NOVEMBER/DECEMBER 2017 | VOL 175 | NO 8

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION

ENERGY MATERIALS

INDUCTION MELTING FOR LI-ION BATTERIES

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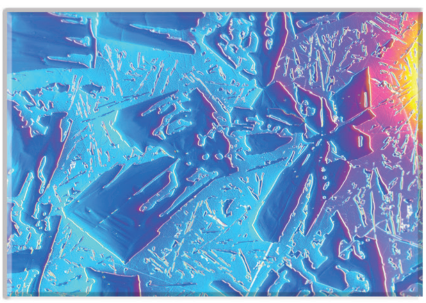
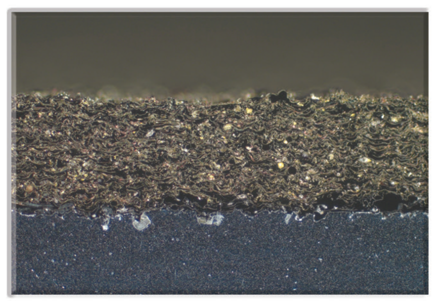
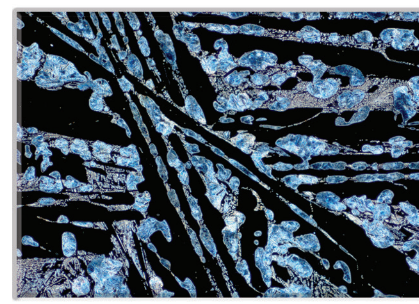
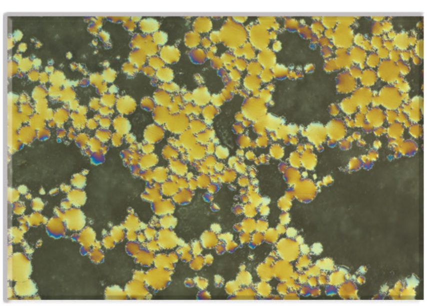
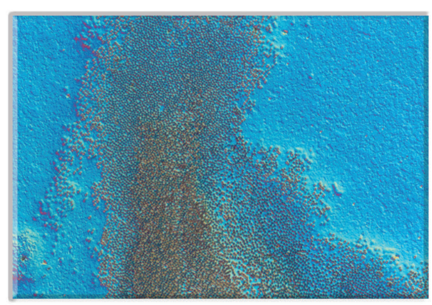
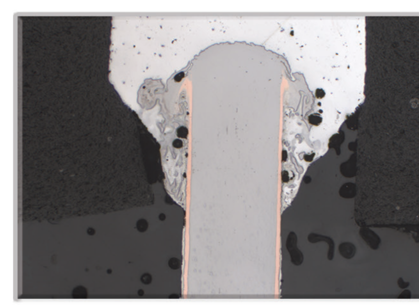


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USING INDUCTION MELTING TO MAKE LITHIUM-ION BATTERY MATERIAL

Wojciech Kasprzak, Delin Li, Gregory S. Patience, Pierre Sauriol, Hernando Villazón Amarís, Mickaël Dollé, Michel Gauthier, Steeve Rousselot, Majid Talebi-Esfandarani, Thomas Bibienne, Xueliang Sun, Yulong Liu, and Guoxian Liang

Using low-cost precursors, a novel induction melting and casting process is being developed to produce $LiFePO_4$—a cathode material for lithium-ion batteries intended for automotive applications.

On the Cover:

Battery packs are a critical component of electric vehicle (EV) drive systems, and developing optimized battery chemistry is key to widespread production.

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TECHNICAL SPOTLIGHT
TRUST BUT VERIFY

In this exclusive *AM&P* interview, testing expert Gordon Styles explains what goes into materials verification processes.

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3D PRINTSHOP

Learn what's new in additive manufacturing from HRL Laboratories, Arconic, and Lawrence Livermore National Laboratory.

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25 THE ROLE OF MATERIALS SCIENCE AND ENGINEERING IN IMPROVING SEA LEVEL RISE PREPAREDNESS-PART II

Harpreet Sidhar, Benjamin Boesl, and Arvind Agarwal

Efforts are underway in every sector of the scientific community to explore and develop possible strategies and solutions to counter sea level rise and climate change.

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The official newsletter of the ASM Thermal Spray Society (TSS). This quarterly supplement focuses on thermal spray and related surface engineering technologies along with Thermal Spray Society news and initiatives.

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The official newsletter of the ASM Heat Treating Society (HTS). This quarterly supplement focuses on heat treating technology, processes, materials, and equipment, along with Heat Treating Society news and initiatives.

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INSPIRING LECTURES KEY TO SUCCESSFUL FALL CONFERENCES

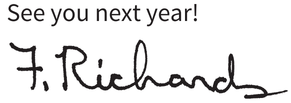
Hard to believe as it may seem, we've come to the final *AM&P* issue of 2017 and we are already planning 2018 activities. Combined with three major materials conferences in a row—MS&T, Heat Treat, and ISTFA—it has been a very busy fall season. We hope that many of you had a chance to attend a conference or two. If you did, I would be interested in hearing your opinion on the highlights. For me, besides the in-person networking that will never be replaced by social media, I find the special lectures to be extremely worthwhile and entertaining. Following are a few gems from these talks:

At MS&T, the TMS/ASM Joint Distinguished Lectureship in Materials and Society was presented by Alexander King, FASM, director of the DOE's Critical Materials Institute. In his talk, "What Do We Need and How Will We Get It," King made the point that today's cellphones contain roughly 70 elements. As the world's middle class grows from about 1.9 billion people today to 5.2 billion by 2030, we can assume that all of these consumers will want phones. Accordingly, what we need is "the whole periodic table and more of it." But today's ores are now weaker than in the past, so we need to do more mining to get less material. King said we need to find ways to diversify sources, look for alternatives to different materials, and make better use of materials by recycling, although he cautioned that "we can't recycle ourselves out of trouble." His last slide showed a "tree of life" image and he pointed out that only 28 elements are essential for all life, from simple bacteria to complex life forms. King says it is time to start thinking about making advanced technology with fewer elements.

In the Alpha Sigma Mu lecture, Joseph Newkirk, FASM, professor at Missouri University of Science and Technology, tackled a similar topic in his talk, "Creating the Materials of Tomorrow." Newkirk began by sharing images from the 1950s of how people envisioned the future. One showed a self-driving hover car with people playing cards inside. He said that although these transportation ideas have not come to fruition, nobody predicted the rise of personal computing devices such as cellphones and tablets. He says it turned out that "making things smaller is easier than lifting steel and people into space." Newkirk also reminded the audience that the world we now live in didn't exist before 1800 and that future technologies will likely involve robotics development, a manned Mars mission, and cheap clean energy. He ended by calling for more visionaries in the materials fields along with improved funding.

Speaking of visionaries, one of the most interesting lectures at the Heat Treat conference paid tribute to induction heating pioneer George Pfaffmann, FASM, presented by Ronald Akers and Aquil Ahmad, FASM. The men shared stories about Pfaffmann's distinguished career, including his key patent for Tocco Inc. involving induction hardening of valve seats, which enabled the switch from leaded to unleaded gasoline. Pfaffmann was also considered a tough negotiator during meetings. When confronted with pricing questions, he was known to say, "We don't sell nuts and bolts, we sell technology." Who could argue with that?

As 2017 winds down, we wish you all a happy and healthy holiday season. See you next year!



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OMG!
OUTRAGEOUS MATERIALS GOODNESS

The rose butterfly, common in India, has soft black wings that keep it warm during cool periods. Inset shows SEM image of butterfly nanoholes. Courtesy of Radwanul Hasan Siddique, KIT/Caltech.

BUTTERFLIES INSPIRE BETTER SOLAR CELLS

A team of researchers at the California Institute of Technology, Pasadena, and the Karlsruhe Institute of Technology, Germany, improved the efficiency of thin film solar cells by mimicking the architecture of rose butterfly wings. Using an electron microscope, the team found the wings to be covered with scales pockmarked with holes. In addition to making the wings lighter, the holes scatter the light striking them, allowing the butterfly to absorb more of the sun's heat. Inspired by the butterfly design, researchers created similar structures in their lab using sheets of hydrogenated amorphous silicon. A top layer with tiny holes of various sizes causes light to scatter and strike the silicon base below. The new design enables picking up roughly twice as much light as previous attempts, say researchers. *caltech.edu, kit.edu/english.*

WORM SECRETIONS FORM RECYCLABLE FIBERS

Velvet worms spray a sticky liquid to ward off enemies like spiders, and as soon as their prey tries to wriggle out of the slimy threads, the struggle causes the threads to harden—leaving no hope of escape. "The shear forces generated by the struggle cause the slime to harden into stiff filaments," says Alexander Bar, a doctoral student at the University of Kassel, Germany. Bar works closely with researchers from the nearby Max Planck Institute of Colloids and Interfaces to study this behavior. It turns out that the nanoparticles from these velvet worm secretions form recyclable polymer fibers: The polymerized slime threads can be dissolved in water within a few hours of drying and then be drawn again from the recovered slime. The redrawn threads behave exactly like fresh secretions under the influence of shear forces—they harden. Researchers say the velvet worms could serve as a model for manufacturers of synthetic polymers and could teach them something about sustainable production of synthetic materials. *www.mpikg.mpg.de/en.*

Velvet worms capture prey with a secretion that forms hard polymer threads as the victim tries to free itself. Courtesy of Alexander Baer/Nature Communications 2017.

Artist rendering. Courtesy of University of Warwick/Mark Garlick.

