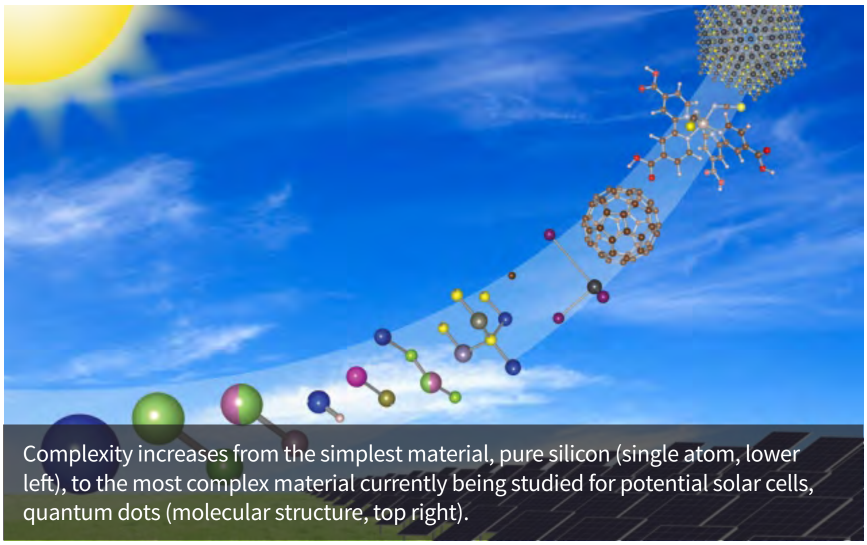
The butterfly sample was positioned 63 m from the x-ray source, and the CCD camera was placed 160 mm away from the sample. This camera-to-sample distance was chosen to yield images with optimal contrast using a method called in-line phase-contrast imaging. Because the butterfly was much larger than the field of view of the camera, different parts of the specimen were imaged separately. Images were then stitched together to construct a broader view. "The images show amazing contrast, as if they were hand-drawn by an artist," says Hanfei Yan, an HXN beamline scientist. *bnl.gov.*



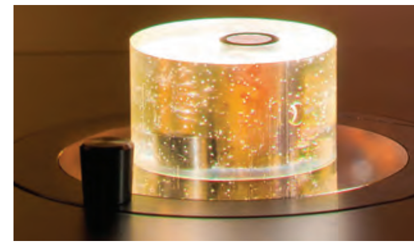
X-ray image of butterfly antennae (a), mouth (b), and claw (c). Imaged regions are indicated in the optical microgram in the center.



ENERGY TRENDS



Complexity increases from the simplest material, pure silicon (single atom, lower left), to the most complex material currently being studied for potential solar cells, quantum dots (molecular structure, top right).



Argonne National Laboratory coordinates nationwide battery research through the Joint Center for Energy Storage Research, in an initiative that aims to make batteries five times more powerful and five times cheaper within five years. Courtesy of ANL.

OVERCOMING SOLAR POWER CHALLENGES

In a broad new assessment of the status and prospects of solar photovoltaic technology, Massachusetts Institute of Technology, Cambridge, researchers say it is “one of the few renewable, low-carbon resources with both the scalability and technological maturity to meet ever-growing global demand for electricity.” Solar photovoltaics use is growing at a phenomenal rate—worldwide installed capacity has seen sustained growth averaging 43% per year since 2000. To evaluate the prospects for sustaining such growth, researchers look at possible constraints on materials availability and propose a system for evaluating the many competing approaches to improved solar-cell performance.

The report divides the many technologies under development into three main classes: Wafer-based cells, which include traditional crystalline silicon, as well as alternatives such as gallium arsenide; commercial thin-film cells, including cadmium telluride and amorphous silicon; and emerging thin-film technologies, which include perovskites, organic materials, dye-sensitized solar cells, and quantum dots. *web.mit.edu.*

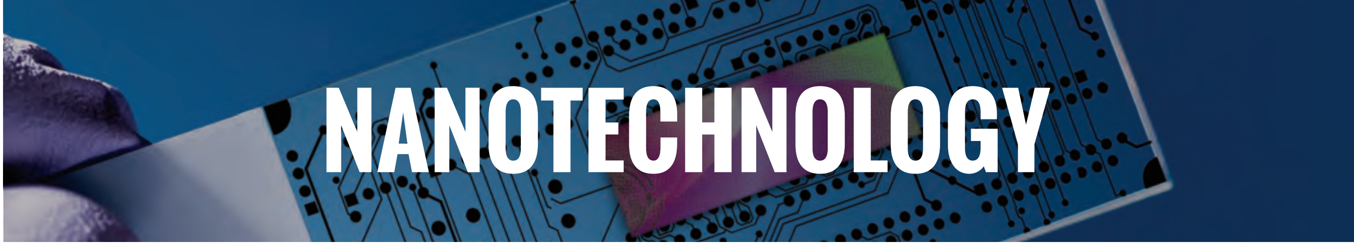
BUILDING A SUPER BATTERY

A new book by Steve LeVine, *The Powerhouse: Inside the Invention of a Battery to Save the World,* takes an inside look at Argonne National Laboratory's (Lemont, Ill.) research into building a super battery. The book, according to Levin, lays out the high stakes of the battery race: The winner would steer geopolitical power away from Russia and the Middle East, dominate the production of affordable electric cars, and mitigate climate change by transforming the electric grid, drastically reducing fossil fuel consumption. For LeVine, a veteran reporter for the *Wall Street Journal, The New York Times,* and *Newsweek,* finding the epicenter of American battery research was easy. Argonne employs several of the world's top experts, including Michael Thackeray, a pioneer in the lithium battery technology inside the hybrid-electric vehicle Chevy Volt. But while the lab's work is no longer top secret, it still took LeVine a year to gain permission to embed himself within the lab. Even after the Department of Energy granted approval, Argonne's scientists had reservations about LeVine spending two years with them. Although he didn't witness a major scientific breakthrough, LeVine's book culminates with Argonne's successful 2012 bid to host the DOE's battery innovation hub, to be modeled after the scientific management characteristics of the Manhattan Project. *stevelevinebooks.com, anl.gov.*

BRIEF

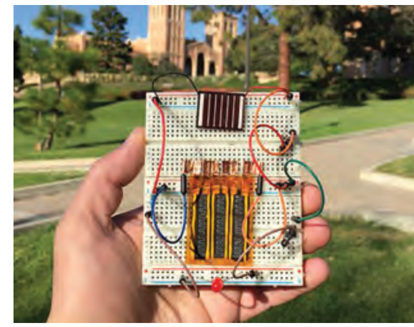
Five years and more than 35,000 European sales since the launch of its all-electric LEAF vehicle, proprietary data released by **Nissan Motor Corp.,** Switzerland, shows that the failure rate of the battery power unit is less than 0.01%—just three units in total—a fraction of the equivalent industry-wide figure for defects affecting traditional combustion engines. With only three main components—the on-board charger, inverter, and motor—Nissan says the LEAF is 40% cheaper to maintain compared to petrol or diesel-powered alternatives. *www.nissan.co.uk.*

Nissan LEAF. Courtesy of Business Wire.



NANOTECHNOLOGY

Artist's impression of shape-complementary DNA components that self-assemble into nanoscale machinery. Courtesy of C. Hohmann/NIM.



A hybrid supercapacitor developed at UCLA stores large amounts of energy, recharges quickly, and can last for more than 10,000 recharge cycles.

DNA ORIGAMI ENABLES NANOMACHINERY

The latest DNA nanodevices created at the Technische Universität München (TUM), Germany, including a robot with movable arms, a book that opens and closes, and a switchable gear may demonstrate a breakthrough in the science of using DNA as a programmable building material for nanoscale structures and machines. Researchers developed a new approach to joining and reconfiguring modular 3D building units, by snapping together complementary shapes instead of zipping together strings of base pairs. This not only opens the way for practical nanomachines with moving parts, but also offers a toolkit that makes it easier to program their self-assembly.

The field popularly known as *DNA origami* is advancing quickly toward practical applications, according to Hendrik Dietz, professor at TUM. To create a dynamic DNA nanomachine, researchers first programmed self-assembly of 3D building blocks that are shaped to fit together. A weak, short-ranged binding mechanism called nucleobase stacking can then be activated to snap these units in place. Dietz compares it to building with children's toys like LEGOs, "You design the components to be complementary, and that's it. No more fiddling with base-pair sequences to connect components." *For more information: Hendrik Dietz, professorenprofile@zv.tum.de, www.tum.de/en.*

QUICK-CHARGING SUPERCAPACITORS HOLD PROMISE FOR STREET LIGHTING

A new hybrid supercapacitor developed at University of California, Los Angeles, stores large amounts of energy, recharges quickly, and can last for more than 10,000 recharge cycles. The dramatic rise of smartphones, tablets, laptops, and other personal and portable electronics has brought battery technology to the forefront of electronics research. Even as devices have improved by leaps and bounds, the slow pace of battery development has held back technological progress. Researchers at UCLA's California NanoSystems Institute have successfully combined two nanomaterials to create a new energy storage medium that combines the best qualities of batteries and supercapacitors.

Researchers also created a microsupercapacitor that is small enough to fit in wearable or implantable devices. Just one-fifth the thickness of a sheet of paper, it is capable of holding more than twice as much charge as a typical thin-film lithium battery. *For more information: Richard Kaner, rbk@chem.ucla.edu, chemistry.ucla.edu.*

BRIEF

The Chancellor of the Exchequer George Osborne officially opened the **National Graphene Institute (NGI) at The University of Manchester,** UK. The NGI will enable academia and industry to work side-by-side on future graphene applications. More than 35 companies from around the world have already chosen to partner with the university to work on graphene-related projects. The 7825 m^2, five-story building features cutting-edge facilities and equipment to create a world-class research hub. The NGI's 1500 m^2 of clean room facilities is the largest academic space of its kind for dedicated graphene research. *www.graphene.manchester.ac.uk.*

TECHNICAL SPOTLIGHT

USING 3D PRINTING TO BUILD FLIGHT-CERTIFIED HARDWARE

Additive manufacturing continues to make strides in aerospace parts production.

In 1941, Arthur M. Young demonstrated an ingeniously engineered model helicopter flying on a tether while working for Bell Aircraft Corp. Five years later, the company received the first-ever certification for a commercial helicopter. Today, Bell Helicopter Textron Inc., Fort Worth, Texas, has manufactured more than 35,000 helicopters. Bell Helicopter works with Harvest Technologies, Belton, Texas, an additive manufacturing (AM) services provider with more than 40 AM systems, many of them used to create end-use components and assemblies.

Collaboration between Bell and Harvest proves that AM is a high quality, repeatable, and cost-effective manufacturing process, in this case with plastic laser-sintering technology from EOS GmbH Electro Optical Systems, Germany.

From concept to reality, Arthur Young poses with his final research model, alongside the commercially certified Bell Model 47B helicopter. Courtesy of Bell Helicopter Textron Inc., circa 1947.

LASER SINTERING PRODUCES 3D-PRINTED PARTS

For years, Bell Helicopter and Harvest have partnered to produce flight-certified hardware on a standard laser-sintering platform. Bell believed it could achieve success with laser sintering due to its extensive experience qualifying both products and manufacturing processes, while Harvest has the necessary expertise in AM.

Harvest purchased an EOSINT P 730 plastic laser-sintering system in 2011. The system features twin 50-W lasers working in tandem over an expansive build area—a first for laser-sintering technology—to achieve a layer-by-layer build speed of 35 mm (1.38 in.) per hour of height. The platform offers several advantages for qualifying this machine for end-use parts production.

"The parts we get from the P 730 have very good feature definition, and the powder color is consistently less oxidized," says Harvest quality manager Caleb Ferrell. "Mechanical properties are also good. We're especially happy with the larger platform size and the nestability aspect."

The ample platform size and nestability contribute to reducing per-unit cost. The build platform measures 700 × 380 × 580 mm (27.5 × 15 × 23 in.), larger than Harvest's standard laser-sintering systems. The increased size enables production of more components in a batch and far more than traditional laser-sintering platforms, especially when careful nesting practices are used. Nesting also achieves more cost effective, low volume production.

For example, Bell Helicopter and Harvest converted a number of aircraft parts made using other manufacturing processes to laser sintering. "A preconception is that additive manufacturing is more costly compared with alternate manufacturing methods, with design flexibility being the premium feature, but we often discover that production cost per piece is substantially reduced using the P 730," says Elliott Schulte, Bell Helicopter engineer. (See sidebar.)

VERIFICATION PROCESS

Before production could begin, Bell Helicopter and Harvest needed to prove out the P 730 and its processing capabilities to certify the platform for use. While the new technological advances included in the system along with the sheer platform size provide greater efficiencies, the companies needed to ensure this was not at the cost of part integrity.

The dual laser system and subsequent "knit line" presented new considerations to analyze and evaluate. Verifying a new platform meant not only addressing these factors, but also examining other common issues such as heat distribution (part bed temperature consistency), powder degradation, dimensional accuracy, repeatability, part quality, part performance, and overall economics of the platform.

Bell Helicopter initially characterized a variety of laser-sinterable Nylon 11s and 12s, for which materials and manufacturing methods were covered by company-authored specifications. The resulting materials characterization and properties database ensured that the P 730 machine qualification (both system and process) was accomplished quickly.

Mechanical properties of each laser-sintered build were characterized to confirm that the EOS system met specification requirements and produced the same product quality each time. A number of different material lots and a series of individual builds were tested to establish that laser sintering was robust and highly repeatable for producing identical results.

After laser sintering, completed parts require "breaking out" from the powder.

Bell Helicopter also followed its standard procedure used to audit suppliers, which not only ensures conformance to its process specification, but also serves as a quality audit by

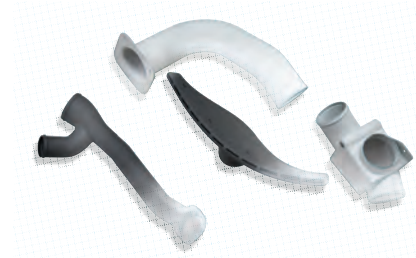
Excess powder is removed and much of it reused for subsequent builds.

periodically reviewing Harvest's QA system with respect to AS 9100C—the SAE quality management standard for aerospace. After qualifying the AM system and nylon materials, Bell Helicopter and Harvest began the meticulous sequence of manufacturing aerospace hardware, which involves many checks and confirmations along the way.

PARTS PRODUCTION

Consider a hypothetical example of Bell Helicopter wanting to incorporate a new piece of ductwork into the environmental control system (ECS) of a commercial helicopter. The engineering team would use the database created to qualify the P 730 to design a duct based on specified mechanical properties. The part could differ from an earlier design by merging several components into one (part consolidation), or by creating its form for maximum functionality rather than manufacturing demands such as draft angle for molding, wall thickness limitations due to material input, or rounded corners for CNC machining. The final design must meet the same performance specifications.

It is possible that the redesigned part could have a different shape and features, according to Christopher



Plastic laser sintering is capable of creating complex shapes such as ductwork. Images on this page courtesy of Harvest Technologies.