IRIDIUM AIDS BATTLE AGAINST CANCER

According to new research by a collaboration between the University of Warwick, UK, and Sun Yat-Sen University, China, cancer cells can be targeted and destroyed with metal from the asteroid that wiped out the dinosaurs. The research team demonstrated that iridium can be used to kill cancer cells by filling them with a deadly version of oxygen, without harming healthy tissue. The scientists created a compound of iridium and organic material, which can be directly targeted towards cancerous cells, transferring energy to the cells to turn the oxygen (O_2) inside into singlet oxygen, which is poisonous. The process is triggered by shining visible laser light through the skin onto the cancerous area—reaching the compound's light-reactive coating and activating the metal to start filling the cancer with singlet oxygen. The team found that after attacking a model tumor of lung cancer cells, the activated organic-iridium compound had penetrated and infused into every layer of the tumor to kill it. *www.warwick.ac.uk.*

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

FEEDBACK

3D PRINTING NOT A CURE-ALL

I read with interest the article on "Additive Manufacturing for Aerospace Applications—Part II" (September 2017) by Sam Froes, Rod Boyer, and Bhaskar Dutta. 3D printing of components and patterns will positively change every aspect of our lives. We must be cautious in our application of 3D printing because as intriguing as it is, a specific material or process application may or may not be the best fit. Direct metal printing is the hottest new application of 3D printing and is rightfully drawing significant attention from the engineering and manufacturing communities, but all material processes have limitations.

For the second time in as many months, I have seen articles discussing direct metal printing and claiming that printed metal parts "reduce energy use by up to 50%." Having seen no editorial reply to those claims, I thought it appropriate to respond.

All metal components start as a casting. Metal casting is the most direct, and lowest energy, line of manufacturing to take metal ores from the ground and convert them into a final product. Refined ores are made into ingots, which are remelted, alloyed, and cast to near net shape. Adding a step where the metal is remelted, atomized, and then welded back together with a 50-micron laser or electron beam (EB) is much more energy intensive than casting it.

The article claims that "half the cost of the final (cast) part is associated with the machining cost" and implies that the final finishing/machining cost for direct metal printed parts is less. That is just not the case. The support structures required for direct metal printed parts are every bit as substantial as the gating/runner system for a casting. (The cutoff casting gating system is subsequently recycled as low-energy charge material in the manufacture of subsequent castings.) Investment casting polymeric patterns are routinely produced by 3D printing and investment shells can now be 3D printed without tooling or cores. 3D-printed patterns and/or shells eliminate the need for draft in design and allow all of the advantages claimed by direct metal printed parts. The cleaning, machining, heat treating, HIP, and finishing requirements for both direct metal printed parts and investment cast parts (and the energy embodied in them) are similar. Currently, direct metal printed parts are more expensive than investment castings, a strong implication that they embody *more* energy in their manufacture than investment castings.

BALD bracket for USAF joint strike fighter built using AM electron beam melting technology. Courtesy of Oak Ridge National Laboratory.

Investment casting currently embodies less energy than direct metal printed parts. (The difference can vary significantly by material/process combination, component configuration, and product volume.) Much of the energy embodied in investment castings results from the amount of resources required to produce the ceramic shells and cores. As 3D printing of ceramic shells is mainstreamed, the energy in the investment casting process will be reduced. The challenge for direct metal printed parts is to minimize the support structure and subsequent finishing operations, but one cannot remove the energy from meticulously welding together metal powders with lasers and EB.

New casting technologies are developing that use fully recyclable, 3D-printed molds with no tooling, featuring all of the design freedom of direct metal printing and requiring much less energy. Direct metal printing directly competes with the metal casting process. Both processes will benefit from advances in 3D printing technologies and from competition with the other. The engineering and manufacturing community must scrutinize new material/process combinations to seek the best solutions for their applications. No one material/process combination is the best at everything and, like it or not, this tends to shake out in a proper cost analysis.

John R. (Chip) Keough, PE, FASM

AUTHORS' RESPONSE: 3D PRINTING ARTICLE

We, the authors of the article on additive manufacturing (AM), appreciate the interest taken in the article by Mr. Keough, and compliment him on his insightful remarks. In particular, we find his comments on the fabrication of investment casting shells by 3D printing very interesting. Casting or forging is certainly more energy efficient for larger batches of parts, but when the quantity is low or for a one-off prototype part, casting and forging require a lot of energy when the die manufacturing and energy consumption for die material is considered. In addition, for parts with a high buy-to-fly ratio, casting/forging often yields a lot of scrap material and requires much more machining time than AM parts. Every pound of material waste and additional machining time is also associated with energy consumption. There

FEEDBACK

are some cradle-to-grave studies on energy consumption of 3D-printed parts and conventionally manufactured parts that have demonstrated this very well. For example, 3D-printed lattice structures have shown a savings of about 25% in energy as compared to EDM machined structures. Another consideration is that AM enables much greater detail and thinner gages that are not possible with castings.

One benefit of AM-built parts is the design freedom for manufacturing and weight savings that can be obtained. This not only saves materials and energy for manufacturing the part, but also saves energy throughout the part's entire life if the part is used in the transportation industry. Direct metal printing also allows repair and refurbishment of used components. Refurbishing a used but damaged component not only saves material and money, but also saves the energy that would have been involved in manufacturing a spare part.

Another aspect that must be taken into account, at least for aerospace applications, is the casting factor—a factor applied to castings that reduces strength by a factor of a minimum of 1.25, and typically 1.5 to 2. The strength is divided by the casting factor. Consider a casting factor of 1.5, and a casting procured with a tensile strength of 125 ksi. In this scenario, the usable strength of the part is 125 ksi/1.5, or 83.33 ksi. So, the part could be much heavier than it would be for something machined from plate or a forging (this can be negated by design advantages for the cast structure). The casting factor takes into account the potential variability of the properties, much of which is due to process variability at different foundries.

Weld repair of castings is also a concern. Aerospace castings typically

24-in. diameter Inconel housing for turbine engine built using DM3D Technology's TransFormAM.

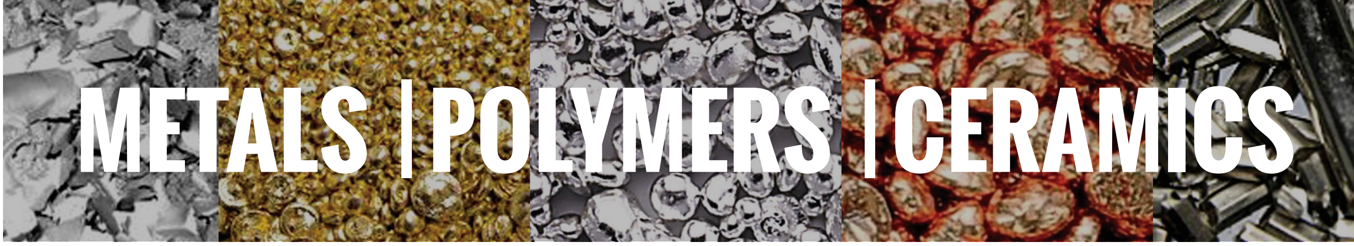
have extensive weld repair, which can significantly add to the cost and raise concerns about the possibility of lack of fusion at the bottom of the repair. Mr. Keough also notes the high cost of atomized titanium powder used in the AM process. We should point out that there are a number of emerging techniques for production of low cost, meltless spherical titanium powder suitable for AM, such as the hydrogen-assisted process developed by Professor Fang and his group at the University of Utah.

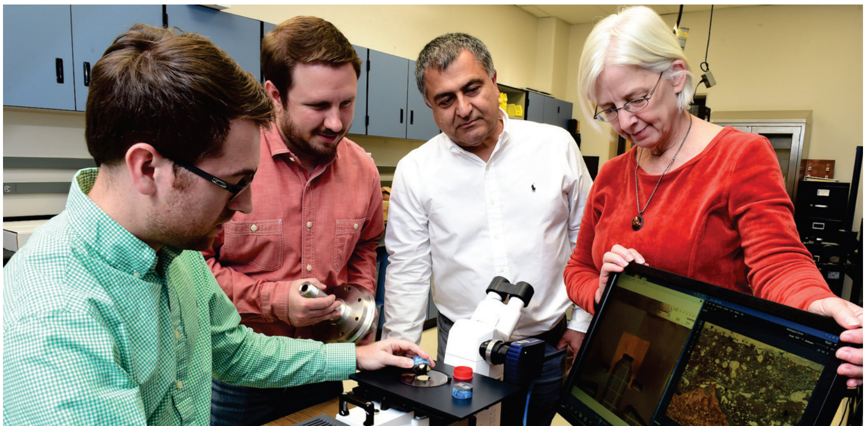
In closing, we absolutely agree with Mr. Keough that 3D printing is not a solution for all problems, but is another tool in the toolbox. There are many applications that will save material and energy by using 3D printing. We also appreciate Mr. Keough's insightful comments about 3D printing of molds and patterns and its benefits. As engineers create more demanding and better performing designs, the manufacturing industry will advance and 3D printing is expected to help the industry along.

A final point. The October issue of *AM&P* includes an article by A. Pawlowski et al. on how AM can be combined with traditional casting to create a hybrid process to produce a custom material for applications with specific performance needs. So, the old and the new *can* work together.

F.H. (Sam) Froes, FASM
Rod Boyer, FASM
Bhaskar Dutta

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





Majid Babai (center), advanced manufacturing chief at NASA's Marshall Space Flight Center, along with Professor Judy Schneider of the University of Alabama and two students, examine a cross section of the rocket engine igniter created via bimetallic 3D printing. Courtesy of NASA/MSFC/Emmett Given.

BIMETALLIC 3D PRINTING GETS NASA FIRED UP

For the first time, a 3D-printed rocket engine prototype part made of two different metal alloys was fabricated and tested for NASA. To make the igniter, two metals—a copper alloy and Inconel—were joined using automated blown powder laser deposition. Engineers at NASA's Marshall Space Flight Center, Huntsville, Ala., and the University of Alabama low-pressure hot-fire tested the part more than 30 times to demonstrate its functionality, then examined its bimetallic interface through a microscope. The images revealed that the two metals had interdiffused, eliminating any hard transitions that could lead to cracking during the extreme forces and temperature gradients of space travel.

The prototype was created on a hybrid machine made by DMG Mori, Hoffman Estates, Ill., that can alternate between freeform 3D printing and CNC machining. The unique single build process enables the part's interior to be machined during manufacturing—like building a ship in a bottle—before the exterior is finished and closed. Until now, rocket igniters were brazed and welded together from four components. The new method eliminates the need for these lengthy processes, potentially reducing rocket engine costs by up to a third and manufacturing time by 50%. *nasa.gov.*

FLOATING A NEW FORM OF FEATHERWEIGHT ALUMINUM

Researchers at Utah State University (USU), Logan, and Southern Federal University, Russia, used an innovative design approach to create a crystalline form of aluminum that is reportedly lighter than water. To build the ultralight material's molecular structure, researchers began with a known crystal lattice—in this case, diamond—and used computational modeling to replace every carbon atom with an aluminum tetrahedron. The team says that subsequent calculations confirm

USU professor Alex Boldyrev and colleagues from Russia's Southern Federal University say they have computationally designed a new metastable, ultralight form of crystal aluminum.

BRIEFS

The Institute for Advanced Composites Manufacturing Innovation (IACMI) is launching an initiative to develop a robust and scalable recycling method for both process scrap and end-of-life composites. Led by the **American Composites Manufacturing Association,** the project includes **Continental Structural Plastics, CHZ Technologies, A. Schulman,** and **The University of Tennessee, Knoxville** (UTK), with support from **Owens Corning** and **Ashland LLC.** IACMI is a 150+ member consortium led by UTK and the DOE committed to increasing production capacity and jobs across the U.S. composites industry. *iacmi.org.*

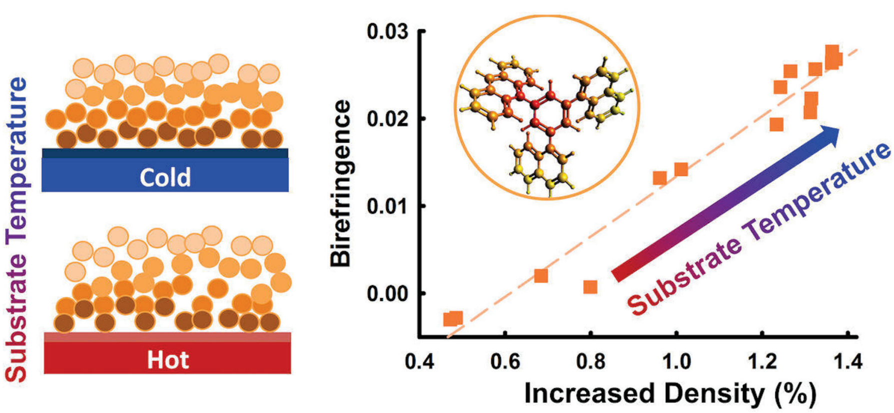
Alcoa Corp., Pittsburgh, announced plans to restart three of five potlines at its Warrick Operations aluminum smelter near Evansville, Ind. The process to restart the lines, with 161,400 metric tons of annual capacity, should be complete in early 2018. The potlines will supply the Warrick rolling mill, which serves the North American market with flat-rolled aluminum for the food and beverage can packaging industry. *alcoa.com.*

that the structure is a new metastable form of crystal aluminum, and that—to their surprise—it has a density of just 0.61 g/cm^3. This falls well below conventional aluminum's density of 2.7 g/cm^3, and even below water's density of 1 g/cm^3, allowing the material to float. *For more information: Alexander Boldyrev, 435.797.1630, a.i.boldyrev@usu.edu,www.usu.edu, www.sfedu.ru/www/site.english.*

THROUGH THE LOOKING GLASS

Researchers at the University of Pennsylvania, Philadelphia, developed a unique form of amorphous stable glass—a type of closely packed glass produced by vapor deposition onto a cold substrate—and determined that its optical properties can be engineered without inducing order in its structure. To create the glass, the researchers designed and synthesized a molecule that can never perfectly align due to its spherical shape. Expecting the glass to be amorphous and isotropic, the team was surprised to discover its light refraction index differed in directions parallel and normal to the substrate. This birefringence typically results from molecule alignment, and the new glass exhibited a level analogous to having nearly 30% of its molecules ordered. However, subsequent photoluminescence experiments, crystal structure simulations, and refraction index calculations confirm there is zero order in the material.

The researchers learned that the deposition layering process allows molecules to pack more tightly in the direction normal to the surface, causing the birefringence. The denser the glass, the more extreme the effect, with the degree of densification controlled by substrate temperature. The work, which demonstrates that high-density amorphous phases can exist, could allow engineers to manipulate the layering of a glass to tailor its mechanical properties, making it suitable for applications such as anti-scratch coatings. *upenn.edu.*



Researchers found that certain optical properties in stable glasses are due to the layer-by-layer nature of the deposition that allows molecules to pack more tightly in the direction normal to the surface during deposition.

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Magnetic tomography developed at Helmholtz-Zentrum Dresden-Rossendorf is an important prerequisite for controlling mold injection in continuous steel casting. Courtesy of HZDR/F. Bierstedt.

CONSORTIUM SETS SIGHTS ON NEXT-GEN PROCESS CONTROL

A European collaboration of 12 research institutions and 15 companies, coordinated by Helmholtz-Zentrum, Germany, launched an initiative to develop imaging-based industrial process control. The group, "Smart Tomographic Sensors for Advanced Industrial Process Control" (TOMOCON), seeks to capitalize on today's ultrafast parallel-data processing capabilities to create real-time sensors for machines and processing plants similar to those used in self-driving cars. Doctoral education and industrial training will be offered to 15 researchers, and topics of inquiry will include sensor technology, process tomography, industrial process control, computational physics and process modeling, human-machine interaction, and massive parallel-data processing.

TOMOCON will also undertake four technical demonstrations in close collaboration with industry partners. Smart tomographic sensors will be created for use in inline fluid separation for the chemical and petrochemical industries, and magnetic tomography sensors will be developed to control mold injection in high-speed continuous steel casting. In addition, ultrasound-controlled industrial crystallization will be investigated, along with the drying of impregnated polymer foams via tomography-controlled microwave heating. *www.hzdr.de.*

AFM REDESIGN BRINGS NEW MEASUREMENTS TO LIGHT

Engineers at the National Institute of Standards and Technology, Gaithersburg, Md., redesigned the detection system of the atomic force microscope (AFM), pushing the instrument to an unprecedented level of both precision and speed. The researchers slimmed down the AFM's probe to weigh a mere trillionth of a gram, then integrated it with a nanoscale optical disk resonator. Because the two components are just 150 nm apart, the probe's infinitesimal movements alter the resonant frequencies in the disk, translating tiny mechanical motions into amplified optical signals. The new system can register a displacement as small as a

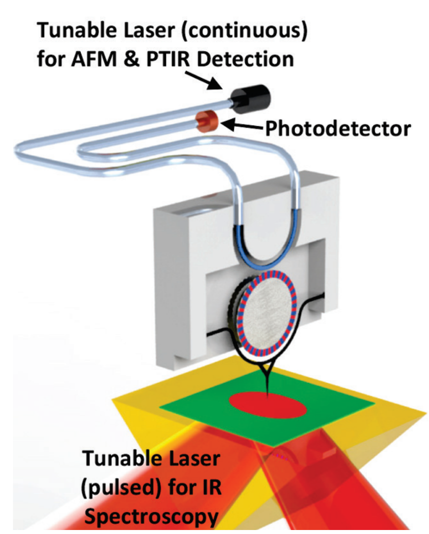


Illustration of a newly fabricated atomic force microscope probe integrated with an optical, disk-shaped resonator. Courtesy of NIST.

BRIEFS

Inspection and nondestructive testing provider **Versa Integrity Group Inc.,** New Orleans, will acquire **Carbon Steel Inspection Inc.** (CSI), Pittsburgh. CSI specializes in eddy current services and products for refining, chemical, and power generation customers, and will operate as a subsidiary of Versa. *versaintegrity.com.*

The National Science Foundation awarded $23.2 million over the next six years to **The Cornell Center for Materials Research,** Ithaca, N.Y. The award will fund three projects: Mechanisms, Materials, and Devices for Spin Manipulation; Structured Materials for Strong Light-Matter Interactions; and 2D Atomic Membranes for 3D Systems, which will create 2D materials that self-fold into highly responsive 3D structures. *ccmr.cornell.edu.*

trillionth of a meter occurring over a time scale as short as 10 billionths of a second.

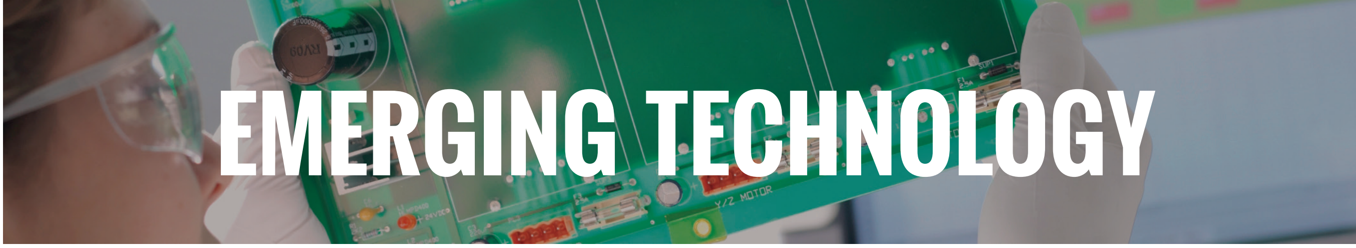
The researchers exercised the instrument's new capabilities in an experiment using photothermal induced resonance (PTIR), which combines AFM and infrared light to determine material composition. The AMF-PTIR system allows researchers to record how long it takes for microcrystals in a metal-organic framework (MOF) to cool and resume their original size after thermal expansion, and with this data, the thermoconductivity of individual MOF microcrystals was determined for the first time. The system could allow the study of other phenomena—such as protein folding or heat diffusion—that cannot be measured by existing AFMs. *nist.gov.*

TRACKING CORROSION IN TINY SPACES

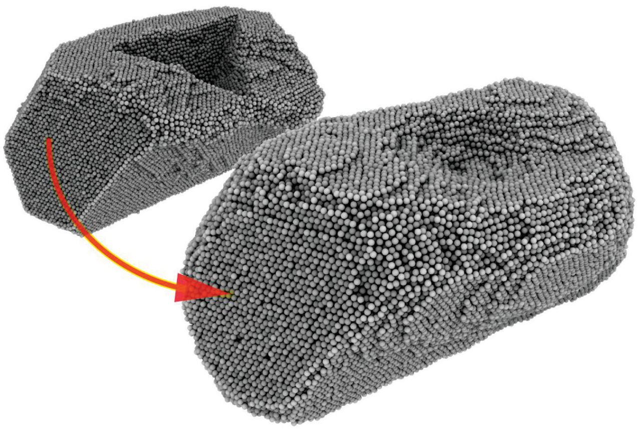
Scientists at the University of California, Santa Barbara (UCSB) snagged a real-time glimpse into how crevice and pitting corrosion progresses in confined spaces—like gaps between machine parts or seams where two surfaces meet. The researchers studied the initiation and progression of the process where a nickel film contacted a mica plane. Using a surface forces apparatus, the team determined the thickness of the metal film and observed electrochemical dissolution over time, discovering that the process was not homogeneous. Instead, areas with microscale surface defects experienced intense local corrosion and sudden pitting. Once a protective surface layer was breached, corrosion spread from the pits—often rapidly.