Gravelle, leader of Bell Helicopter's rapid prototyping lab. For example, it might not be possible to use the exact configuration of bosses made of laser-sintered nylon for attachment points as those used for a metal part. Many designs are treated as a mostly "clean slate," because laser sintering provides a great deal of flexibility and freedom.

After final review of the design for system producibility, a 3D CAD model is sent to Harvest with a request for quote for development of a build strategy. Some questions include: Is the part large enough to manufacture on its side, speeding up the build? Should it be made (or grown) standing vertically to take advantage of tighter uniformity and accuracy on the *x-y* axis? How nestable is it, and how many units can be made in a single build? Answering these and other questions enables submitting an accurate pricing quotation.

When production begins, before each batch, a rigorous checklist of preproduction inspections (for example, a nitrogen leak rate check) developed by Harvest is carried out, which reduces waste and ensures part quality. The list is developed specifically for the P 730 based on previous production runs.

Batches of laser-sintered parts built successively (often left unattended overnight) are thoroughly inspected and tested for tensile and flexural properties. This requirement was established by Harvest for process assurance. Tensile bars are incorporated along the *x*, *y*, and *z* axes of each batch during part production. If the bars pass the tensile test, parts built in that batch pass as well. Harvest also documents manufacturing from beginning to end, including

MAKING AIRCRAFT PARTS ON THE EOSINT P 730

Bell Helicopter and Harvest selected the EOSINT P 730 for manufacturing aircraft parts after careful study and testing, focusing on the intertwined technical and financial benefits. In addition to increased nestability, the larger EOS build platform provides a number of benefits. For example, building bigger components in one piece rather than in sections enables a stronger and more lightweight part, and also eliminates some assembly operations.

Another advantage of the EOS system is the clean surface it produces. Some competing AM technologies produce satisfactory parts, but peripheral heat from the laser beam melts adjacent powder resulting in unwanted particle adhesion and the need for additional post-processing to polish the surfaces.

"We were able to achieve the desired quality with the other additive system," says Ron Clemons, director of business development at Harvest, "but there was a lot more finishing labor associated with it than on the EOS platform." The P 730 incorporates a software fix for laser sintering that provides crisper detail and smoother surfaces. Switching to the EOS system offered significant post-processing cost savings and shorter lead times for Bell Helicopter.

An important secondary benefit of EOS laser-sintering technology is increased recyclability of the plastic powder. With other AM processes, breaking out the part from the bed of powder leaves behind a significant amount of unusable partially melted powder, which must be discarded, so the bulk of production is performed with virgin powder. The reduction of waste in the P 730 enables recycling of leftover powder.

Laser-sintered ductwork installed in a helicopter airframe. Images on this page courtesy of Bell Helicopter Textron Inc.

Parts of the environmental control system of the Bell 429 commercial helicopter were produced using EOS laser-sintering technology.

mechanical integrity, unique serial IDs for each part, and material certification.

A preproduction sample is sent to Bell Helicopter for examination to ensure that it is functional, fits accurately with other components, meets engineering specifications, and that Harvest's inspection procedure is correct and complete.

"We have full confidence in Harvest and their quality assurance program," says Schulte. "Once their QA is complete, when warranted, we go to some lengths ourselves to make sure that the design intent is also met. We continue to work with Harvest to streamline production and take advantage of additive manufacturing technology maturation." Only when this final scrutiny is complete does Harvest ship the rest of the production batch to Bell Helicopter.

LOOKING AHEAD

Bell Helicopter continues to propose innovative designs in the form of CAD models that Harvest turns into physical parts. In fact, Bell is interested in using laser-sintered parts throughout the aircraft systems of its commercial helicopters. Currently, the company is mostly using laser-sintered components in the ECS system, but is starting to incorporate laser-sintered hardware into other assemblies. It will also evaluate laser sintering of high-temperature plastics intended for use in more demanding roles and environments.

AM is transforming more than the designs at Bell Helicopter. Engineers are taking advantage of the freedom that comes with applying EOS technology, creating small components, working with larger ones than in the past, and using the part-integrating capability of laser sintering to eliminate assembly costs. **~AM&P**

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ADVANCED TURBINE AIRFOIL DEVELOPMENT STRATEGIES: HARVESTING LOW-HANGING FRUIT

Oxide dispersion strengthened alloys still have potential to improve turbine blade temperature capability beyond that of superalloy single crystals.

Mike Nathal, NASA Glenn Research Center (retired), Cleveland

A high-pressure turbine rotor is subjected to the most demanding conditions in the turbine engine, which places stringent requirements on the materials used. Turbine blades require a balance of creep resistance, high temperature capability, environmental resistance, and damage tolerance. Today's blade performance and durability are achieved through a combination of advanced alloys, sophisticated internal cooling schemes, and thermal barrier coatings (TBCs). Turbine blades have been made of nickel-base superalloy single crystals for 30 years. Improvements in alloy strength were achieved over the years by increasing refractory element (RE) content and reducing chromium content, and the various alloys are categorized into about four generations of development.

Successive generations of alloys significantly increased creep strength together with concurrent increases in cost and alloy density and decreases in microstructural stability and environmental resistance (especially in the third and fourth generations). Further, the magnitude of improvement in creep resistance with each succeeding generation diminished as shown in Fig. 1. Alloy development in recent years has aimed at reducing density[1] and Re levels[2] while maintaining current creep resistance rather than increasing it.

Improvements in fuel efficiency and exhaust emissions expected from next-generation turbine engines require further increases in hot section materials capability. There is no obvious materials development strategy available to produce further improvements in temperature capability without upsetting the balance of properties achieved in single-crystal superalloys. Higher reliance on TBCs is a possible strategy, although the consequences of coating spallation are still quite serious. One means of mitigating the risk of coating spallation is to incorporate self-indicating features into the coating system, whereby dopants at different depths within the topcoat layer have varying luminescence and thus enable easy inspection for erosion or spallation[3].

Ceramic-matrix composites (CMCs) remain the prime candidates to replace superalloys for ultimate gains in performance, especially at temperatures above about 1200°C. SiC/SiC composites exhibit substantial improvements in mechanical performance[4], and manufacturing technology has matured substantially[5]. However, risks associated with CMCs include relatively low strength

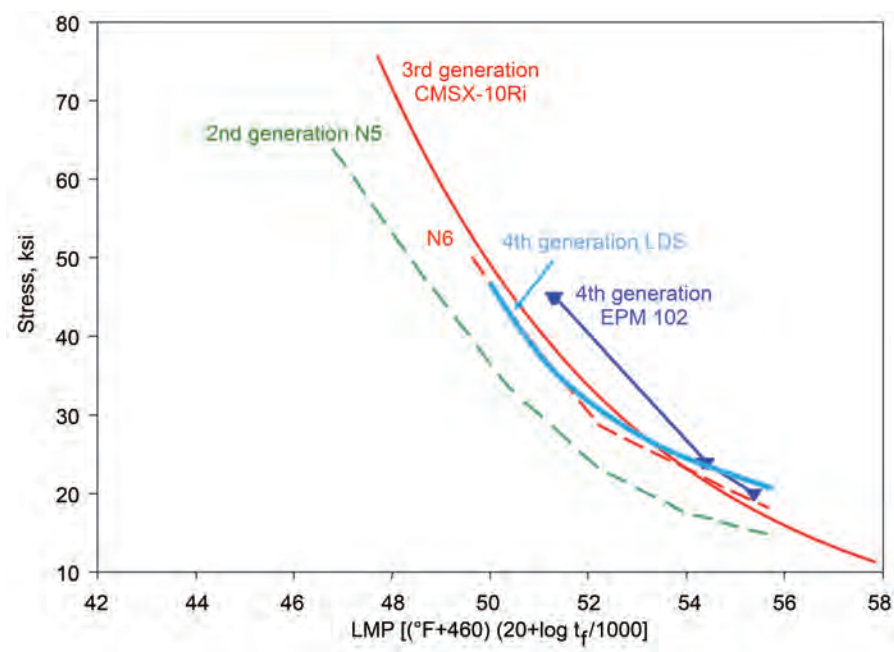

Fig. 1 — Larson-Miller curves for single-crystal superalloys. Improvements in creep strength of succeeding generations of alloys have diminished.

levels for cracking and environmental ingress, poor response to foreign object impact events, and moisture-induced recession effects in high combustion pressures[6], requiring reliance on environmental barrier coatings on component surfaces[7]. Thus, it is still premature to assume ubiquitous applications of CMCs throughout an engine.

Significant resources were invested over the past 20 years on high-temperature silicides as potential replacements for superalloys. $MoSi_2$-[8], MoSiB-[9] and NbSi-[10] base alloys emerged from screening numerous research results as the most promising candidates, as they improved strength, toughness, and oxidation resistance. However, no alloys were developed with the balance of properties required for a turbine blade, especially for a high-pressure turbine. In addition, many improvements in toughness were achieved through compositing strategies, which can be equally applied to CMCs that have much lower density than any other silicide. Thus, there appears to be very little room for silicides between superalloys and CMCs.

The recent discovery of γ-γ' microstructures in Co-base alloys has sparked interest[11]. Advantages include higher melting points and improved solidification behavior compared with Ni-base alloys, and high toughness compared with ceramics. However, their high densities (exceeding 9 g/cm^3), low γ' solvus, and unknown oxidation resistance remain formidable barriers to their use. While it is too early to rule out Co-base alloys as candidates for high-pressure turbines, the alloy strategy is yet unproven.

In this article, the case is made for what appears to be "low-hanging fruit" to replace single crystals as high-pressure turbine blades—oxide dispersion strengthened (ODS) Ni-base alloys. ODS alloys combine proven technology, substantial gains in capability over today's alloys, and a clear development path to overcome identified risks.

HISTORICAL BACKGROUND

Mechanically alloyed ODS superalloys were developed in the 1970s, primarily by Inco Alloys. Both Fe- and Ni-base alloys were developed and commercialized, and are used in aircraft gas-turbine engines and industrial turbines[12]. Components include turbine blades and vanes, nozzles, and combustor/augmenter assemblies. However, ODS alloys fell out of favor and have not been actively pursued in the U.S. for more than 20 years.

Mechanical alloying is used to produce a uniform distribution of submicron oxide particles in a highly alloyed matrix[13]. Alloys are formed from pure elemental or pre-alloyed powders plus about 2 vol% very fine (25 nm) yttria (Y_2O_3). The powder mixture is milled in high-energy ball mills to fully homogenize the elemental additions, followed by consolidation and hot working. Typically, ODS alloys are then directionally recrystallized to form an elongated grain structure. After milling and consolidation, Y_2O_3 is converted to yttrium aluminum garnet (YAG). FeCrAl-base alloys MA956 and PM2000, NiCrAl-base solid solution alloys MA754 and PM1000, and γ'-strengthened MA6000 were the most widely used alloys.

Oxidation and hot corrosion resistance of commercial ODS alloys range from good to excellent[14]. In addition, ODS alloy compositions are so similar to those of superalloy single crystals that compatibility with existing aluminide and overlay coatings[15], as well as TBCs, is expected to be excellent. Solid-solution alloys have excellent creep strengths at very high temperatures, usually at or above 1100°C. However, creep strengths at intermediate temperatures (750-850°C) are much lower than γ'-strengthened alloys. MA 6000 was developed to compete with single crystals as a turbine airfoil alloy, and is strengthened by both oxides and γ'. It has significantly improved intermediate temperature creep strength without sacrificing very high temperature strength. Benn and coworkers developed more advanced alloys, known as Alloys 51 and 92, that improved the intermediate temperature creep strength of MA6000[16].

Most importantly, two other studies show substantial improvements in high-temperature creep strength. Glasgow[17] showed that combining ODS with γ' strengthening produced an alloy with more than 150°C increase in temperature capability compared with the same alloy with γ' strengthening only (Fig. 2). Kawasaki, et al.[18,19], reported exceptional creep properties for two alloys, TMO-20 and TMO-16. Figure 3 shows that TMO-16 has a 100°C advantage over Rene N6 at 200 MPa. Alloy densities of ~8.9 g/cm^3, calculated using JMatPro[20], are roughly equivalent to third generation single-crystal alloys. An important feature of these

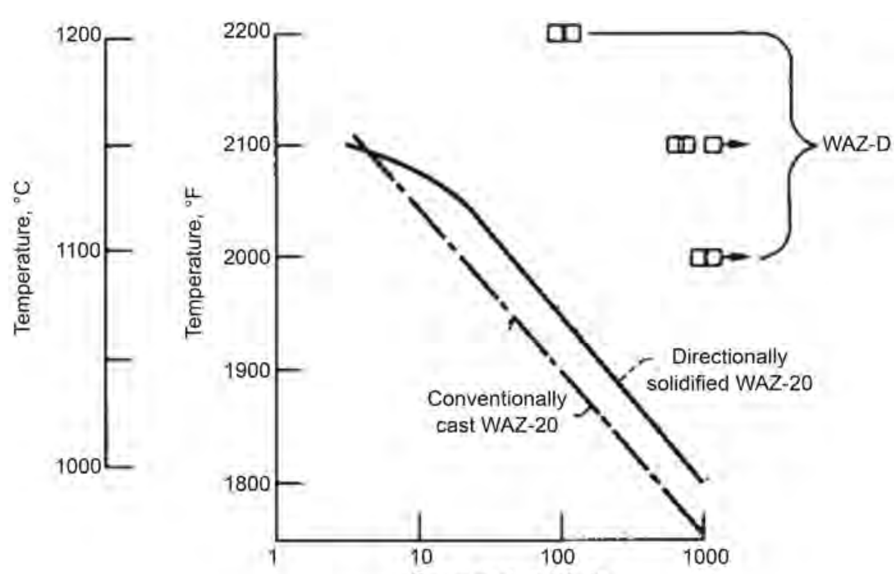

Fig. 2 — Benefits from combining γ' and oxide strengthening. ODS alloy WAZ-D shows a creep strength improvement of 130°C over WAZ-20, with essentially the same composition[17].

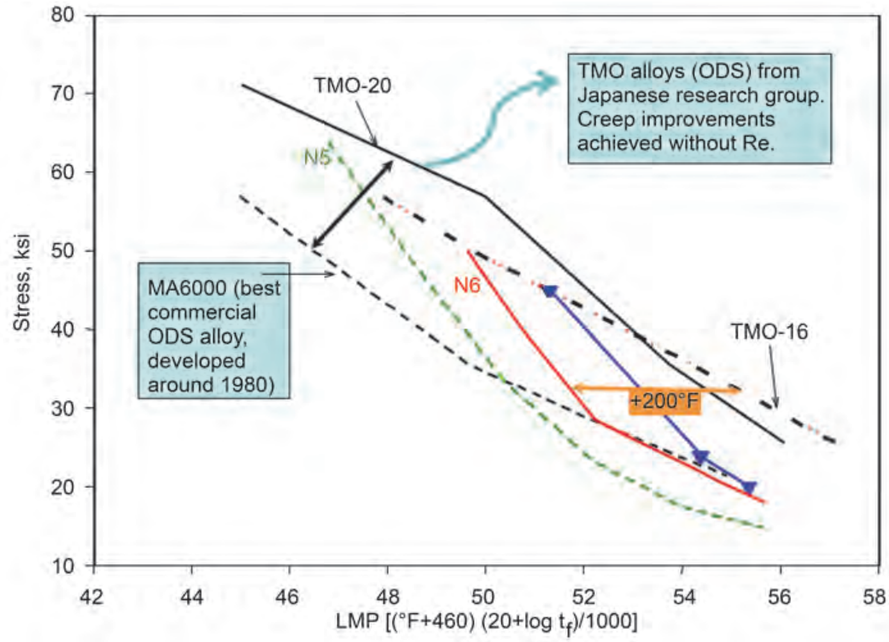

Fig. 3 — Early ODS alloys show substantial improvements in creep capability over the best single crystals, which is still true today, and without any refractory element additions[18,19].

results is that the exceptional creep properties were obtained without any Re additions.