"Because you've got diffusion occurring, it affects the rate at which the metal dissolves both in and out of the crevice," says Professor Jacob Israelachvili. "It's very anisotropic." The researchers also found that corrosion is more likely to begin, and to spread quickly, when the electric potential difference between the film and the opposing surface reaches a certain critical value. In this case, the nickel film corrodes while the more chemically inert mica remains whole. The work could lead to predictive models for material failure in confined spaces and be used to control corrosion rates in different applications. *ucsb.edu.*

UCSB researchers are now able to capture a nanoscale glimpse of crevice and pitting corrosion as it happens.



EMERGING TECHNOLOGY



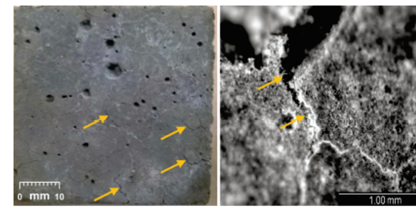
Gold atoms move into a previous dent, refilling it almost completely. Courtesy of KIT.

SHAPE MEMORY RESEARCH STRIKES GOLD

Scientists at the Karlsruhe Institute of Technology (KIT), Germany, and the Technion – Israel Institute of Technology observed, for the first time, self-healing in tiny particles of pure gold. The discovery overturns the long-held assumption that pure metals are incapable of shape memory. First, researchers simulated mechanical defects in gold particles of various shapes using high-powered computing, then produced the defects in actual particles with the measurement tip of a scanning force microscope. They found that annealing air temperatures far below the melting temperature of gold caused the gold atoms to move along surface steps back into the dents, refilling them almost completely and nearly returning the particles to their original shapes. Because such surface steps occur in many deformed metals, the scientists expect that other metals possess self-healing properties as well. Until now, the search for self-healing materials has been concentrated on metal alloys and complex polymers, neither of which exhibit complete shape memory. The new findings could lead to the design of components for structures smaller than one thousandth of a millimeter. *kit.edu/english, www.technion.ac.il/en.*

SNOW-CLEARING CONCRETE

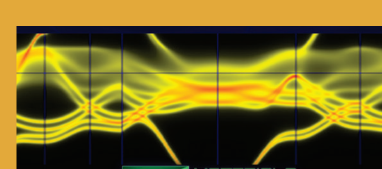
A group of U.S. researchers demonstrated a method to produce road and runway surfaces that clear themselves of ice and snow, offering an environmentally friendly, nondestructive alternative to chemical deicers, salt, and plowing. The team—from Drexel University, Purdue University, and Oregon State University—embedded the phase change material (PCM) paraffin oil into concrete. Paraffin oil is widely available, chemically stable, and relatively inexpensive, and like all PCMs, it releases thermal energy when shifting between physical states. As temperatures fall, paraffin in a roadway would change from liquid to solid, emitting heat and melting ice and snow.



Adding paraffin oil to the aggregate used in concrete mix could give it the ability to melt ice and snow when temperatures fall.

To test their method, the team created three concrete slabs—one containing paraffin-filled pipes, one containing porous, paraffin-infused aggregate, and a control slab without paraffin. Each was sealed each in an insulated container and covered with five inches of lab-made snow. At temperatures between 35° and 44°F, both paraffin-treated slabs completely melted the snow within 25 hours, while the control remained frozen. The slab with tubes melted the snow fastest, probably because the consistent diameter of the tubes allowed the paraffin inside to solidify more quickly. In a second experiment, with air temperatures below freezing, the aggregate was most effective because capillary pore pressure reduced the rate of freezing, allowing a more gradual release of heat. Next, the team plans to research how embedded PCMs affect the durability, skid resistance, and long-term stability of pavement. *drexel.edu, purdue.edu, oregonstate.edu.*

BRIEF



The **U.S. DOE** is launching a multi-lab effort to apply high-performance computing to the development of materials for severe environments. The **High Performance Computing for Materials Program** will connect U.S.-based industry with the resources of national laboratories including **Lawrence Livermore, Los Alamos, Oak Ridge,** and the **National Energy Technology Laboratory,** adding more as the program grows. The initial focus will be challenges posed by corrosion, chemicals, vibration, fatigue or stress, and extremes in pressure, radiation, and temperature, along with lightweight materials development. *hpc4mtls.llnl.gov.*

PROCESS TECHNOLOGY

New insights into how animals spin silk could lead to greener ways of producing synthetic fibers.

SILKWORMS PULL TEXTILE INDUSTRY IN GREENER DIRECTION

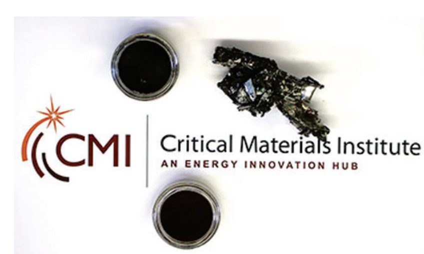
Scientists at the University of Sheffield, UK, discovered that animals such as spiders and worms spin silk not by pushing it out of their bodies, as was previously assumed, but by pulling it. Mimicking that pulling process in an industrial setting could make textile manufacturing more efficient and environmentally friendly. To run their experiments, researchers adapted a rheometer—normally used to measure viscosity—into a highly sensitive spinning wheel. Using a combination of computer models, experimental data, and practical measurements, the Sheffield team discovered that pushing unspun silk through a worm's silk gland would require an amount of force impossible for an animal of its size to generate—more pressure than in a firing diesel engine. However, the force required to pull silk from the animal's body, known as *pultrusion,* is well within the silkworm's capacity.

Currently, textiles such as nylon and polyester are manufactured by extruding a liquid feedstock through a dye, then solidifying it using extreme temperature change and exposure to harsh chemicals. Silk, which solidifies at room temperature leaving only water as waste, is a promising green alternative to these synthetic fabrics. Until now, industrial silk production methods have proven arduous and time-consuming. Understanding the natural pultrusion process is the first step in developing an industrial method for efficient silk production, say researchers. *www.sheffield.ac.uk.*

RARE EARTH RECYCLING FINALLY MAKES CENTS

Researchers at the DOE's Critical Materials Institute, Ames, Iowa, developed a promising new rare earth magnet recycling process that is cleaner and greener than traditional methods—and potentially profitable. The process dissolves magnets in an acid-free solution and recovers high purity rare earth elements without using hazardous mineral acids or producing toxic fumes. The technology, which has been applied to waste materials from U.S. magnet processing plants, is remarkably selective in recovering rare earth elements, even from electronic waste. In shredded computer hard drives, for example, rare earths were selectively removed from waste without pre-sorting or pre-concentrating the materials' magnet content, reducing steps and costs.

Economic and environmental challenges have largely prevented rare earth recycling from being a viable solution to the scarcity problem, but the new process could change that. Not only has it been adapted to recover rare earths from Nd-Fe-B and Sm-Co magnets, it can also recover other marketable byproducts from electronic waste for further recycling, including copper, chromium, and nickel, enabling the process to pay for itself. *cmi.ameslab.gov.*

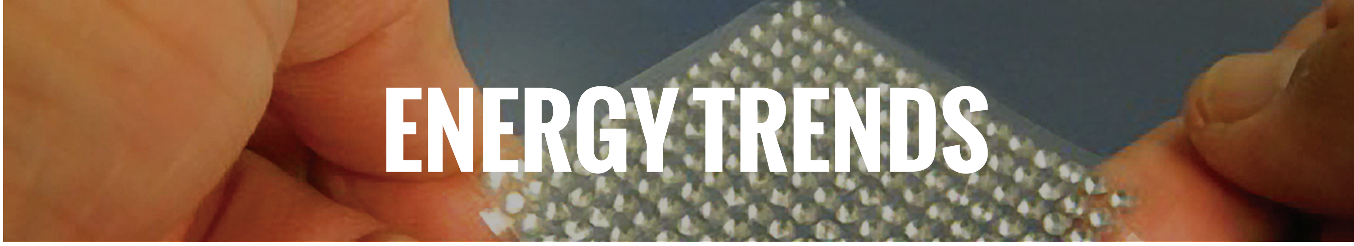


Shredded electronic waste (top right) is processed into rare-earth oxide.

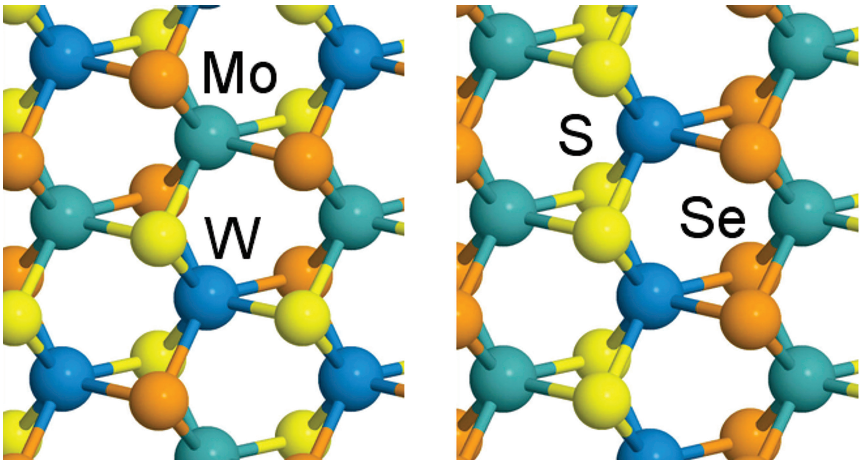
BRIEFS

United Technologies, Farmington, Conn., will purchase flight deck maker **Rockwell Collins,** Cedar Rapids, Iowa, for $22.75 billion. Rockwell Collins will merge with United Tech's aerospace division to become a new unit named **Collins Aerospace Systems,** which will make airplane seats, landing systems, and other parts for commercial and military planes. The deal should be complete within a year. *utc.com.*

Specialty chemicals producer **CRC Industries Inc.,** Horsham, Pa., will acquire **Weld-Aid Products,** Detroit. Weld-Aid's major business units include an aftermarket division for welding-related cleaning and lubrication products and the zinc rich coatings division, which serves the galvanizing and infrastructure markets. Additionally, the company markets products such as zinc coatings, anti-spatter, and lubricants. *crcindustries.com.*



ENERGY TRENDS



Subtle changes in growth temperature alter the form of a four-component alloy created at Rice University. Courtesy of Alex Kutana.

TEMPERATURE TUNES 2D ALLOY

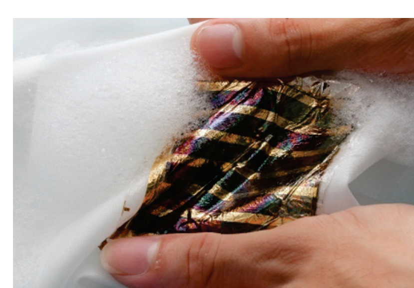
Researchers at Rice University, Houston, developed a four-material 2D alloy with an optical bandgap that can be tuned by adjusting its growth temperature. Before growing the alloy—composed of molybdenum, tungsten, sulfur, and selenium—researchers generated 152 random models. These reveal that the bandgap could be tuned from 1.62 to 1.84 electron volts by varying the growth temperature from 650° to 800°C. After performing these simulations, the thermodynamically stable materials were made in a chemical vapor deposition furnace at 50-degree increments and tested. Images from Oak Ridge National Laboratory, Tenn., detail the position of each atom and confirm that changes in growth temperature correspond to changes in the way the atoms assemble, as well as in the properties that determine light absorption and emission. These bandgap changes are extremely regular and result in predictable optical properties.

Although labs have made 2D materials with two or three components, the researchers believe theirs is the first attempt with four, which allows unprecedented freedom. "With fewer materials, every adjustment you make to change the bandgap turns it into a different material. That's not the case here," explains Rice postdoc Chandra Sekhar Tiwary. Because the material can be tuned to cover the entire spectrum of visible light—from 400 to 700-nm wavelengths—the discovery could impact solar cells and light-emitting diodes, leading to smaller, more efficient devices. *rice.edu.*

WASH AND WEAR SOLAR CELL

Scientists at Riken, Japan, and the University of Tokyo invented an ultra-thin photovoltaic device that provides electricity even after being submerged in water, stretched, or squished. The cell could make its way into the Internet of Things as a component of washable, wearable electronics. To create the device, an organic solar cell based on a material called PNTz4T was deposited in an inverse architecture onto a 1-μm-thick parylene film. The ultra-thin device was then sandwiched between two identical acrylic-base elastomer films, sealing it within a flexible coating that admits light but prevents the infiltration of water and air. Experiments show that the device has an energy efficiency of 7.9%. Based on simulated sunlight of 100 mW/cm^2, it produces a current of 7.86 mW/cm^2 and a current density of 13.8 mA/cm^2 at 0.57 V. When the device is soaked in water for two hours, its efficiency decreases by just 5.4%, and after being compressed in half for 20 cycles while subjected to water droplets, the cell maintains 80% of its original efficiency.

Past attempts to create photovoltaics that could be incorporated into textiles have lacked long-term stability in both air and water, energy efficiency, or robustness. The new cell overcomes these obstacles, paving the way toward devices such as health monitors that can be incorporated into everyday clothing. *www.riken.jp/en, www.u-tokyo.ac.jp/en.*



Washable, ultra-thin organic solar cells.

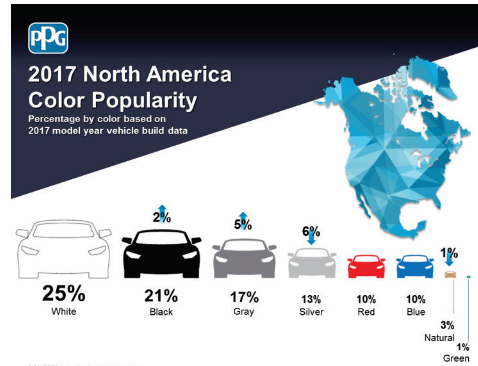
BRIEF

Clean technology company **alpha-En Corp.,** New York, will enter a joint research program with **Mercedes-Benz Research and Development North America,** Sunnyvale, Calif., and **Princeton University,** New Jersey. The project aims to investigate the use of alpha-En's highly pure lithium metal nanorod thin films in next-generation battery technologies with the aim of improving cell performance and battery production for electric vehicles and consumer products. *alpha-encorp.com.*

STRESS RELIEF

WHITE ON CRUISE CONTROL AS TOP CAR COLOR

PPG Industries Inc., Pittsburgh, recently unveiled its latest automotive color trends report, citing white as the most popular hue and blue as the fastest-growing shade for automobiles around the world. Color preferences by region for 2017 include:



North America: White (25%) remains steady as the top color preference, while black (21%) and gray (17%) rose 2% and 5%, respectively. Silver (13%) dropped 6%, and is followed closely by red and blue (both 10%).

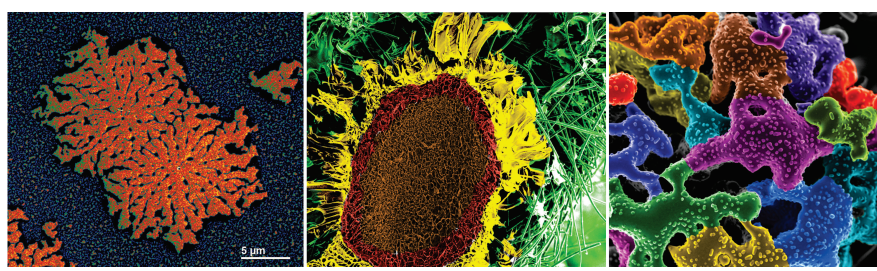
South America: White (38%) continues to dominate in this region, while silver (31%) is close behind. Black (10%), gray (9%), and red (8%) hold ground as other popular choices.

Europe: White (32%), gray (18%), black (17%), and silver (9%) remain nearly consistent with 2016, while blue (9%) achieved an increase in consumer preference.

Asia Pacific: White (44%) remains the most popular in this region. Black (15%) trailed, as well as silver (10%), and natural (10%), which includes gold, beige, orange, and brown hues.

SCIENCE IMITATES ART

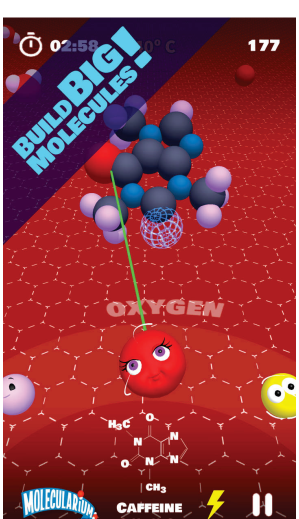
Two images share top honors in the DOE's Pacific Northwest National Laboratory (PNNL) 2017 Science as Art contest based on online voting by staff and the public that resulted in a tie. The annual contest has been a regular fixture at PNNL since 2010. Winners of the Popular Choice Award were selected from a group of 94 images on the lab's Facebook page. Pictured left, the image submitted by scientist Venkateshkumar Prabhakaran is part of research that will contribute to the design of new energy generation, conversion, and storage technologies. The middle image, submitted by researcher Luis Estevez, is part of an initiative to develop new carbon-fiber based materials with applications from catalyst supports to electrodes for flow batteries. Pictured right is the Director's Choice Award winner selected by PNNL Director Steven Ashby, which represents research that will contribute to development of materials to treat and reduce vehicle exhaust or power plant emissions. The image was submitted by materials scientist Radha Kishan Motkuri. *pnnl.gov.*



Winning images from PNNL's 2017 Science as Art contest.

NEW GAME APP BUILDS MOLECULES

Want to build some molecules and have fun at the same time? There's an app for that. My Molecularium is a new game that challenges players to build a wide variety of molecules from water and vitamin C to caffeine and adrenalin. The goal is to create as many molecules as possible in the shortest period of time. Fun facts about each molecule are shared with players along with an accuracy bonus for each completed item. The app is the latest effort of the Molecularium Project spearheaded by faculty at Rensselaer Polytechnic Institute, Troy, N.Y., and funded by the National Science Foundation and others to excite audiences of all ages to explore and understand the molecular nature of the world around them. The game is available for free at the Apple App Store or Google Play. *molecularium.com.*



My Molecularium adds joy to learning about molecules.

USING INDUCTION MELTING TO MAKE LITHIUM-ION BATTERY MATERIAL

Wojciech Kasprzak and Delin Li
CanmetMaterials, Natural Resources Canada

Gregory S. Patience, Pierre Sauriol, and Hernando Villazón Amarís
Chemical Engineering Department, Polytechnique Montreal

Mickaël Dollé, Michel Gauthier, Steeve Rousselot, Majid Talebi-Esfandarani, and Thomas Bibienne
Chemistry Department, University of Montreal

Xueliang Sun and Yulong Liu
Mechanical and Materials Engineering Department, Western University, Canada

Guoxian Liang
Johnson Matthey Battery Materials Ltd., Canada

Fig. 1 — Contemporary hybrid and electric vehicles[8].