These properties underlie the central reason for the current proposal to revive ODS alloys as turbine blade materials. Exceptional creep properties were already demonstrated in compositions that are inherently ductile, oxidation and corrosion resistant, and of acceptable density. Further, design of ODS alloys is comparatively unexplored, so the opportunity for future improvements is quite large. For example, MA6000's high Cr content (15%) and low refractory metal content reflect its targeted application of industrial gas turbines and betrays its age—and is a major reason for optimism in predicting improved properties via alloying.

POTENTIAL BARRIERS TO ODS ALLOYS

As mentioned previously, in the 1980s and 90s, ODS alloys suffered from competing with single-crystal superalloys. Described here are past ODS shortcomings, which can serve as a list for technology improvements required to develop these alloys for future engines.

Competition from single crystals in terms of creep strength. Continued improvements in single-crystal properties since the 1980s are reported in the literature, in contrast to very limited improvements in ODS alloys, especially over the temperature range of interest from 750° to 1100°C. As described previously, it is under-appreciated that exceptional creep properties were generated in Re-free alloys by Glasgow in 1976 and Kawasaki, et al., in 1990. These studies may have been discounted due to other issues with ODS alloys, but they have more significance now because development of single-crystals appears to have reached a point of limited improvements.

Competition from single crystals in terms of cost and near-net shape processing with internal cooling passages. The high-cost processing route for ODS alloys was exacerbated in components with complex hollow geometries. However, the cost differential has shrunk, because advanced single-crystal alloys contain substantial amounts of expensive elements such as Re, Ru, and Ta. Also, complex cooling geometries can be achieved by fabricating blades from stacked wafers with etched cooling passages[21]. While the methods are not inexpensive, they became more viable as they matured over the past 20 years. Another potential route to lower costs is improving the mechanical alloying process, including application of modern process-modeling methods. Several new processing methods are applied to Fe-base alloys[22] and might work with Ni alloys. Also, on a cost basis, ODS alloys compare more favorably than CMCs.

Low ductility of ODS alloys. ODS alloys have low ductility, especially in transverse directions[23]. They also suffer from embrittlement due to prior creep exposure[24]. However, experience with low ductility materials has broadened since the 1980s, and ductilities of ODS alloys reported in earlier publications do not seem as intimidating to engineers experienced with γ-TiAl and CMCs, especially when combined with fracture toughness values of about 40 MPa $\sqrt{m}$[25]. In addition, conventional superalloys also suffer from reduced ductility after high temperature exposure[26], yet still perform well in service. A reexamination of ductility is an essential part of a revitalized ODS development program. However, incorporating alternative tests to determine ductility, such as ballistic impact testing[27], would be more relevant to the intended application.

Anisotropy in ODS alloys. MA6000 has a predominantly [110] texture after directional recrystallization, and TMO alloys have textures ranging from [100] to [111], depending on the alloy. This raises a question of whether exceptional creep properties in ODS alloys are a result of their non-[001] orientations. This appears to be unlikely, because creep anisotropy at temperatures above 1000°C is generally not very significant. The debit in thermal fatigue resistance in non-[001] orientations[28] is also of concern. This is a more serious issue and must be addressed in future development efforts. Two lines of thought indicate a degree of optimism that the issue can be resolved. First, it is known that texture after recrystallization is a function of alloy composition[29], and it is conceivable that a more desirable texture can be achieved through alloy and process development. Second, a wafer-blade processing scheme allows for reorienting wafers prior to bonding.

Transverse properties of ODS alloys. In addition to lower ductility, mentioned previously, the creep strength of ODS alloys is noticeably weak in transverse directions. It is not clear how serious this issue is, as many successful ground engine tests of ODS alloys[30] and directionally solidified eutectics (also with large creep anisotropy) were accomplished in the past. If transverse properties are a serious issue, one route for mitigation could be improved understanding of recrystallization methods. The ability to control recrystallization to produce single crystals[31] in wafers, for example, would eliminate the transverse-property debit. The entire topic of recrystallization would be an excellent focus for future integrated computational materials engineering (ICME) study. Models to predict recrystallization response as a function of alloy composition, oxide dispersion parameters, and thermomechanical processing history would accelerate ODS alloy development.

Inspection limits. An unpublished reason for the lack of success for MA6000 as a turbine blade material is its sensitivity to small unrecrystallized regions that could serve as sites for premature failure. These regions could not be reliably detected by nondestructive inspection methods. Future work must revisit this issue and quantify its effect. Adopting a wafer-blade processing scheme should enable easier inspection of wafers prior to bonding.

SUMMARY

The case for reemphasizing ODS alloys to improve turbine blade temperature capability beyond that of superalloy single crystals appears to be quite strong. Experimental alloys already exist that exceed the best single crystals, and further improvements are possible through updated alloy design. Exceptional creep properties were achieved without relying on expensive, strategic elements such as rhenium.

Compared with ceramics, intermetallics, and cobalt alloys, the risks are modest and the payoffs significant. In contrast to these alternatives, technology solutions either already exist or have been identified to achieve the balance of properties required for a high-pressure turbine blade including cost, strength, toughness, impact resistance, oxidation and corrosion resistance, TBC compatibility, and manufacturability.

A program directed at developing ODS alloys for use in turbine blade applications is recommended. In addition to alloy development, concerns that must be addressed in future development efforts include ductility, thermomechanical fatigue, and processability. Use of modern modeling and design tools could accelerate maturation of this promising technology. **~AM&P**

For more information: Mike Nathal (retired) was chief of the Advanced Metallics Branch, Structures and Materials Division, NASA Glenn Research Center, miken345@wowway.com, www.etsy.com/shop/MikesCoolWoodArt.

Acknowledgment

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INTERNATIONAL THERMAL SPRAY CONFERENCE AND EXPOSITION, AEROMAT, AND MICROSTRUCTURAL CHARACTERIZATION OF AEROSPACE MATERIALS AND COATINGS

May 11-15
Long Beach, Calif.

All three shows are co-located in one venue and offer access to more than 400 technical presentations. This “Mega Show” features a plenary presentation by Dr. John Grotzinger, chief scientist and head of strategic science planning for NASA’s $2.5 billion Curiosity rover mission to Mars. Crowds will gather on the show floor to learn the latest industry trends across the thermal spray, aerospace, and metallurgy industries. New products and services will be discovered, while business relationships are built.

SPECIAL PLENARY PRESENTATIONS

Monday, May 11
11:15 a.m.–12:00 p.m.
Hamish L. Fraser
The Ohio State University, Columbus

This keynote presentation will focus on the application of advanced characterization methods to the understanding of mechanisms of microstructural evolution in aerospace alloys. First, there will be a focus on titanium alloys, involving determination of the role of nonconventional transformation pathways, using a combination of aberration-corrected (scanning) transmission electron microscopy and atom probe tomography, which result in various distributions of constituent phases in metastable beta alloys. The second part of the talk will involve the application of direct 3D characterization of refractory high-entropy alloys, which is essential for the accurate description of microstructures in these new types of alloys.

Monday, May 11
1:30–3:00 p.m.
John Grotzinger
California Institute of Technology, Pasadena

Grotzinger is the chief scientist and head of strategic science planning for NASA’s $2.5 billion Curiosity Rover Mission to Mars, which riveted the country with its daredevil landing. A veteran geologist with more than 30 years of exploration of Earth and Mars, Grotzinger has led expeditions to the far corners of the globe. He received NASA’s prestigious Outstanding Public Leadership Medal for the unprecedented success of the mission.

Tuesday, May 12
1:00–3:30 p.m.
Humberto Luiz de Rodrigues Pereira
Embraer Executive Jets, Melbourne, Fla.

Luiz de Rodrigues Pereira is responsible for the development, certification, and support for the operation of all executive aviation products. He has worked for Embraer for 25 years, starting his career as a stress engineer, working on the development of several products such as EMB-120-Brasilia and EMB-312-Tucano. He led the ERJ-145 Structural Engineering Team in designing the entire primary structure of this airplane.

Robert Vassen
Forschungszentrum Jülich GmbH, Germany

Vassen is professor of mechanical engineering at the Ruhr University Bochum in Germany and employed at Forschungszentrum Jülich GmbH, where he researches energy systems. He is also a guest professor at University West, Trollhattan, Sweden. Vassen’s research fields include thermal spray technology, protective high-temperature coatings (thermal and environmental barrier coatings), powder technology, ceramics processing, lifetime modeling, and solid oxide fuel cells and membranes.

Frank Mücklich
Saarland University, Germany

Mücklich is a professor at Saarland Univeristy in Germany. One of his research interests includes 3D microstructure characterization, which plays a key role for quantitatively understanding the relationship between processing, microstructure, and properties of high-performing materials. Recent progress in tomographic techniques has led to quantitative insights into the evolution of materials microstructures with gradual field of view sizes.


Fraser


Grotzinger


Pereira


Vassen


Mücklich

NETWORKING OPPORTUNITIES

Be sure to join your fellow attendees during these special events.

EXPO WELCOME RECEPTION
Monday, May 11 on the show floor
5:30–7:00 p.m.

Connect with exhibitors in a relaxed environment as we celebrate the opening of this collocated event with ITSC, AeroMat, and IMS!

5K FUN RUN/WALK
Tuesday, May 12
5:45 a.m.

Start your Tuesday with an energizing run/walk along the beautiful California Coast with your fellow conference attendees. At the end of your invigorating jaunt, recharge during a networking refreshment break before heading off to sessions. A portion of the proceeds will benefit the National Stroke Association. Separate registration is required.

Sponsored by: SAINT-GOBAIN 350

CONFERENCE SOCIAL EVENT
Tuesday, May 12 at the Queen Mary
7:00–10:00 p.m.

A special event aboard the historic Queen Mary will give attendees the opportunity to build business relationships and network with key contacts. This historic ship, named after King George's wife Mary, was once hailed as the grandest ocean liner in the world and carried Hollywood celebrities like Bob Hope and Clark Gable. Attendees will be able to enjoy her rich history during an old Hollywood glamour event with special surprises and entertainment.

ITSC 2015 TECHNICAL PROGRAM FOCUS*

Fundamentals/R&D

Symposia Chair: James Ruud, General Electric

This symposia covers topics such as cold spray metals and ceramics, suspension plasma spray, HVOF and HVAS, cold spray processing, arc spray, novel processes, and much more.

Thermal Spray Applications

Symposia Chairs: Mitch Dorfman, FASM, Oerlikon Metco, Robert Gansert, Advanced Materials and Technology Services Inc., and Richard Vander Straten, ES3

This symposia covers topics such as corrosion, testing and characterization, energy, biomedical, and more.

Advanced Coatings for the Aerospace Industry (Joint symposium with AeroMat)

Symposia Chair: Rogerio Lima, National Research Council of Canada

This symposia covers topics such as thermal barrier coatings (TBCs); engineering, protection, and repair of aircraft structural parts, bond coat development for TBCs, and much more.

AEROMAT 2015 SESSION DESCRIPTIONS

Additive Manufacturing (AM)

These sessions include presentations on advances in metallic AM technologies in the aerospace, medical, and transportation industries. Presentations cover AM methods, applications, materials and processes, mechanical properties, and design practices.

Advanced Aluminum Alloys—Light High-Performance Alloys and Structures

These sessions cover research, development, and applications of aluminum alloys and aluminum alloy-based hybrid materials (e.g., FML, MMC). Technical presentations cover subjects ranging from alloy development to evaluations of the performance of structural subcomponents and components.

Composite Materials, Processes, and Structures

These composite sessions will cover current work ranging from fundamental science and technology development to process development and fabrication, and include matrix and reinforcement materials development, processing and process modeling, dimensional control, and applications.

Emerging Materials and Processes

These sessions will focus on new alloy developments and novel processing techniques across the range of aerospace materials.

Failure Analysis of Aerospace Components

This session will highlight a variety of recent cases with a special presentation on the future of aviation failure analysis.

High Temperature & Turbine Materials

Advances in alloys, ceramics, intermetallics, and coatings for high-temperature applications will be presented, with emphasis on how integrated computational materials engineering (ICME) has become enabling to cost-effective and rapid development.

Integrated Computational Materials Engineering (ICME)

This session covers research related to the computational modeling and accelerated development of advanced new aerospace materials.

Nondestructive Evaluation Techniques in Aerospace

This session will review the following techniques: Acoustic wave, laser ultrasonics, quantitative percussion diagnostics, phased array ultrasonics, and full matrix capture and computed tomography.

Surface Engineering and Fatigue Life Enhancement

This session covers research and commercial advances based on surface microstructural modification, metallic coatings, and methods to induce beneficial residual compressive stresses.

Sustainability of Aerospace Materials & Processes

These sessions aim to highlight and report on challenges in environmental sustainability specific to the aerospace industry, elucidate leading sustainable approaches, and recommend best practices.

Titanium Alloy Technology

These processing and metallurgy sessions will provide an update on the latest titanium aerospace technologies covering near-alpha, alpha/beta, and beta alloys.

Welding and Joining

The welding sessions cover many areas of friction, power beam, and fusion welding technologies, and adhesive hybrid bonding for a variety of aircraft and space applications.

*For more information about ITSC, see page 44 in the iTSSe Newsletter.

METALLURGY LANE

Metallurgy Lane, authored by ASM life member Charles R. Simcoe, is a continuing series dedicated to the early history of the U.S. metals and materials industries along with key milestones and developments.

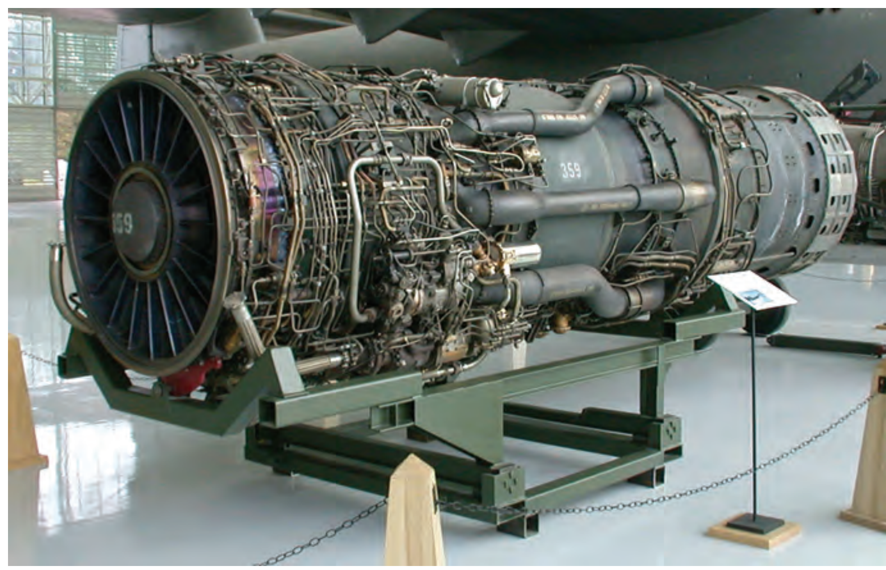
TITANIUM: A METAL FOR THE AEROSPACE AGE – PART III

TITANIUM'S POTENTIAL WAS NOT FULLY REALIZED UNTIL 1956 WHEN METAL PRODUCTION REACHED 5200 TONS AND SPONGE PRODUCTION NEARLY 15,000 TONS.