Stringent Corporate Average Fuel Economy (CAFE) standards in North America require 54.5 miles per gallon (~4.5 L/100 km) fuel economy for passenger vehicles by 2025. Industry has responded to this challenge and expanded their R&D activities. They are predominantly focused on vehicle weight reduction as well as internal combustion engine (ICE) power efficiencies[1]. These efforts have already made an impact. However, achieving appreciable and sustainable levels of decarbonization requires that consumers broadly adopt electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) (Fig. 1).

Battery packs and cathode chemistry are key components of the EV drive systems that affect capital cost as well as performance. Battery pack development is crucial for successful implementation of EVs[2]. A number of battery chemistries have been developed over the last decade (Fig. 2). Lithium-ion battery (LIB) compositions have attracted the most interest due to their higher energy density (Wh/kg) compared with other commercial batteries, and vary from 120-250 Wh/kg at the cell level. They weigh less than traditional lead-acid batteries (~40 Wh/kg) used for starting-lighting-ignition (SLI), and nickel-metal hydride (NiMH) (~90Wh/kg) batteries that are used to power almost all current hybrid electric vehicles (HEVs)[3,4].

Discovered in the 1980s, $LiCoO_2$ (LCO) became a key cathode material in LIBs for portable electronics. Sony commercialized this chemistry in the 90s and it has become the international standard for portable electronic devices such as cellphones and laptop computers[5]. These batteries are light, compact, exhibit good charge retention, and have no memory effect. In the 1990s, $LiFePO_4$ (LFP) was discovered to feature superior thermal stability and environmental impact compared to $LiCoO_2$. The initial challenge of the LFP chemistry was its low electrical conductivity and mass transfer resistance, but these limitations were overcome by carbon coating (C-LFP) and particle size reduction[6]. Such improvements of the C-LFP performance strengthened its position as the optimum cathode choice when considering characteristics such as specific power (W/kg), thermal stability, cyclability, and safety.

The vast majority of commercially available lithium-based batteries belong to the LIB category and use carbon as anode, $LiPF_6$ in organic solvent as electrolyte, and cathode materials such as mixed oxides (e.g., NMC: $Li(Ni/Mn/Co)O_2$; NCA: $Li(Ni/Co/Al)O_2$ and LFP) for various applications. The advantages of LFP for large batteries comes from the potential low cost that can be achieved by using widely available precursors such as iron and phosphorus. This is in contrast to expensive cathode chemistries such as NMC and NCA that contain cobalt with concerns about availability, toxicity, and rising cost (Fig. 3).

EV AND PHEV APPLICATIONS

Requirements for LIBs for EVs and PHEVs include a lifespan of 8-15 years, operating temperature range between -40° and 60°C, vibration resistance, affordable cost, and safety[3]. Despite improvements in LIB performance, today's C-LFP cathode materials struggle to become the first choice for automotive batteries. This is due to the lower energy density of LFP relative to metal oxide alternatives along with high LFP material costs, owing to energy intensive and

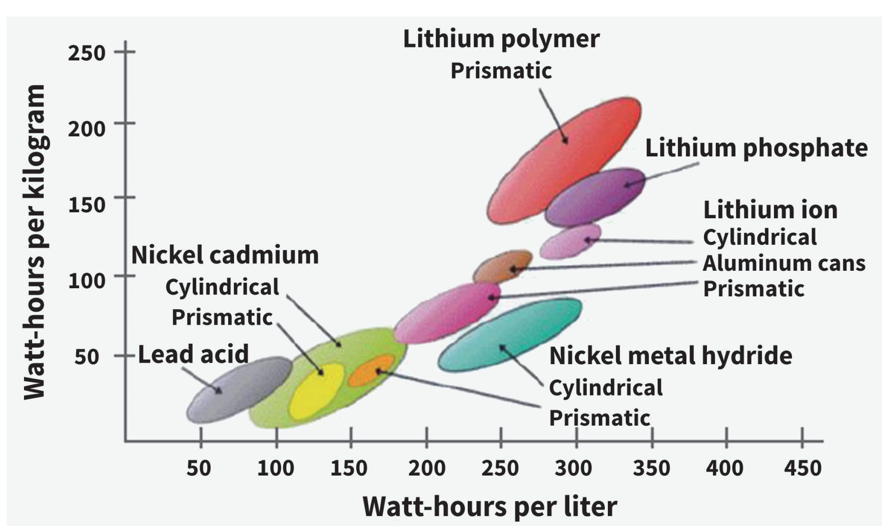


Fig. 2 — Various battery chemistries and their corresponding energy density (Wh/L) and specific energy (Wh/kg). Source: electropaedia.com.

complex materials processing involved in the synthesis of high quality C-LFP, not yet reflecting the potential low cost of iron and phosphorous. Consequently, as shown by a recent cost analysis of five common cathode materials (LCO, NMC, NCA, LMO, and LFP), they have nearly the same effective energy cost of approximately \$55-61/kWh[7] for the cathode material only. At the battery level, the cost must drop by a factor of 3 to 5 to be less than \$150/kWh at 1000 cycles to achieve market acceptance.

LIBs for automotive applications are now predominantly used in luxury gasoline-powered vehicles for applications such as SLI and idle stop (Porsche and McLaren offer as standard or as an option). Also, they are used in mild hybrid (Mercedes S400) and full hybrid cars (BMW ActiveHybrid 3/5, Hyundai Sonata, Ford C-Max). The market is now introducing or anticipating the arrival of several new electric vehicles including the Tesla 3 (successor of Tesla X), Chevrolet Bolt, and also a few models from other manufacturers including Ford, Hyundai, Toyota, and Volkswagen that could potentially use LIBs. This would complement the existing offering of EVs (Tesla, Nissan Leaf), PHEVs (Chevrolet Volt) and HEVs already in production. Automobile manufacturers are introducing these EVs to meet more stringent regulations in California, which demands that 15% of new vehicles must have “zero” emissions by 2025 as well as plans to ban gasoline and diesel-powered cars by 2050[8].

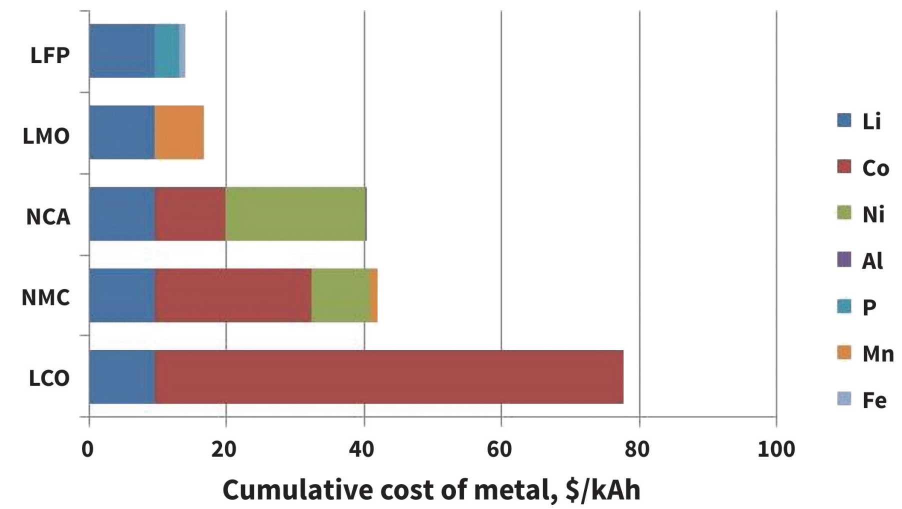


Fig. 3 — Price of metals used for common cathode materials in lithium-ion batteries (on a theoretical kAh basis): LFP = $LiFePO_4$; LMO = $LiMn_2O_4$; NCA = Li(Ni0.8Co0.15Al0.05)O_2; NMC = Li(Ni0.33Mn0.33Co0.33)O_2; LCO = $LiCoO_2$.

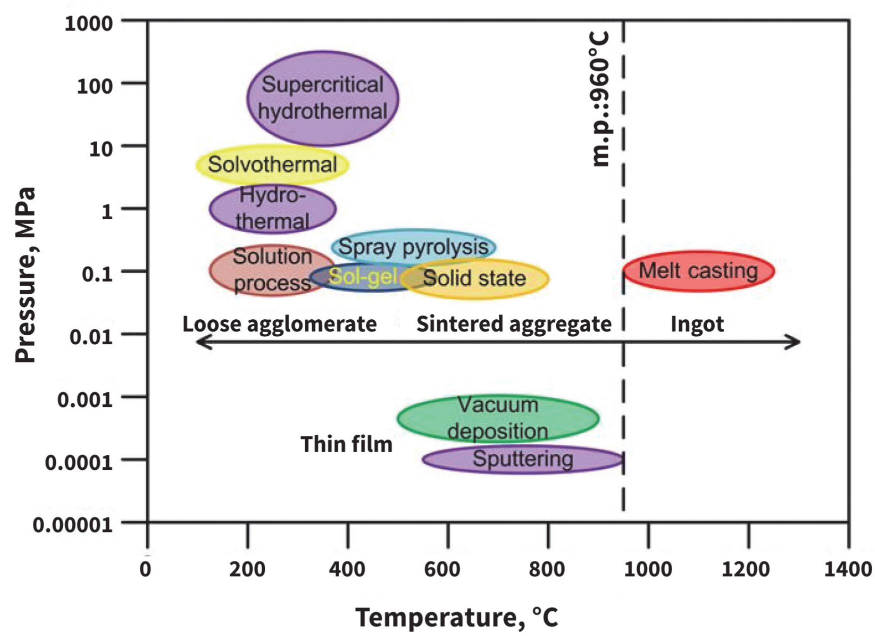


Fig. 4 — Types of LFP synthesis methods and their operating conditions (pressure vs. temperature)[14].

C-LFP CATHODE MATERIAL PRODUCTION METHODS

Both solid state and hydrothermal processes synthesize C-LFP at the industrial scale. However, they require multiple, time-consuming steps and/or costly precursors (Fig. 4). The hydrothermal process is suitable for power applications because the particles are finer[5]. As electrochemical performance of C-LFP depends on the synthesis method, current research is dedicated to optimizing existing processes and developing new manufacturing technologies[4]. The specific capacity of good quality, commercially produced C-LFP exceeds 150 mAh/g at 0.1 C and has mass fraction between 2-3% carbon and average primary particle size between 0.5 to 1 µm[9]. The “C” value is a rate of battery discharge/charge where 0.1 C represents a complete discharge/charge in 10 hours.

Melting lithium-, iron-, and phosphorus-bearing precursors in near stoichiometric ratios and casting the LFP that forms around 1000°C requires fewer processing steps and shorter reaction time. Moreover, the melt synthesis can consist of less expensive, commodity chemicals, ores, battery recycling, or a mixture of such reactants[4,5,10]. Further, the molten synthesis can operate with coarser reactant particles compared to solid state processes. One drawback of this technology is that the synthesized LFP is coarse: The capacity of large particles is lower than that of small particles and their capacity loss with extended charge-discharge cycles is greater[4]. So, comminution steps are required to reduce the synthesized LFP down to submicron particles. Despite this drawback, melt-casting synthesis has the potential to produce a good cathode material with low-cost raw materials faster than solid state processes, which would reduce the overall cost of the cathode and accelerate EV adoption by consumers.

Casting synthesis experiments to date have produced only small quantities (grams) at the laboratory scale, with resistance furnaces used as a heating source. Processing cycles are slow in these facilities because their energy flux per unit of volume is insufficient to rapidly reach 1000°C (e.g., above the melting point of LFP). Melting synthesis techniques for high capacity (>100 kg) require a high energy flux, along with excellent control of melt homogeneity and the solidification process.

In 2013, a Canadian research consortium led by Polytechnique Montreal initiated a battery of tests at larger scale (~40 kg) to generate basic data to scale-up the melt-casting synthesis of C-LFP cathode material to commercially relevant quantities. The experimental design varied the operating parameters of the processing steps, raw materials, and melting and casting conditions. The objective was to achieve high-purity LFP that meets the electrochemical performance standards at low cost[11]. This article shares insights on applying an induction melting and casting process as a synthesis method of LFP material for larger volumes.

MELT CASTING SYNTHESIS OF LFP CATHODE MATERIAL

Production of cathode material using the melt casting method includes mixing the precursors, melt synthesis, milling, drying, carbon coating, and pyrolysis. Melt synthesis is the key processing step because it affects all subsequent steps and consequently the battery performance. Various precursors can be used to synthesize the LFP compound as long as the precursors' mixtures have the proper stoichiometric ratios[5] (Table 1). Also, conditions during synthesis and casting need to be maintained as inert or slightly reducing to ensure high purity of the final product.

An image showing precursors in the furnace is shown in Fig. 5. These compounds are in the form of powder, are nonconductive, and when they melt above approximately 1000°C, the viscosity is similar to molten glass (called *molten slag* in the metal casting industry).

Various melt synthesis methods were examined at a pilot-scale foundry at the CanmetMaterials laboratory (Fig. 6). Initially, an electric resistance furnace was tested to melt the precursors to synthesize LFP. An induction furnace reduced the melting cycle time and improved temperature homogeneity compared to resistive heating. Typically, non-metallic charges cannot be directly heated by

TABLE 1 – VARIOUS PRECURSORS USED FOR MELTING SYNTHESIS OF LFP[5,12]

Li	Fe	P
Li_2CO_3 $LiOH{\cdot}H_2O$ LiH_2PO_4 Li_3PO_4	Fe_2O_3 Fe_3O_4 FeO $Fe_3(PO_4)2{\cdot}8H_2O$ $FePO_4{\cdot}2H_2O$ Fe	$NH_4H_2PO_4$ $Fe_3(PO_4)2{\cdot}8H_2O$ P_2O_5 LiH_2PO_4 Li_3PO_4

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induction. However, when using electrically conductive crucibles (susceptor)—such as graphite, silicon carbide (SiC), or metal—rapid and efficient melting of the inorganic precursors is possible. Selection of the crucible affects product build-up resulting from the affinity of molten lithium oxide with metal and oxide species. The melt temperature was controlled in a range of 1000° to 1400°C during the melt hold time using a contactless infrared pyrometer. This method was used instead of thermocouples to avoid their dissolution and subsequent melt contamination. A protective atmosphere, such as argon, is required during melting in the furnace as well as during casting and solidification in molds. Figure 7 shows crucible lip pouring of LFP melt into an ingot mold. Thermal analysis cooling curves of the LFP solidification process show liquidus (beginning of solidification) as well as solidus (end of solidification process) at 970° and 950°C respectively (Fig. 8). The recorded cooling curves could be used as an in-situ quality check to detect LFP and impurities during the process. The final LFP product is shown in Fig. 9 in the form of a 5-kg cast ingot as well granules of LFP ranging between 2 to 5 mm achieved by quenching liquid material in water. Synthesized LFP needs to have minimum contamination including over-reduced species such as Fe, Fe_2P, and Fe_3C, and oxidized species including Fe_2O_3 and $Li_3Fe_2(PO_4)_3$ in order to achieve the desired battery electrochemical performance and cycle life.

Following the melt synthesis, LFP specimens undergo subsequent processing including crushing, grinding (dry and/or wet), drying, and carbon coating as needed for testing battery assemblies in coin cells. An SEM micrograph of a cast ingot's fractured surface clearly shows large LFP crystals. In addition, secondary crystal phases are seen at the crystal boundary, indicating a different purity or concentration between the two regions (Fig. 10). Phase purity in the final product depends not

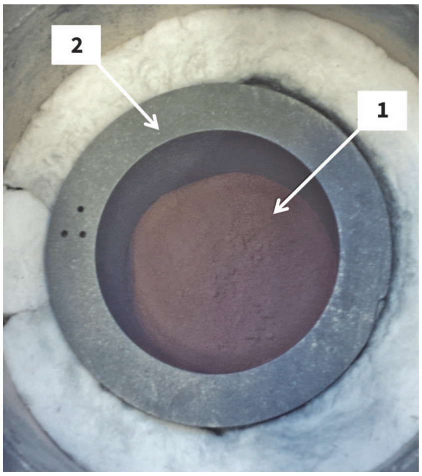

Fig. 5 — Precursors (1) loaded in the crucible (2) inside the induction furnace.

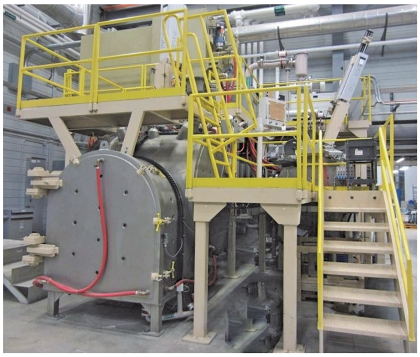

Fig. 6 — Vacuum induction furnace setup in a pilot-scale casting laboratory at Canmet-Materials.

Fig. 7 — Pouring LFP melt at approximately 1000°C into 5-kg ingot molds.

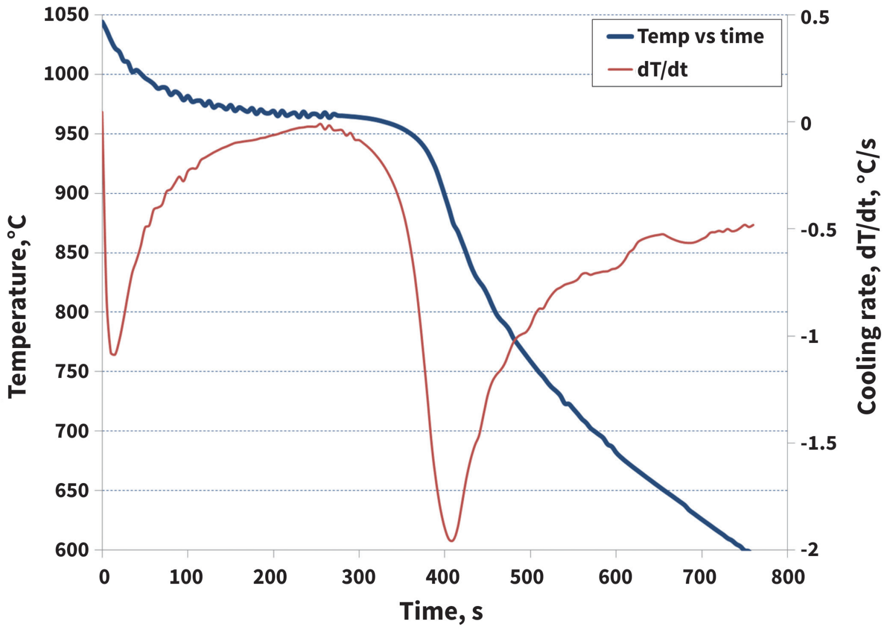

Fig. 8 — Thermal analysis curves of the LFP material recorded during solidification; temperature vs. time (blue) and first derivative (cooling rate) vs. time (red).