While the business side of titanium was improving, most of the alloy product was going into jet engines. Airframe manufacturers were still grappling with problems in sheet material, as better alloys were needed to form parts and improve strength. More uniform properties were also needed. Variation in properties from one supplier to another—or even within the same shipment—was a cause for concern. The learning curve for making titanium sheet products was more difficult than expected. In fact, the Department of Defense (DoD) initiated a $3.5 million project in 1956 to combat a host of sheet metal problems.

This project, called the DoD Sheet Rolling Program, was administered by the National Materials Advisory Board (NMAB) of the National Academy of Sciences. Representatives from all the major airframe manufacturers, jet engine builders, titanium producers, the armed forces, and other government agencies with an interest in titanium assembled at NMAB headquarters in Washington. One of the most comprehensive technical programs ever undertaken in metallurgy was designed by this group to overcome the problems hindering the rapid growth of titanium in airframe construction. Three promising alloys, including Ti-6Al-4V, were selected for study.

Over several years, this project produced not only improved alloys and better material quality, but also a deeper appreciation of the reliability of titanium as an aerospace material. An indirect benefit was the close relationships formed by individuals within all parts of the industry participating in this common goal.



Pratt & Whitney J58 engine on display at the Evergreen Aviation & Space Museum in Oregon. Jet engines were the first application to use titanium alloys. Courtesy of en.wikipedia.org.

PEAKS AND VALLEYS

Improved business conditions, along with rising enthusiasm within the industry, continued into 1957. First quarter metal shipments reached 2200 tons, which indicated an annual goal of perhaps 9000 to 10000 tons. Titanium was on its way to becoming the aerospace metal that its promoters had hoped for. Then an earthquake shook the aerospace and titanium industries: Defense Secretary Charles Wilson, formerly of General Motors Corp., announced a decision to base the U.S. defense strategy on missiles rather than manned aircraft. The accompanying reductions and contract cancellations rocked the industries, as this major cutback in aircraft and engine production meant a near total collapse of the titanium market. The most promising metal of the postwar era—which had received an estimated $200 million in government support—was in serious danger of extinction by the very Defense Department that had brought it into being.

The ramifications were swift and drastic. Orders were cancelled and by the fourth quarter of 1957, titanium shipments skidded to 350 tons. The price of sponge plunged to $2.25 per lb as production mounted to 17,000 tons in addition to competition from 3500 tons of Japanese imports. Metal product prices decreased to an average of $10 per lb. Prices continued to decline over the next several years to as low as $1.60 for sponge and $7 for metal.

Many bailed out of the industry. The Remington Arms Division of DuPont sold its 50% interest in Rem-Cru to partner Crucible Steel Co., who remained

The transition from manned aircraft to missiles in 1957 cut the B-52 Bomber program from 17 wings to 11. Many other aircraft were canceled entirely.

The B-1 Bomber was built to withstand speeds of 2000 mph. The heat generated required titanium alloys, mainly Ti-6Al-4V.

in metal production for a brief time and then left the field. Cramet Inc., jointly owned by Crane Co. and Republic Steel Corp., ceased operation and Republic stopped producing titanium metal products. Dow Chemical first put their sponge plant on standby, then closed it shortly after. Union Carbide reduced sponge production to 25% of capacity and later closed. Mallory-Sharon Titanium Corp. sold a one-third interest to National Distillers, a new sponge producer. Within a few years, both P.R. Mallory and Sharon Steel sold their interests to National Distillers, who renamed the operation Reactive Metals. Even DuPont, the first company to enter sponge production, closed their plant in 1962. Witnesses to this situation believed that the DoD Sheet Rolling Program was a major factor in holding together what remained of the industry. One new producer was building a plant in Albany, Ore., called Oregon Metallurgical Corp. They would struggle through this period, but remained in the titanium business.

Titanium metal shipments would not exceed those of 1957 (5600 tons) until 1962 (6500 tons). During this time, the remaining producers were pressed to find other applications. One new,

The Lockheed SR-71 Blackbird, built in the 1960s, was the first plane with all-titanium construction.

all-titanium military plane from the 1960s was the SR-71 Blackbird, built to replace a spy plane that was shot down over Russia. The reduced jet engine market was still the major customer, but slowly applications were found in chemical and nuclear plant construction where corrosion resistance was the main property required. In addition, the growing missile technology field began to consume higher amounts of titanium, as did the civilian airline industry with the introduction of jet-powered aircraft. These planes included the Boeing 707 and Douglas DC-8, in addition to later models such as the Boeing 727 and 737, and the DC-9. All of these planes featured a few percent of the airframe weight in titanium as well as substantial weight in the engines.

AIRFRAMES AND ENGINES

Jet engine builders were the major consumers of titanium and Pratt & Whitney was the first to embrace this metal in their military jets from the early 1950s. Later, when commercial jet engines became popular in the 1960s and beyond, they continued to expand titanium use. Eli Bradley was chief materials engineer at Pratt during this crucial period of commercial jet engine development. For 20 years, he was a leading expert in titanium applications in the jet engine industry. Bradley received the ASM Engineering Achievement Award in 1975, and the ASM Gold Medal in 2002—the same award that was given to William Kroll in 1967.

Introduction of wide-bodied air transport planes in the late 1960s improved the markets for titanium. A number of factors coincided to increase titanium use to nearly 30,000 tons, the amount forecast in the early 1950s. Ci-

The Boeing 777 is the first commercial plane to use a titanium alloy (Ti-10V-2Fe-3Al) for landing gear. Courtesy of Altair78/Wikimedia Commons images.

vilian transport aircraft construction and chemical and nuclear uses reached peak levels and an export business had developed to serve the growing military and civilian aircraft production in Europe. This peak usage would not be repeated for many years due to the rapid decline in all of these markets in 1982-83. The one bright spot was the 100 all-titanium, Mach 3, B-1 bombers built by North American Rockwell.

The most recent commercial aircraft designs use substantial amounts of titanium, according to Rodney R. Boyer, a technical fellow at Boeing Materials Technology, Commercial Airplane Group. The Boeing 777 uses 13,000 lb of Ti-10V-2FE-3Al in the landing gear of each plane. This is a beta alloy that is heat treated to 160,000 to 170,000 psi.

The Air Force F-22 uses approximately 42% (9000 lb) of titanium alloys in the airframe: Although several alloys are now available, the largest amount is still Ti-6Al-4V. The Pratt & Whitney engines for this plane contain both Ti-6Al-4V and the newer alloy, Ti-6Al-2Sn-4Zr-2Mo-0.2Si.

The original enthusiasts, individuals, companies, government agencies, universities, and research laboratories believed in a great future for a strong, lightweight, heat-resistant, corrosion-resistant metal. Their dream came to pass after a decade of difficult R&D and an investment of several hundred million dollars by the government and industry. The cost of producing titanium, however, has limited its major applications to jet engine and airframe construction. Titanium has fulfilled its promise as a new metal for the aerospace age.

For more information: Charles R. Simcoe can be reached at crsimcoe1@gmail.com.

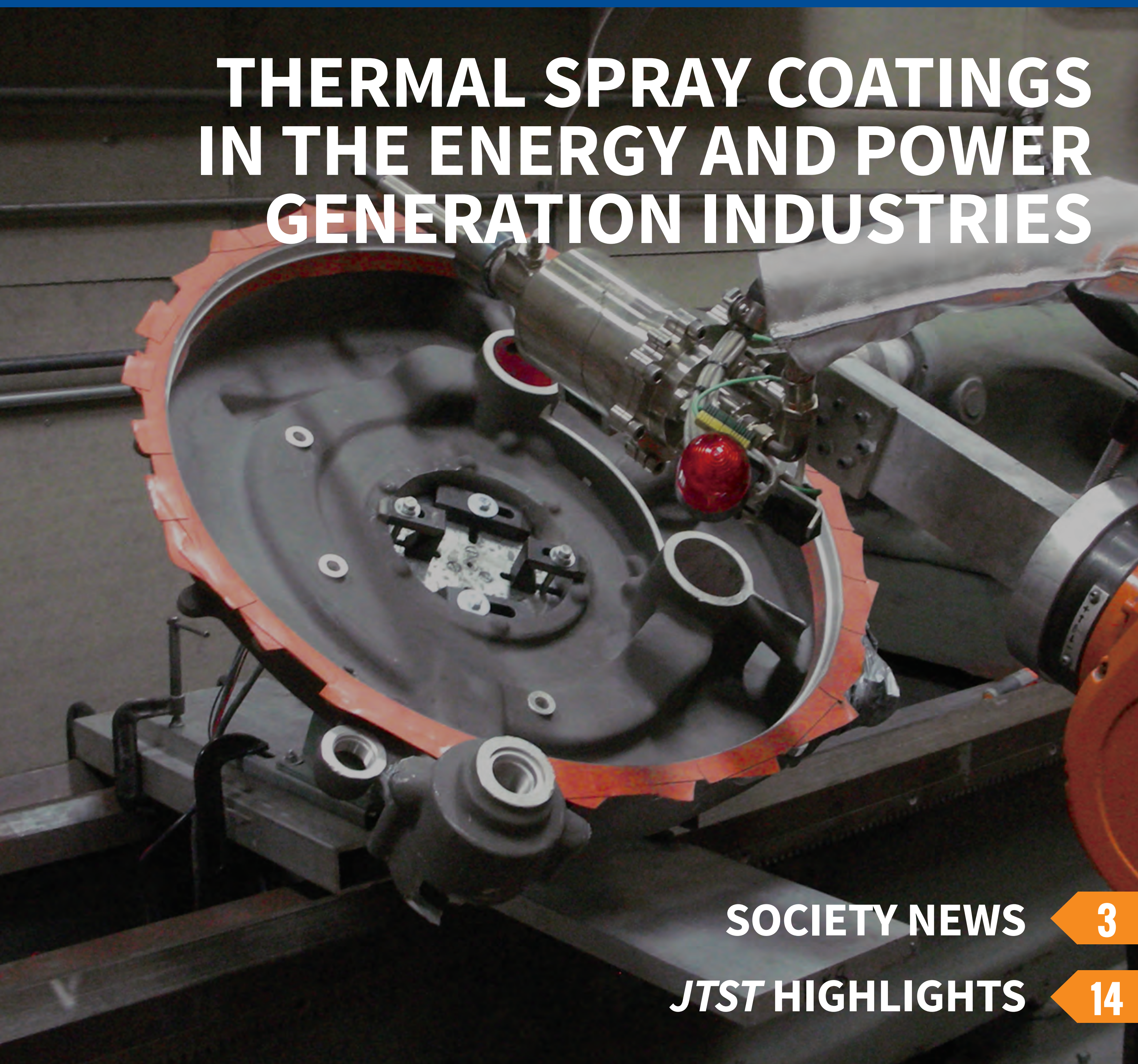
Thermal Spray Society
ASM INTERNATIONAL

MAY 2015 | VOL. 10 | ISSUE 2

iTSSe

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY



THERMAL SPRAY COATINGS IN THE ENERGY AND POWER GENERATION INDUSTRIES

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High Purity Yttria Thermal Spray Powder

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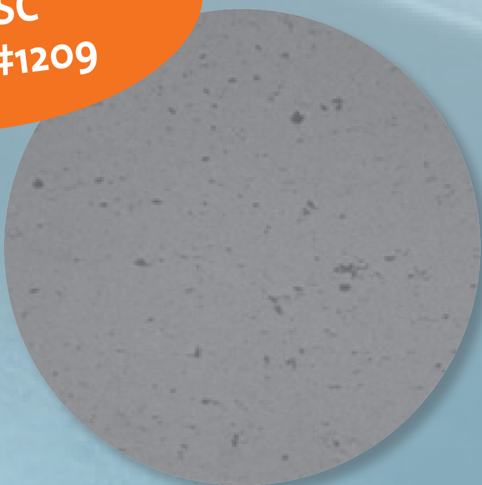

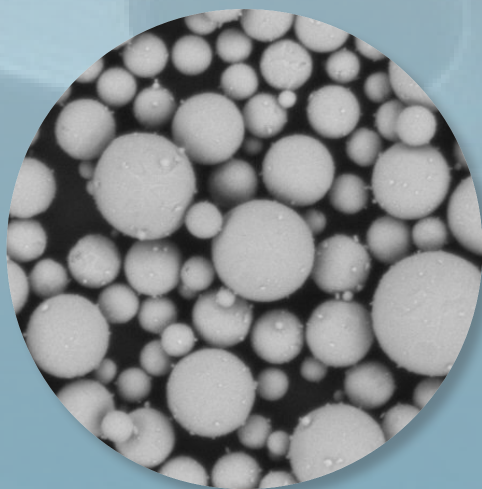

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TSS Thermal Spray Society
ASM INTERNATIONAL

MAY 2015 | VOL. 10 | ISSUE 2

iTSSe

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

DEPARTMENTS

ABOUT THE COVER

Hellicraft Magnesium Gear Box Sump being processed with CP Aluminum using high pressure cold spray. Robotic arm and turntable to control feed and speed for critical nozzle spray distance. Courtesy of ASB Industries Inc. asbindustries.com.

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EDITORIAL OPPORTUNITIES FOR iTSSe IN 2015

iTSSe's editorial focus for 2015 reflects established applications of thermal spray technology as well as emerging applications.

August Issue:
Automotive & Industrial Applications

November Issue:
Emerging Technologies/Applications & Case Studies

To contribute an article, contact Julie Lucko at julie.lucko@asminternational.org.

To advertise, contact Kelly Thomas, at kelly.thomas@asminternational.org.

ITSC IS UPON US!

Robert Gansert, Ph.D.
President
Advanced Materials & Technology Services Inc.

Hello everyone and welcome to the collocated "Mega Show!" This event includes the International Thermal Spray Conference and Exhibition, AeroMat, and Microstructural Characterization of Aerospace Materials and Coatings—providing access to over 400 technical presentations. The show also features a plenary presentation by Dr. John Grotzinger, chief scientist and head of strategic science planning for NASA's $2.5 billion Curiosity rover mission to Mars. Grotzinger is the lead scientist for Curiosity's mission to explore the past climate and geology of Mars. He will describe what the rover has discovered since landing on the Red Planet, and how the Mars Science Laboratory onboard Curiosity will continue the search for signs of extraterrestrial life.

In addition to Grotzinger, other special plenary sessions feature Humberto Luiz de Rodrigues Pereira, vice president, engineering, Embraer Executive Jets; Robert Vassen from Forschungszentrum Jülich GmbH, Germany; and Frank Mücklich from Saarland University, Germany.

There are also many networking opportunities both on and off the exhibit floor including a special dinner aboard the Queen Mary. Enjoy an exciting evening with friends and colleagues during this year's social event on the historic ship. Separate registration is required and includes a cocktail hour, dinner buffet, live entertainment, and a cigar bar. Don't miss out on this one-of-a-kind social event that won't disappoint! Transportation is provided from the Hyatt Regency and the Hyatt Pike while cocktail attire is optional.

The International Thermal Spray Conference and Exposition takes place May 11-14 in Long Beach, Calif.

The show also features a 5K Fun Run/Walk on Tuesday, May 12 at 5:45 a.m. You can start your day off with an energizing run/walk along the beautiful California coast with fellow conference attendees. At the end of your invigorating jaunt, recharge during a networking refreshment break before heading off to sessions. In honor of National Stroke Awareness Month in May, a portion of the proceeds will benefit the National Stroke Association. Separate registration is required for this event sponsored by Saint-Gobain.

With all this and over 400 technical sessions, ITSC 2015 is not an event to be missed! I am looking forward to connecting with you all here in Long Beach.

THERMAL SPRAY SOCIETY INDUCTS THREE INTO THE THERMAL SPRAY HALL OF FAME

Three professors and leading researchers in thermal spray technology will be inducted into the Thermal Spray Hall of Fame during the ITSC Plenary Session, taking place May 12 in Long Beach, Calif.

Coddet

Christian Coddet is recognized "for developing innovative thermal spray techniques and applications and for developing international collaboration programs dedicated to thermal spray research in developing countries." Coddet has been engaged in thermal spraying for 30 years. As a professor and head of IRTES-LERMPS University of Technology of Belfort-Montbeliard, France, he established the internationally recognized surface engineering laboratory, which includes thermal spraying activities, PVD films, additive manufacturing, and powder manufacturing. He is very active in developing many international collaboration programs dedicated to thermal spray research and applications. Coddet is a 26-year member of ASM and member of the TSS Journal of Thermal Spray Technology Committee.

Lech Pawlowski is cited "for sustained and innovative thermal spray research and development and significant contributions to the fundamental and technical advancement of thermal spraying." A professor at the University of Limoges, France, he contributed to new aspects of thermal spray, in particular, the suspension and solution plasma sprayed oxides and coatings, conducting experiments and modeling of the phenomena occurring during flight in plasma spray source, and during deposition of coatings. He authored the textbook, *The Science and Engineering of Thermal Spray Coatings,* which has been translated to Chinese and cited 903 times. Pawlowski is associate editor of the *Journal of Thermal Spray Technology* and one of the original creators of the European Thermal Spray Association.

Pawlowski

Sanjay Sampath, FASM, is recognized "for innovative interdisciplinary thermal spray research bridging the gap between fundamental science and industrial practice through better understanding of coating properties and the development of advanced diagnostic tools." Sampath is a professor and

Sampath

director of the Center for Thermal Spray Research at the State University of New York in Stony Brook. In addition to his significant contributions to thermal spray science and applications, he also established a unique NSF Materials Research Science and Engineering Thermal Spray Center. He was named an ASM Fellow in 2005, has been an ASM member for 28 years, and recently served on the TSS Board.

DORFMAN RECEIVES TSS PRESIDENT'S AWARD

Mitchell R. Dorfman, FASM, Metco Fellow at Oerlikon Metco, is the 2015 recipient of the TSS President's Award for Meritorious Service. He will be recognized during ITSC 2015 in Long Beach, Calif.


Dorfman

HVO COLLOQUIUM 2015: HIGH VELOCITY OXY-FUEL FLAME SPRAY IN FOCUS

For experts from the field of thermal spray, the city of Erding is now closely linked with an exciting branch of this technology: High velocity oxy-fuel flame spray (HVOF). On October 29-30, Erding will again become a hub for specialists as the host of the 10th HVOF Colloquium. Topics such as environmental protection, energy efficiency, standards, training, and occupational safety will be addressed. Coating businesses and developers will obtain insights into the practical application of HVOF spraying and the accompanying exposition will offer ample scope for face-to-face discussions. Presentations will be translated simultaneously into German and English. Organizers include the Association of Thermal Sprayers GTS e.V., Linde AG, and Helmut-Schmidt University Hamburg. Visit http://hvof.gts-ev.de to learn more.


HVOF Conference Hall

CELEBRATE THERMAL SPRAY WEEK FROM JULY 6-10 WITH ONE OF THESE COURSES

INTRODUCTION TO THERMAL SPRAY, JULY 6-7
MATERIALS PARK, OHIO
INSTRUCTOR: RICHARD A. SAYMAN

Thermal spray has evolved from a technology designed to be a cost effective method of repairing worn components and machined parts to a process used to provide improved part performance and add longer life to components. As the thermal spray profession has changed, so has the need to ensure safe and consistent methods for thermal spray operators. ASM International brings together the leaders in the Thermal Spray Society to compile their knowledge and experience in a comprehensive, easy-to-understand course.

THERMAL SPRAY FOR GAS AND OIL INDUSTRIES, JULY 10
MATERIALS PARK, OHIO
INSTRUCTOR: ANDRÉ MCDONALD

This course is beneficial to thermal spray operators in the oil and gas industry. Given the special needs of the oil and gas sector for wear and corrosion resistant coatings with high longevity, the certification process and validation of the coatings produced by those examining them will need to be different. Therefore, this course includes training and testing information that applies specifically to the oil and gas sector.

THERMAL SPRAY TECHNOLOGY, JULY 8-9
MATERIALS PARK, OHIO
INSTRUCTOR: CHRISTOPHER C. BERNDT, HOF, FASM

This course provides a thorough grounding and understanding of thermal spray processes, depicts complex scientific concepts in terms of simple physical models, and integrates this knowledge to practical engineering applications and commonly accepted thermal spray practices.

VISIT ASMINTERNATIONAL.ORG/EDUCATION TO REGISTER TODAY.

THERMAL SPRAY OF SUSPENSIONS & SOLUTIONS (S&S) SYMPOSIUM (TS4)
DECEMBER 2-3
MONTREAL, CANADA

Scientists and engineers interested in emerging S&S TS technologies will have a chance to address both research challenges and development of industrial applications. The conference will comprise a balanced group of speakers from industry, academia, and national laboratories. The show is geared towards participants interested in advanced coating materials and processes who are looking for innovative solutions to improve coating performance in the aerospace, energy generation (gas turbine and fuel cells), and transportation industries. As S&S TS technologies have the potential to replace more expensive coating processes such as electron-beam physical vapor deposition (EB-PVD) for deposition of advanced thermal barrier coatings, they attract attention from OEMs, equipment vendors, and research communities in North America and abroad. Visit asminternational.org/suspension-2015 for more information.

ASM HANDBOOK, VOLUME 5A: THERMAL SPRAY TECHNOLOGY

Volume 5A is a replacement for the *Handbook of Thermal Spray Technology,* edited by J.R. Davis (2004) and provides an introduction to modern thermal spray processes including plasma spray, high velocity oxy-fuel, and detonation gun deposition, as well as a description of coating properties and their wear, corrosion, and thermal barrier characteristics. Principles, types of coatings, applications, performance, and testing/analysis also are covered. A greatly expanded selection of applications includes examples and figures from various industries, including electronics and semiconductors, automotive, energy, and biomedical. Emergent thermal spray market sectors such as aerospace and industrial gas turbines, and important areas of growth such as advanced thermal barrier materials, wear coatings, clearance control coatings, and oxidation/hot corrosion resistant alloys also are reviewed. Visit asminternational.org to learn more.

COMING SOON—HIGH PRESSURE COLD SPRAY: PRINCIPLES AND APPLICATIONS*

ASM International will publish a new technical book on high pressure cold spray in late 2015. Here we preview this exciting new edition.

The new technical book on *High Pressure Cold Spray: Principles and Applications* is a highly practical and useful reference book that presents an in-depth look at the high pressure cold spray process, and also describes applications in various industries. The book, to be published later this year, is expected to be a trusted, "go-to" resource that is both comprehensive and technically advanced.

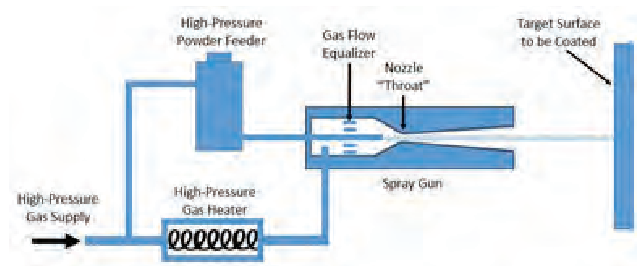
Cold spray continues to be the fastest developing spray technology of the past decade, and a significant number of scientists, engineers, and technologists are joining the cold spray community around the globe. The technology is relatively young and work is being simultaneously pursued in universities, research centers, and many high-tech industries. As this novel technology spreads quickly into many new application areas, there is an urgent need for authoritative information.

The new book is expected to address this need and be indispensable to universities, libraries, and those involved in thermal spray. This comprehensive volume presents baseline information on design and modeling, materials science of engineered coatings, and specific applications in various high-tech industries, and will also be a hands-on resource for cold spray operators.

The new technical book was authored by a group of global cold spray experts and is edited by Charlie Kay and Jegan Karthikeyan of ASB Industries, Barberton, Ohio, with an introduction by Mark Smith of Sandia National Labs. Selected topics include:

- Theory, modeling and fundamental science by Thomas Klassen and his group at Hamburg University, Germany
- Cold spray equipment by Peter Richter Sr. of Impact Innovations, Germany
- Mechanical and metallurgical characterization of coatings by Dheepa Srinivasan of General Electric, India
- Applications of cold spray coatings in various industries, including Nuclear (Eric Irissou, et al., NRC, Canada), Defense (Tim Eden, Penn State University, College Park), Automobile (Changhee Lee and Jaeick Kim, Hanyang University, South Korea), Aerospace, Oil & Gas, and Power Generation (Eklavya Calla and Dheepa Srinivasan, General Electric, India)

*Working title



The high-pressure cold spray (HPCS) process uses a high-pressure gas heater and a high-pressure powder feeder to inject the spray powder upstream of the nozzle throat. The process gas is initially heated in order to increase the flow velocity of the gas in the spray nozzle and thus increase spray particle velocities. Although the gas may start out at moderately high temperatures, it cools very rapidly as it expands in the long diverging section of the spray gun nozzle and the spray particle temperatures therefore remain well below the melting point.

Various applications of cold spray processes including protective coating production, development of performance-enhancing layers, repair and refurbishing of parts, and NNS fabrication are elaborated in each industry with illustrative case studies by cold sprayers actively involved in the field. The book is a must-have resource for anyone involved in cold spray technology, from coating design and development to performance of coatings and coated parts in both the laboratory and industrial environments.

ABOUT THE EDITORS

Charles M. Kay, vice president, ASB Industries, Barberton, Ohio

Kay

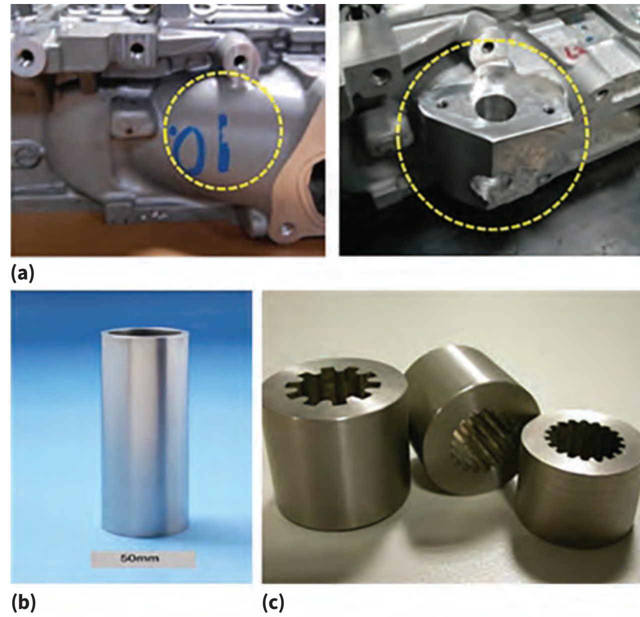
Charles Kay has been with ASB Industries for over 29 years, which focuses on expanding the reach of thermal spray technology in new areas. He specializes in identifying new application areas in various industries such as steel, paper, power generation, and also catering to their needs. He has co-authored many technical articles on cold spray technology published in various peer-reviewed journals and conference proceedings. He has served as president of the Thermal Spray Society and is an active member of various TSS Committees.

J. Karthikeyan, FASM, Director of Research and Development, ASB Industries, Barberton, Ohio

Karthikeyan

J. Karthikeyan received his Ph.D. from Bombay University, India, and specialized in thermal spray and advanced material processing technology. Since 1972, he has pursued research in BARC (Atomic Energy Commission), India, Nuclear Research Center (Kernforschungsanlage), Germany, Monash University, Australia, and SUNY at Stony Brook, New York. He has been involved in industrial research and development since 1997, developing advanced coating techniques and engineered coatings. He is one of the pioneers of cold spray technology and has carried out R&D on almost all aspects of the technology, from design and development of nozzles, guns, and systems to engineered coatings for specific industries. He has authored over 100 publications, mostly in peer-reviewed journals. During the last 15 years, he has been leading industrial cold spray R&D and has authored over 50 peer reviewed papers and six patents in various aspects of cold spray technology.

He served as conference chairman of the ASM-sponsored "Cold Spray 2004," "Cold Spray 2007," and "Cold Spray 2010" meetings in Akron, Ohio. He also organizes special symposium on cold spray technology at international thermal spray conferences every year. He is a Fellow of ASM International and has served as a member of the ASM Thermal Spray Society Board (2008-11). He is a member of the International Board of Review of many prestigious journals such as the *Journal of Thermal Spray Technology*. iTSSe



Practical examples of 3D-printed products using the cold gas dynamic spray process: (a) prototype machine component, (b) Ti seamless heat pipes, and (c) Ti machine components.

NANOCOMPOSITE THERMAL SPRAY REVIEW

Jo Ann Gan
*Christopher C. Berndt, FASM**

The following is an excerpt of the full review article, "Nanocomposite coatings: Thermal spray processing, microstructure and performance," from International Materials Reviews, *Vol 60 (4), May 2015. The full 50-page review, with 394 references, can be found at maneyonline.com/loi/imr through mid-June. Copyright 2015 Institute of Materials, Minerals and Mining, and ASM International.*

Nanomaterial and nanocomposite processing have made advances since the 1990s. The growth and opportunities this technology offers is based on research and development funding trends, science citation index (SCI) publications, and patent applications. This article reviews the current state of thermal spray nanocomposite coating development, while types of commercially available nanocomposite thermal spray feedstock materials, as well as those in development, are assessed.

Thermal spray approaches to depositing nanocomposite coatings including conventional plasma spray and high velocity oxygen fuel (HVOF) processes are discussed, as are more recently developed processes of cold spray, suspension thermal spray (STS), and solution precursor thermal spray (SPTS). These processes are assessed in relation to their deposition mechanisms and the specific nanocomposite materials used for each technique. The unique microstructure of coatings deposited by each method is highlighted in relation to process and compositional control. The exceptional attributes of nanocomposite coatings, such as mechanical strength and toughness, wear resistance, and thermophysical and electrical properties are also highlighted with regard to specific applications.

NANOMATERIAL PROPERTIES

Nanomaterials demonstrate unique optical[13,14], thermal[15,16], mechanical[17,18], electrical[19,20], and magnetic[21,22] properties that are not exhibited by their bulk counterparts. The attributes of nanostructured materials that are size-dependent arise from surface and grain boundary effects due to a significant increase of surface-to-volume ratio and quantum effects due to confinement of electron movement; changes in the electronic structure and interatomic relation; and defect presence[12,23]. Nanomaterials are found in many practical applications ranging from electronics to aerospace.

Two basic approaches to producing nanostructured materials include top-down and bottom-up methods (Fig. 3). The top-down approach involves the breakdown of a bulk material structure to reduce crystal size to sub-micrometer or nanoscale. The bottom-up approach involves processing or building up a material from the atomic scale or nanoclusters to retain the original nanoscale structural units.

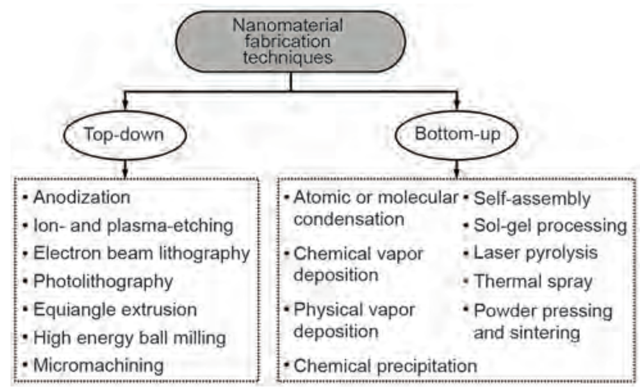


Fig. 3 — The top-down and bottom-up approaches for nanomaterials fabrication.

The focus here is on thermal spray to deposit nanocomposites—a bottom-up approach. It might be argued that the impact process during thermal spray coating formation causes fragmentation of micrometer-sized particles to the nanoscale, which is a top-down approach. However, because this is not the preferred formation process that would retain a lamellar structure, the bottom-up approach is considered dominant.

NANOCOMPOSITE COATING ADVANTAGES

Despite their advantages, bulk nanocomposites can be expensive to produce due to nanomaterial production costs and technical limitations in preserving a nanostructure in a consolidated product due to excessive grain growth[40]. Nanocomposite coatings use lesser amounts of nanostructured materials because they are quite thin—several micrometers up to a millimeter depending on the deposition technique, and can potentially cover large areas. Therefore, nanocomposite coatings offer an alternative that takes advantage of the many remarkable properties of nanomaterials without the production costs of bulk nanocomposites. There are two types of nanocomposite coatings: matrix-reinforced, where the reinforcing phase is within nanoscale, and layered coatings, where the thickness of individual layers are within nanoscale dimensions (Fig. 6).

Thermal spray processes and nanocomposites have already been reviewed independently; therefore nanocomposite coatings deposited by thermal spray processes in relation to their processing, microstructure, and performance will be reviewed here. Feedstock materials for thermal spray come in

*Member of ASM International and Thermal Spray Society

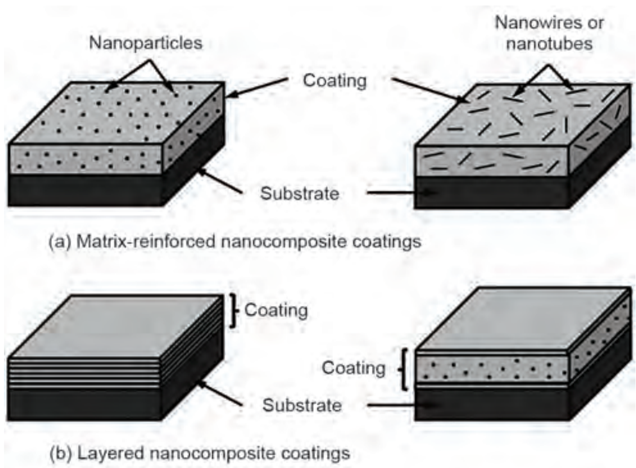


Fig. 6 — Schematics of nanocomposite coatings: (a) matrix-reinforced, and (b) multi-layered.

powder, wire, or liquid form. (A section of this review is dedicated to their production and characteristics.)

The *Thermal spray deposition: Process and microstructure* section highlights the formation mechanisms and nano/microstructure of nanocomposite coatings manufactured by conventional thermal spray processes as well as modern processes such as cold spray, suspension, and SPTS. Prominent nanocomposite materials deposited by thermal spray are assessed in the *Nanocomposite coatings* section, with emphasis on process-dependent phase transformations and their correlations with nano/microstructure and coating properties. The properties and applications of selected nanocomposite coatings with a view towards future uses are presented in the *Properties and potential applications* section.

CHALLENGES AND OUTLOOK

Thermal spray can be segmented into five distinct groupings as shown in Fig. 40. The sequence is intended to be logical—thermal spray starts with an appropriate feedstock and finishes with testing and evaluation for quality control purposes before being implemented towards specific applications as indicated in Box 6.

Nanostructured coatings exist in some microstructural form for the majority of thermal spray coatings, necessitated by the rapid solidification process[52,338]. Thus, microstructural artifacts such as splat sizes, porosity, cracks, phase

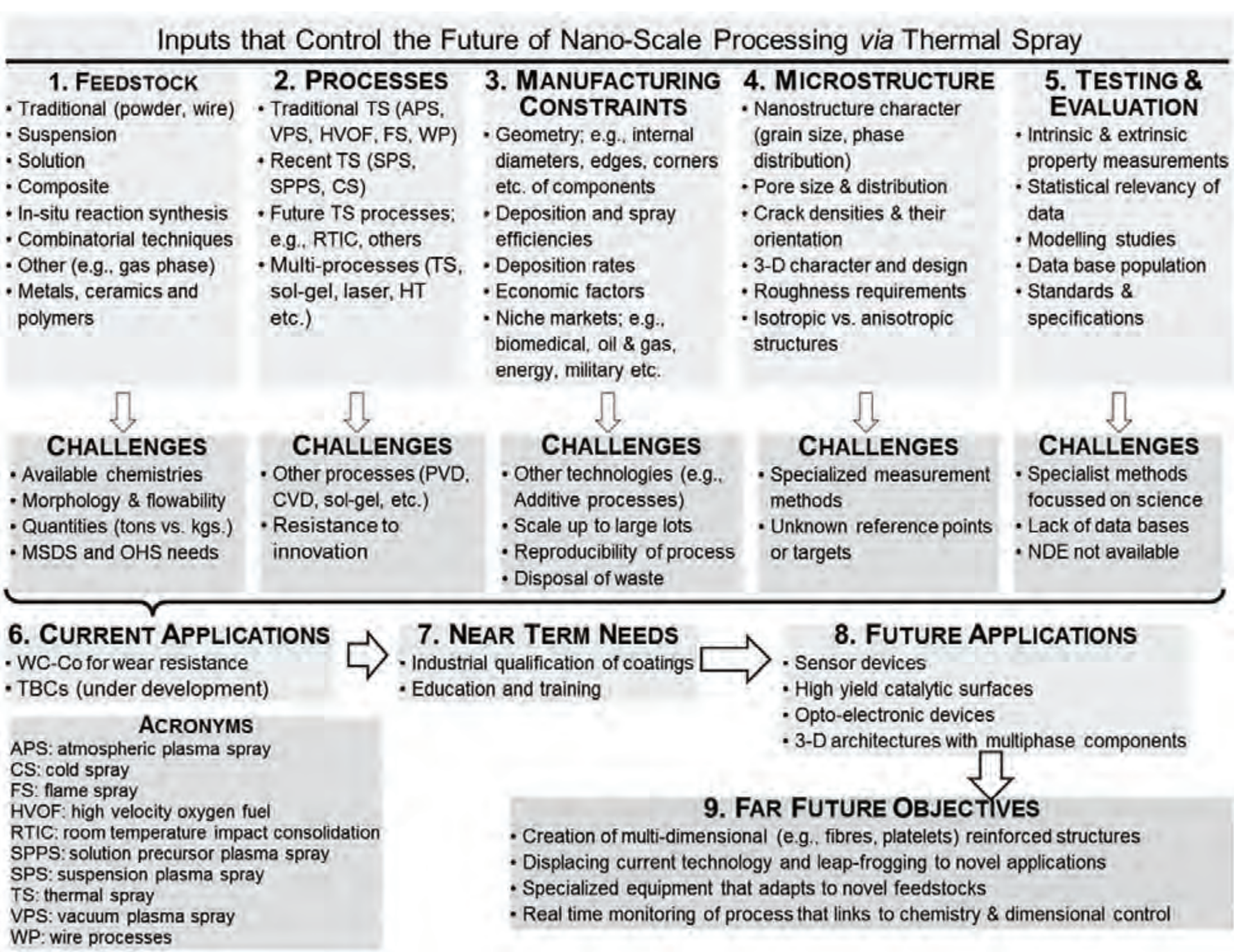


Fig. 40 — Input criteria that determine the outcomes for nanoscale materials manufactured by thermal spray methods.

distributions, and grain sizes are likely to form. However, the future will demand such features to be dominant and manufactured in a controlled fashion rather than being just a curious and scientifically interesting anomaly. The most appropriate feedstock is consolidated from nanoparticulates produced via a chemical route. Thermal spray requires artistic adjustment of spray parameters so only partial melting occurs to maintain consolidated nanostructures into an integral coating by partially melted particles[75,79,103].

Suspension thermal spray and solution precursor plasma spray methods show considerable promise in lowering the feedstock cost barrier and achieving nanostructured deposits. However, challenges exist with regard to attaining high deposition efficiencies and high rates of deposition[104,105,339], characteristics that are both vital for manufacturing environments. Specific applications such as thermal barrier coatings or electronic devices are speculated to be the primary drivers to grow these methods.

The main challenge with regard to feedstock is to attain nanostructured deposits. It is suggested that duel injection port strategies and use of a single injection port, along with slurry feedstock consisting of traditional solid and low-viscosity mixtures, will pave the way for increased production.

Further needs include the ability to scale up feedstock production and ensure long-term storage capability, especially if any fluid components are present, and safeguarding and controls with respect to occupational health and safety. iTSSe

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Dedication

The authors dedicate this review to the memory of Prof. Joachim "Jockel" V.R. Heberlein—8/19/1939-1/17/2014. Jockel made significant contributions in the topical area of nanomaterials that were manufactured via thermal plasma techniques. "His lively spirit, intense interest, and amazing energy all left him…I wonder where they went."

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Be inspired by Dr. John Grotzinger, the chief scientist and head of strategic planning for the Mars Rover Mission, keynote speaker for the Monday plenary session. Grotzinger is responsible for NASA's $2.5 billion Curiosity rover mission to Mars, the robotic space exploration in search of evidence of past life.

For more information on the ITSC technical program see page 27.

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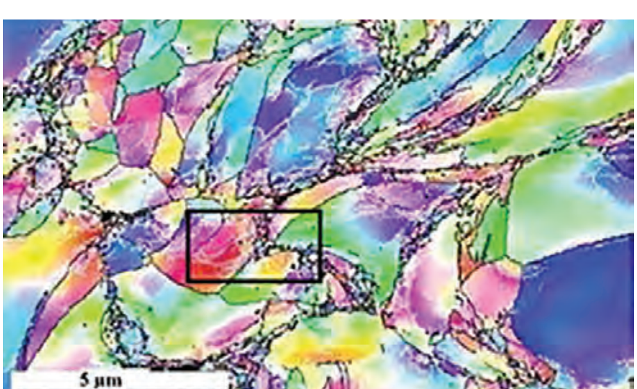
The *Journal of Thermal Spray Technology* (*JTST*), the official journal of the ASM Thermal Spray Society, publishes contributions on all aspects—fundamental and practical—of thermal spray science, including processes, feedstock manufacture, testing, and characterization. As the primary vehicle for thermal 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 February and April issues, as selected by *JTST* Editor-in-Chief Christian Moreau, are highlighted here. In addition to the print publication, *JTST* is available online through springerlink.com. For more information, visit asminternational.org/tss.

MICROSTRUCTURE OF KINETIC SPRAY COATINGS: A REVIEW

Changhee Lee and Jaeick Kim

Kinetic spray is used in various industries such as automotive, aviation, and defense because it can produce a high-performing coating layer. However, because the properties of the kinetic-sprayed coating layer are significantly affected by deposited microstructures, the deposited microstructures should be controlled to acquire an advanced coating layer and a deep understanding of microstructural evolution must be achieved before controlling the coating layer's microstructure. An overview of contents related to the microstructure of kinetic-spray deposition is offered. The most powerful influencing factors in microstructural evolution of the kinetic-spray coating layer are instant generation of thermal energy and high-strain and high-strain-rate plastic deformation at the moment of particle impact. A high-density coating layer with low porosity can be produced, although some micro-cracks are occasionally induced at the interparticle boundary or at the particles' inner region. Also, a microstructure which is distinct from the inner particle region is created in the vicinity of the particle-particle or particle-substrate interface region. However, almost no crystal phase transformation or chemical reaction is induced since the deposited particles are not heated directly by a thermal energy source.

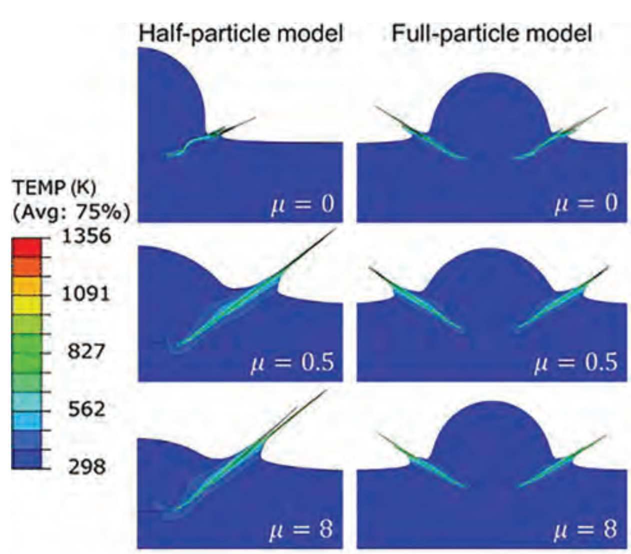


EBSD characterization of the as-sprayed Ni coating: (a) Euler angle map.

THE EFFECTS OF CONTACT CONDITIONS ON THE ONSET OF SHEAR INSTABILITY IN COLD-SPRAY

Fanchao Meng, Huseyin Aydin, Stephen Yue, and Jun Song

Using ABAQUS/Explicit, the effects of contact conditions between the particle and substrate, including tangential friction, normal constraint, and contact geometry on the plastic deformation during the cold spray process are studied. The onset of shear instability, an event often used to indicate the establishment of bonding, was found to be very sensitive to the choice of contact conditions. This suggests that the onset of shear instability does not serve as an accurate means to identify the plasticity threshold responsible for bonding. On the other hand, it is demonstrated that the evolution of the overall equivalent plastic strain (PEEQ) and the overall von Mises stress, being linearly proportional to each other, are both independent of contact conditions. Furthermore, it is shown that an energy value, defined as the product of the PEEQ and the von Mises stress integrated over all particle elements, can quantitatively represent the energy dissipated via plastic deformation while being independent of contact conditions. The PEEQ and associated energy value as defined may provide robust tools to assess the plasticity and the consequent bonding during cold spray.



Deformed particle/substrate configurations and temperature contours at the onset of shear instability in a half-particle model and full-particle model for three representative friction coefficients $\mu = 0$, 0.5, and 8.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EFFICIENT LARGE-SCALE COATING MICROSTRUCTURE FORMATION USING REALISTIC CFD MODELS

Thomas Wiederkehr and Heinrich Müller

To understand the physical effects during thermal spray coating layers formation and the deduction of the macroscopic properties of a coating, microstructure modeling and simulation techniques play an important role. A coupled simulation framework consisting of a detailed, CFD-based single splat simulation, and a large-scale coating build-up simulation capable of computing large-scale, 3D, porous microstructures by sequential drop impingement of more than 10,000 individual particles on multicore workstation hardware is presented. Due to the geometry-based coupling of the two simulations, the deformation, cooling, and solidification of every particle is sensitive to the hit surface area and thereby pores develop naturally in the model. The single splat simulation uses the highly parallel Lattice-Boltzmann method, which is well suited for GPU acceleration. In order to save splat calculations, coating simulation includes a database-driven approach that reuses already computed splats for similar underground shapes at the randomly chosen impact sites. For a fast database search, three different methods of efficient pre-selection of candidates are described and compared against each other.

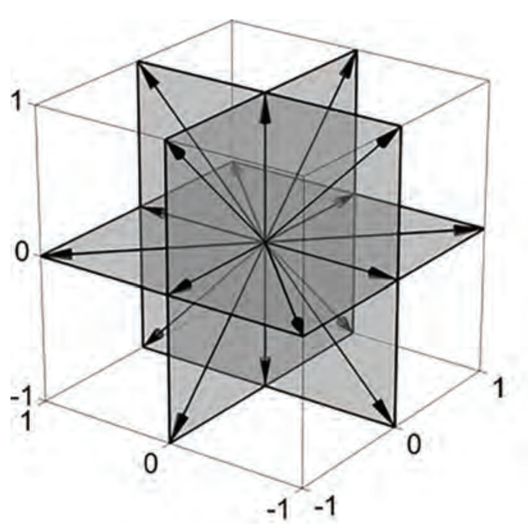
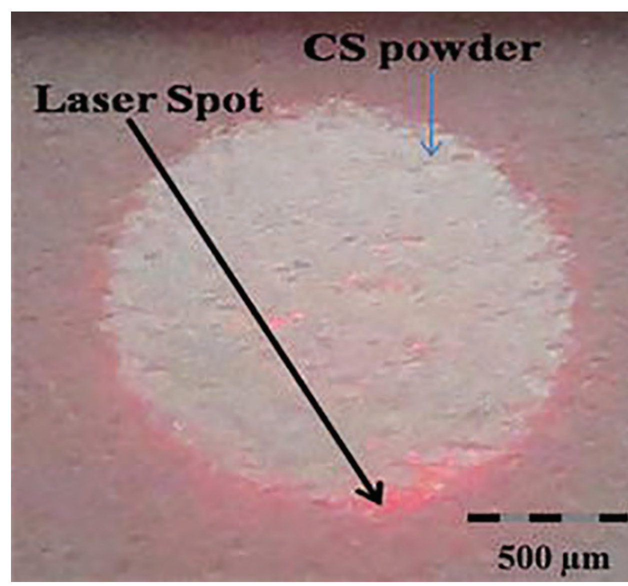


Illustration of the 19 directions e α of the D3Q19 lattice model.

MICROSTRUCTURAL AND MECHANICAL EVALUATION OF LASER-ASSISTED COLD SPRAYED BIO-CERAMIC COATINGS: POTENTIAL USE FOR BIOMEDICAL APPLICATIONS

Monnamme Tlotleng, Esther Akinlabi, Mukul Shukla, and Sisa Pityana

Bio-composite coatings of 20 wt%, HAP and 80 wt%, HAP were synthesized on Ti-6Al-4V substrates using LACS technique. Coatings were produced with a laser power of 2.5 kW, powder-laser spot trailing by 5 s. Coatings were analyzed for microstructures, microhardness, composition, and bio-corrosion using SEM-EDS, XRD, hardness tester, and a Metrohm PGSTAT101 machine. SEM images indicate least pores and crack-free coating with dark-spots of Ti-HAP for the 20 wt%, HAP as opposed to the 80 wt%, HAP coating, which was solid, porous, and finely cracked and had semi-melted Ti-HAP particles. EDS mappings show high content of HAP for the 80 wt%, HAP coating. The diffraction patterns were similar, even though the Ti-HAP peak was broader in the 80 wt%, HAP coating and the HAP intensities were lower for this coating except for the (004) peak. Hardness values taken at the interface inferred that the 80 wt%, HAP coating was least bonded. It was possible to conclude that when this phase material increased the hardness dropped considerably. Bio-corrosion tests indicated that the presence of HAP in coatings leads to a kinetically active coating as opposed to pure titanium coating.

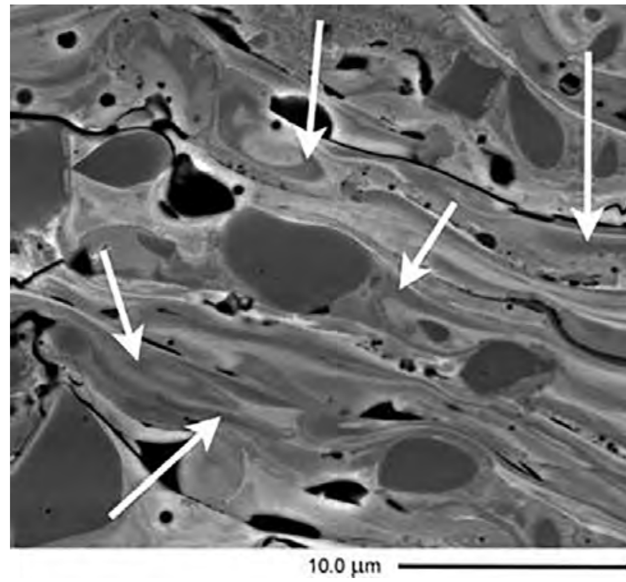


Optimized powder-laser spot interaction.

COMPOSITIONAL DEVELOPMENT AS A FUNCTION OF SPRAY DISTANCE IN UNSHROUDED/SHROUDED PLASMA-SPRAYED CR_3C_2-NICR COATINGS

S. Matthews

Thermal spray of Cr_3C_2-NiCr composites generates varying degrees of carbide dissolution into the Ni binder. During high-temperature exposure, the carbide dissolution zones precipitate high concentrations of small carbides that develop into finely structured networks. This raises the possibility of producing unique tailored carbide composite structures through generation of controlled carbide dissolution and appropriate heat treatment. The first step in this process is production of a supersaturated Ni-Cr-C solid solution from which the carbide phase can be precipitated. In previous work, a broad range of plasma parameters were trialed to assess their effect on the degree of carbide dissolution at a fixed spray distance of 100 mm. The current work builds on the most promising plasma parameters from those trials. Part 2 of this article series investigates the effect of spray distance on the compositional development in Cr_3C_2-NiCr coatings during high-energy plasma spray. Coating compositions were analyzed in detail and quantified through Rietveld fitting of the coating XRD patterns. Coating microstructural features were correlated with the observed variations in composition. The effect of the spray parameters and spray distance on the equilibrium coating compositions is discussed.



Cross-sectional BSE image illustrating the dark contrast "swirl" features in splats in which high degrees of carbide dissolution occurred.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ASMNEWS

Nominations Sought for 2016 ASM/TMS Distinguished Lectureship in Materials & Society

Nominations are now being accepted for the ASM/TMS Distinguished Lectureship in Materials & Society. The lecture was established in 1971 and is jointly sponsored by The Minerals, Metals & Materials Society (TMS) and ASM International. The topic of the lecture shall fall within these objectives:

- To clarify the role of materials science and engineering in technology and in society in its broadest sense.
- To present an evaluation of progress made in developing new technology for the ever changing needs of technology and society.
- To define new frontiers for materials science and engineering.

Qualifications of the lecturer include:

- A person experienced in national or industrial policy-making in the field of materials science and engineering.
- An eminent individual who has an overall understanding of technology and society, and how both are affected by developments in materials science and engineering.
- A person associated with government, industry, research, or education.

Nominations may be proposed by any member of either Society. Submit nominations by September 1 for consideration. Recommendations should be submitted to the headquarters of either Society. For a complete listing of the rules and nomination form, visit asminternational.org/membership/awards/nominate or contact Christine Hoover at 440.338.5151 ext. 5509, christine.hoover@asminternational.org., or Deb Price of TMS at awards@tms.org

Microscopy & Microanalysis 2015

The Microscopy & Microanalysis 2015 Conference and the 48th International Metallographic Society (IMS) Annual Meeting will take place August 2-6 at the Oregon Convention Center in downtown Portland. Plan to attend the diverse technical program, educational short courses, vendor exhibits, and social activities. Topics of particular interest to IMS members are listed here, while the full schedule of events can be found through the IMS website at metallography.net.

Short Course: Sunday, August 2

X17 – Standard Practice for Production and Evaluation of Field Metallographic Replica, instructor Frederick Schmidt, FASM

Conference Symposia: Monday – Thursday, August 3-6

X02 – Some Unexpected Difficulties in Microscope Operation in Microgravity, plenary session featuring NASA astronaut Donald Pettit

A10 – Advances in Electron Diffraction and Automated Mapping Techniques

P03 – Advances in Microanalysis of Earth and Planetary Materials

P06 – Failure Analysis Applications of Microanalysis, Microscopy, Metallography, and Fractography

P07 – Metallography and Microstructural Characterization of Metals

P08 – Microscopy and Characterization of Ceramics, Polymers, and Composites

P09 – Microscopy of Additive Manufacturing and 3D Printing in Materials and Biology

M&M 2015
MICROSCOPY & MICROANALYSIS
August 2-6 Portland, OR

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

SMST Announces Research Fellowship

The **International Organization on Shape Memory and Superelastic Technologies (SMST)** announces a new fellowship intended for use in a graduate level basic research effort, specifically addressing shape memory materials such as nitinol. It is intended to be the foundation for a future funding grant or research funding mechanism award. The $25,000 fellowship was awarded to **Ahmadreza Jahad** of the University of Toledo for his research, *Additive Manufacturing of Nitinol Fixation Hardware for Reconstructing Mandibular Segmental Defects*. A paper will be presented at the 2015 International Conference on Shape Memory and Superelastic Technologies in Oxfordshire, UK, as part of the plenary session on Wednesday, May 20, at 9:15 a.m. The sponsoring companies and organizations who made this fellowship possible include **Admedes Schuessler GmbH** (Germany), **EuroFlex GmbH** (Germany), **Fort Wayne Metals** (Fort Wayne, Ind.), **G. Rau GmbH** (Germany), **Nitinol Devices & Components** (Fremont, Calif.), and the **International Organization on Shape Memory and Superelastic Technologies** (Materials Park, Ohio).

Correction

Michael Covert, senior metallographer with the Ellwood Group, Ellwood City, Pa., is chair of the International Metallographic Society's Membership, Marketing, and Outreach Committee. This was listed incorrectly in ASM News, February issue.

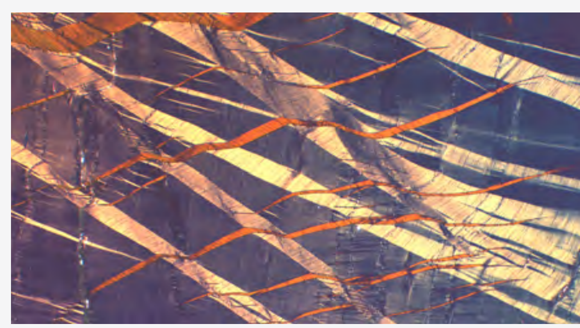
Covert

2015 IMC Continues with Fewer Classes and Larger Prize Money

The International Metallographic Contest (IMC) and Exhibit, cosponsored since 1972 by the International Metallographic Society (IMS) and ASM, is being held in conjunction with the 48th IMS Annual Meeting in Portland, Ore., August 2-6. The contest features the best work of metallographers and microstructure analysts from around the world. Last year's revision of the contest rules—resulting in fewer classes and larger prize money—continue this year. The changes are intended to boost participation and simplify the submission process.

The five classes include:

1. Light Microscopy—All Materials
2. Electron Microscopy—All Materials
3. Undergraduate Student Entries—All Materials
4. Artistic Microscopy—Color
5. Artistic Microscopy—Black and White



Polarized light microscopy of a Cu-Nb nanolaminate showing poor kink band contrast. From the 2014 IMC Jacquet-Lucas award winning entry.

Best-in-Show receives the most prestigious award available in the field of metallography, the Jacquet-Lucas Award, which includes a cash prize of $3000. The award has been endowed by Buehler since 1976. First place winners in Classes 1, 2, 4, and 5 receive $500 and first place winners in Class 3 (student entries) receive $1000 and the George L. Kehl Award. The DuBose-Crouse Award is presented for innovation in metallography in Classes 1, 2, and 3. Second and third place winners in all Classes receive $200 and $100, respectively.

All entries are displayed at the IMS Annual Meeting and again in the fall during MS&T. For contest rules and entry information, visit IMS at metallography.net and click on Awards, or email joanne.miller@asminternational.org. Submission deadline is July 18.

FROM THE PRESIDENT'S DESK


Collins

ASM Chapters: Your Local Materials Community

As ASM President, one of my favorite responsibilities is to visit local chapters to give a technical presentation. It's an opportunity to make new acquaintances and visit old friends. Each chapter is a little different and is a reflection of the local materials community. Inevitably, I come away with new ideas and insights, another experiment to try, or a new book or article to read. ASM chapters provide incredible programming and service to both our members and the local community. Volunteers judge science fairs, set up plant tours and golf outings, highlight local companies at sustaining member nights, and teach technical courses.

The chapter network, a strength of our Society, dates back to ASM's original roots in Detroit over 100 years ago: A community of likeminded individuals began meeting to share technical knowledge. Chapter meetings are where many of our members have their first experience with ASM. If you haven't been to a meeting lately, make room for it on your calendar. In a typical year, there is something for every interest, whether you are looking for insights into the latest materials technology or wish to enjoy a theater outing. While there, be sure to thank the tireless volunteers who keep the chapters running!

Your local chapter is also a gateway to a larger network. If your job changes, or your career takes you to another part of the country, the local ASM chapter will happily take you in. It's like finding an instant network in a new place. A friend of mine once told me, "All institutions are the result of conversations between people." Chapters are where people meet and have those conversations. And that is another reason for getting to your local chapter meetings: You never know who you are going to meet or what conversations you may have.

Sunniva R. Collins
sunniva.collins@case.edu

EMERGING PROFESSIONALS

Navigating an Experienced Workplace as a Young Professional

Rachel Bethancourt, Cherry Aerospace, a PCC Co.


Bethancourt

Entering the workforce as a young professional is an exciting time for new engineers full of ideas and eager to put their skills to use. However, innovative ideas can sometimes be met with opposition from those who are more seasoned. Relationships between young engineers and experienced coworkers can be difficult to navigate, but if done correctly, can yield great results.

Working in a manufacturing facility, some of my coworkers are skilled operators who have been employed here for longer than I have been alive. Their years of experience have given them an immense knowledge of the processes and products at our company. This also means they aren't immediately willing to change lifelong practices at the instruction of a brand new, inexperienced engineer.

As one recent example, the volume of an internal feature needed to be increased in order to improve a part design. The width or depth could be increased, with either change yielding the desired results. In talking to an operator who made the product, I learned that increasing the width would require new tooling and many changes to the setup, but changing the depth would only involve a simple adjustment to the machine. Understanding the impacts of my engineering decisions allowed me to make changes with consideration to the entire process.

My coworkers have become one of my best resources. I never hesitate to ask to be shown how something is done or if they need anything from me to perform their jobs more effectively. Knowing that I am eager to lead projects and consider their input, when they see problems in their areas, they bring it up to me instead of accepting the inefficiency, thinking no one would take the time to address it. There is amazing potential in new engineers who are ready to use their education to make improvements. The collaborative efforts between motivated young engineers and employees with years of experience can be one of the most effective combinations.

Los Angeles and Orange Coast Chapters Tour Bike Facility

Members of the Los Angeles and Orange Coast Chapters pose for a picture in front of Criterion Composites in Garden Grove, Calif. Owner Don Guichard, center, holding bike, gave a tour of his facility and showed how carbon fiber and epoxy are made into racing and custom bicycle frames.

Pittsburgh Hosts Young Members Night

On February 19, the ASM Pittsburgh Golden Triangle Chapter hosted its 29th annual Young Members Night at the city's University Club. The event was organized by the Young Members Night Committee with participating organizations ASM, Carnegie Mellon University, the University of Pittsburgh, and Robert Morris University. The event included a poster competition for graduate and undergraduate students, a presentation by student speaker Vincent DeGeorge, a presentation from guest speaker George Coulston, and an Outstanding College Senior awards ceremony. Sponsors included Alcoa, Carpenter Tech, American Stress Technologies, CBMM North America, Elliot Co., Ellwood Group, Matco Services Inc., US Steel, Product Evaluation Testing, ATI Powder Metals, and Westmoreland Testing and Research Inc.

Poster prize winners, from left to right: Sudipto Mandal, Rachel Ferebee, Tugce Ozturk, Tim Hosch, Ann Rutt, Yeshar Hadi, and Olivia Dippo.

Philadelphia Holds National Officers Night

The Philadelphia "Liberty Bell" Chapter hosted ASM President Sunniva Collins at its National Officers Night meeting in March. This annual event invites ASM's current president to an extended executive committee meeting, providing an opportunity for members to gain feedback from the president on the chapter's activities and goals. Further, it allows members to hear about what ASM headquarters is doing and about its plans. Nicole Hale, chapter relations specialist, also attended. The evening included a social hour and dinner, followed by Collins' presentation on *Orbital Welding for Critical Applications* and also included a live demonstration.

Sunniva Collins, Nicole Hale, and Jerri Jefferies.

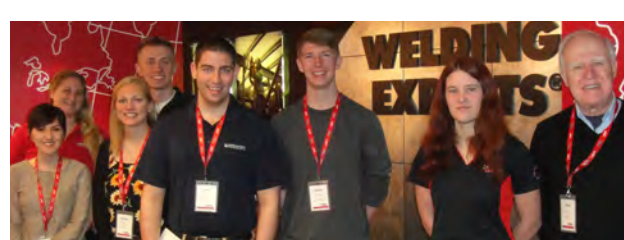
Chicago Hosts Forging Design Workshop

Recognizing the needs of its members for local training opportunities, the Chicago Regional Chapter is offering half-day classes. The most recent was a successful March workshop on the basics of forging design, taught by Jon Tirpak, ASM vice president. Attendees came from several large forge shops in the greater Chicago area as well as Green Bay, Wis. Following the class, Tirpak attended the chapter executive meeting as guest speaker, delivering a presentation on whether additive manufacturing would, to any degree, displace forging for the manufacture of engineered parts and tools.

Jon Tirpak discusses additive manufacturing and forging.

Case Students Tour Lincoln Electric

In April, a group of five students from the Undergraduate Materials Society of Case Western Reserve University, Cleveland, enjoyed a tour of Lincoln Electric's world headquarters in Cleveland. The tour was set up and sponsored by the Cleveland Chapter, with member Dave Brown attending as Chair of the Student Affairs Committee. The tour highlighted Lincoln's diverse product portfolio and many of the solutions they provide to the welding industry. After the tour, the group was treated to a delicious lunch while hearing about career opportunities available at Lincoln Electric. Additionally, the company highlighted its intern/co-op program, which is among the top five in Northeast Ohio.



Jennifer Peverelle, engineering trainee (second from right) arranged the Lincoln Electric tour for Case students and Dave Brown (far right), Chair of the Student Affairs Committee.

Abu-Farha Receives SME Honors

SME, Dearborn, Mich., recently selected 11 new Outstanding Young Manufacturing Engineers for their career achievements, including **Fadi Abu-Farha**. This year's awardees, age 35 or younger, were selected based on their R&D efforts in emerging manufacturing applications, published works, design ingenuity, entrepreneurship, and leadership. Abu-Farha is an assistant professor of automotive engineering at Clemson University International Center for Automotive Research, S.C. His research involves the manufacture of lightweight materials with efforts targeting greater utilization in transportation via the development of cost-effective and energy-efficient manufacturing techniques.

Abu-Farha

Vander Voort Teaches in Turkey

In February, **George Vander Voort, FASM,** taught two courses in Turkey. The first was for Erdemir's Eregli Iron and Steel Works Inc., in Zonguldak, at the request of Oktay Elkoca, manager of hot rolled products and process R&D. The course was titled *Metallography and Microstructure of Steels*. The second class was a two-day course in Istanbul for Applied Laboratory Systems (ALS), Struers' dealer in Turkey. All classes were in English with no translations, and the students were excellent, attentive, and asked good questions, says Vander Voort.

George Vander Voort, front row, third from right, and his students at Erdemir's Eregli Iron and Steel Works Inc. in Turkey.

Kubiak Receives Goldwater Scholarship

Joshua Kubiak, a student at Carnegie Mellon University, Pittsburgh, is among 260 sophomores and juniors nationwide chosen from more than 1200 nominations to receive the Barry M. Goldwater Scholarship for the 2015-2016 academic year. Kubiak is a junior majoring in materials science and engineering and chemistry. As an undergraduate research assistant, he is working to improve methods of creating quantum dot backlights for more energy-efficient LCD screens for displays such as those on televisions or portable electronics. He is a member of the Carnegie Mellon Racing team, Chem-E-Car, and Engineers Without Borders. In the future, he plans to pursue a doctorate in materials science and engineering and investigate novel polymeric materials for alternative energy generation.

Kubiak

Shipilov Receives NACE Award

In March, **Sergei Shipilov, FASM,** ASM Canada Council Past Chair, received the R.A. Brannon Award, the signature award of NACE International. He was nominated for several initiatives, which "enhanced the reputation of NACE International in secondary and post-secondary applied science and engineering education." In 2004, he proposed establishing a NACE Collegiate Student Certificate Program, designed to recognize students who complete a course in corrosion offered as part of the regular curriculum. In 2003, he initiated a partnership that organized a joint ASM/NACE Materials Camps for Teachers. The first joint camp took place in Calgary in 2006 when Shipilov chaired the local ASM chapter. That camp was followed by 13 others in Calgary and Ottawa, serving more than 300 teachers.

Shipilov

Hall to Serve Canadian Vacuum Processing Markets

Solar Atmospheres and Solar Manufacturing, both of Pennsylvania, announce that **Harry Hall** will assume the role of a sales representative focusing on Canadian vacuum processing markets. In 1989, Hall founded Aberfoyle Metal Treaters Ltd. in Guelph, Ontario, where he established a specialized business consisting of large-scale heat treating for heavy industry including steel mills, nuclear power, hydro-electric, petrochemical, and large machine shops. In recent years, his company heat treated and thermally straightened large complex composite tools for the Boeing 787 Dreamliner and Airbus A350. His new venture will be named H.G. Hall Inter-Connect Inc.

Hall

IN MEMORIAM

Word has been received at ASM Headquarters of the death of **Morris D. Thomas, Life Member**, of Frederiksted, V.I. Thomas was proud to be an ASM member, collaborator, innovator, and educator.

CORPORATE SPOTLIGHT

THERMO-CALC SOFTWARE

The use of modelling and simulation tools in materials R&D is growing rapidly as highlighted by the publication from the National Academies on Integrated Computational Materials Engineering (ICME) in 2008, and the announcement of the Materials Genome Initiative (MGI) in 2011.

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More information on these products can be found on our website, www.thermocalc.com.

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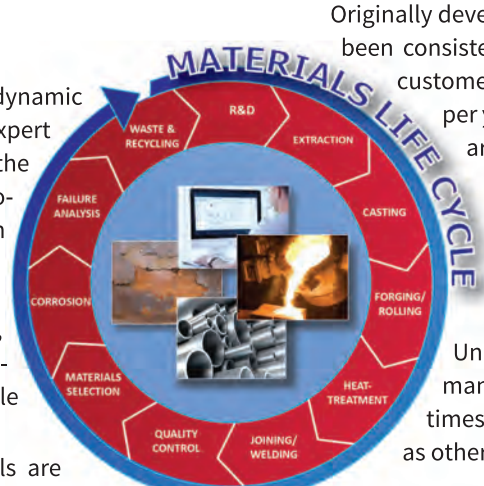

Our modelling and simulation tools are used for many different purposes within the lifecycle of a material, from R&D efforts in designing new materials to identifying optimal processing windows, all the way through addressing waste and re-cycling issues. Typical benefits expressed by our customers include:

- Reducing the number of costly, time-consuming experiments and testing by making better use of pre-screening/pre-test calculations
- Increasing the value of experiments through deeper understanding of the results
- Defining safe and optimal processing windows in terms of composition tolerances and temperatures
- Basing decisions on scientifically supported models, tools and data
- Shortening development times and bringing products to market faster
- Making predictions that are difficult or even impossible with an experimental approach

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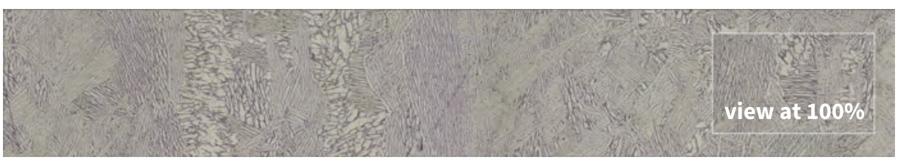

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CORPORATE SPOTLIGHT

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CORPORATE SPOTLIGHT

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NSL serves a wide spectrum of customers from aluminum smelters to zirconium powder producers; engaged in aerospace and aircraft, medical devices, chemical, automotive and transportation, consumer products, energy including alternative and nuclear, electronics, pharmaceutical, and ophthalmic markets.

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- ASME NQA-1 compliant
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- GE-S-400
- Boeing
- SNECMA
- P&W

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JUNE 2015

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AD INDEX

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STRESS RELIEF

ON TOUR WITH 3D-PRINTED GUITARS

Klaxons, the UK indie rock band, had a dream of going on tour using only 3D-printed instruments, and had this vision partially turned into reality with help from 3D-printed guitar company Customuse and experts from the University of Sheffield. The band's announcement was made not long after Sheffield graduates Mahdi Hosseini, Sophie Findlay, and Justas Cernas formed Customuse to make additively manufactured instruments. Hosseini came up with the idea after realizing that his dream of a personalized guitar was financially out of reach—unless he could get one printed.

As a Sheffield student, Hosseini worked with Professor Neil Hopkinson, who is not only a renowned expert on 3D printing but also plays electric bass guitar. "When the Klaxons announced their tour would be 3D printed, they didn't seem to really believe it could happen, but for guitars at least it's a very achievable goal. 3D printing is the ideal technology to create personalized instruments of this kind, as it allows you to have an intricate design with a lightweight body while retaining the necessary strength to ensure the guitar will work well," says Hopkinson. *For more information: Neil Hopkinson, +44.01.142.22.7766, n.hopkinson@sheffield.ac.uk, www.sheffield.ac.uk, www.customu.se.*

3D-printed guitar played on tour with the Klaxons.

HORSE POOP MUSHROOM SHOWS ANTIBACTERIAL POTENTIAL

A fungus that grows on horse dung contains a protein that can kill bacteria.

A fungus, known as copsin, which grows on horse dung contains a protein that can kill bacteria. It has the same effect as traditional antibiotics, but belongs to a different class of biochemical substances. Copsin is a protein, where traditional antibiotics are often non-protein organic compounds. Researchers led by Markus Aebi, a mycology professor at ETH Zurich, Switzerland, discovered the substance in the common inky cap mushroom *Coprinopsis cinerea.* Aebi and colleagues were interested in understanding how this fungus and various bacteria affect each other's growth.

This involved cultivating the fungus in a laboratory along with several different types of bacteria. It was found that *C. cinerea* is able to kill certain bacteria. Further research demonstrates the copsin produced by the mushroom is responsible for this antibiotic effect. "Whether copsin will one day be used as an antibiotic in medicine remains to be seen. This is by no means certain, but it cannot be ruled out either," he says. *For more information: Markus Aebi, +41.44.632.64.13, markus.aebi@micro.biol.ethz.ch, www.ethz.ch/en.html.*

JAZZ MUSIC IMPROVES GOLF GAME

Listening to jazz while putting can boost your performance on the green, according to new research from Clarkson University, Potsdam, N.Y. While any kind of music improves performance compared to listening to no music at all, jazz is the most effective musical genre for improving putting, according to a recently published study. The 22 research participants were university Division I golfers, an average of 20 years old with at least eight years of golf experience. Each of them completed a series of six trials, which comprised attempting five putts at four predesignated locations around a hole. In random order, participants were required to listen to either no music or a musical genre that included classical, country, rock, jazz, or hip hop/rap while putting. *For more information: Ali Boolani, 315.268.1663, aboolani@clarkson.edu, www.clarkson.edu.*

Ali Boolani, assistant professor of Physical Therapy and Physician Assistant Studies, listens to jazz on the green. Courtesy of Clarkson University/Ting-Li Wang.