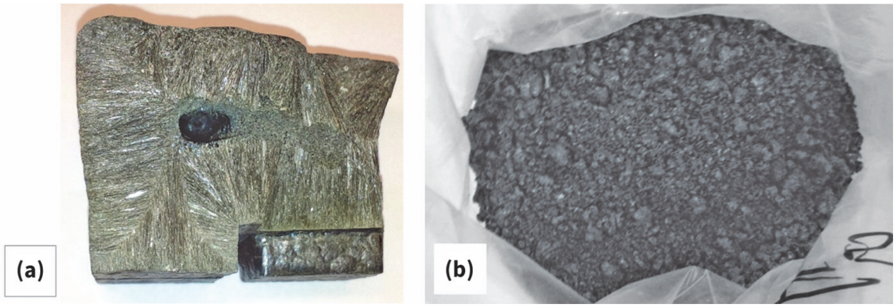

Fig. 9 — LFP specimens produced via a melting and casting synthesis process. (a) As-cast surface morphology of the 5-kg cast ingot, (b) water-quenched granules with diameters ranging between 2 and 5 mm.

only on the stoichiometry of Li, Fe, P, and O[13], but also on the melting and cooling process as well as the partial pressure of oxygen. Figure 11 presents qualitative x-ray diffraction (XRD) analysis results showing the presence of LFP and some of a P-rich secondary phase ($Li_4P_2O_7$), but without other impurities such as Fe_2P, Fe_2O_3, or oxidation products. During process development, it was found that an insufficient reaction time and inadequate argon cover gas during melting and casting steps could lead to the presence of residual Fe^{3+} in the synthesized product. These Fe^{3+} contaminants are typically present in the form of Fe_2O_3 and $Li_3Fe_2(PO_4)_3$ as reported previously[5]. Insufficient melt protection, despite a long reaction time, could result in the final synthesized product having between 5% to 10% of the total iron in the Fe^{3+} state. When operating with adequate melt protection, minor contaminants such as $Li_4P_2O_7$ and $LiPO_3$ were observed as a result of excess precipitation from stoichiometric imbalances.

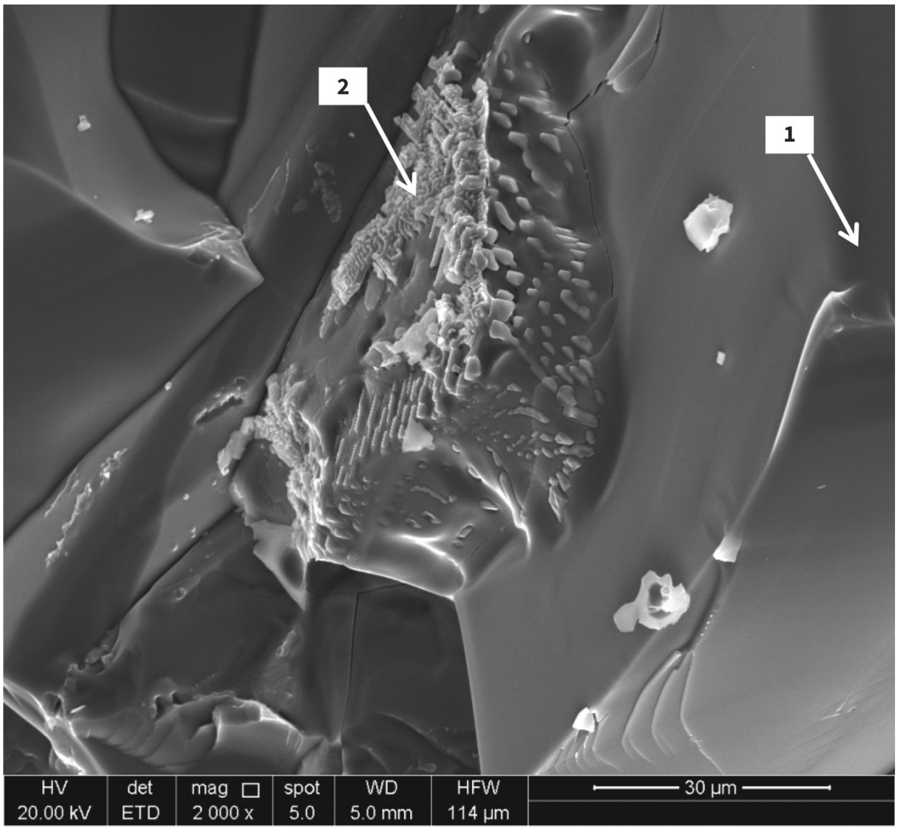

Fig. 10 — SEM micrograph in secondary electron mode (SE) of a fractured surface of a cast LFP specimen. (1) LFP crystals, (2) dispersed impurities such as FeO visible at the crystal surface as identified by Gauthier et al.[5].

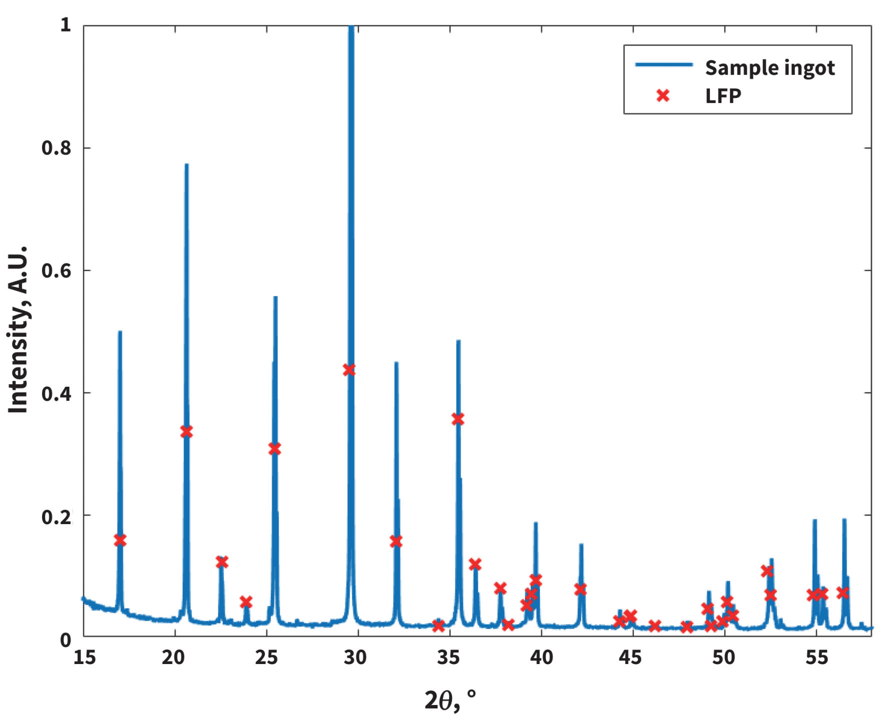

Fig. 11 — X-ray diffraction results of a cast LFP sample showing the LFP phase and some P-rich secondary phase. No other impurities such as Fe_2P or Fe_2O_3 were detected.

Based on 40-kg melt synthesis trials, energy consumption was 3 kWh/kg. This value was achieved for heating the cold batch of precursors from room temperature to a 1400°C peak temperature in a pilot-scale furnace without any energy recovery, insulation, or process intensification, as could be the case in a semi-batch operation.

SUMMARY

An induction melting process was evaluated to produce LFP ingots as well as granules from low-cost precursors. The melt casting process can provide the benefits of utilizing various precursors, rapid reaction kinetics, homogeneous liquid composition, and scale-up readiness. More importantly, this process also offers the possibility of lower-cost battery materials at a similar or better performance level as compared to solid state methods. Further experiments are required to optimize the melting and casting process with regard to LFP purity, melt temperature and holding time, protective atmosphere, and crucible materials. If successful, melt synthesis of battery cathode material could offer a novel application of the conventional casting process. **~AM&P**

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TECHNICAL SPOTLIGHT

TRUST BUT VERIFY

With today's sophisticated measurement technology and testing equipment, manufacturers need never be in doubt over the quality of their starting materials and any property changes that occur in process.

Making products with consistently high quality requires well trained people, effective process control, and the razor sharp eyes of advanced test and measurement equipment. Trusted suppliers, of course, are also necessary, but the goods and materials they provide must still be tested to make certain all specs are met. In-process tests, in a similar way, are necessary to verify each manufacturing step while also generating valuable data for continuous process improvement. *Advanced Materials & Processes* spoke with Gordon Styles, president of Star Rapid Manufacturing Ltd., to learn more about what goes into materials verification processes.


Laser scanning inspection tool for verifying part geometries.

AM&P: Is the testing of incoming materials a common practice for rapid prototyping and low-volume manufacturing companies?

GS: Over 10 years ago, when I first moved to China to explore the idea of starting a factory, we found that many suppliers within the country were providing fake materials. As a result, we invested hundreds of thousands of dollars on test equipment and began running a battery of tests on incoming metals, including x-ray fluorescence and optical emission spectroscopy, also known as spark testing. And for plastics, we began to do RoHS testing and started using Raman spectroscopy. No matter where you are, it is essential to verify all materials that come through the door. Although the practice of testing materials is not common throughout China, it should be.

AM&P: How often do you come across fraudulent materials and have these occurrences increased over the years?

GS: I was shocked by the discovery of fraudulent materials when we began operations in China because I ran a rapid prototyping, low-volume factory in the UK from 1983 to 2000 and never felt a need to test metals and plastics. If the material was stamped "304 stainless steel" or "30% glass filled nylon," there was a high probability that is what it was. When we first started testing in China, we found that about two-thirds of the stainless and one-third of the aluminum was nonconforming or fake.

AM&P: What's the difference between nonconforming and fake?

GS: Nonconforming material is a poorly made material that lies outside of internationally agreed upon tolerances. Maybe there is too little chromium or too much nickel, but the material is still broadly 304 stainless, for example. Fake material is when the supplier delivers a completely different metallurgy, often knowingly and deliberately. The classic fake for 304 stainless is 201, a nonmagnetic stainless steel that looks just like 304. The problem with 201—aside from the fact that it is not easily detectable, i.e., with a magnet, like other types of stainless—is that it rusts quite readily under normal atmospheric conditions and even more so in high humidity and outdoor environments. The key difference between 304 and 201 is that the 300 series is based on chromium-nickel metallurgy, whereas the 200 series is based on chromium-manganese.

Since we purchased our testing equipment, we have seen a large drop-off in the amount of fake and nonconforming materials we have to reject. The ratio is now down to around 10%,


Modern quality control lab for testing parts and materials.

whether it's metals or plastics. We weeded out the truly outrageous suppliers, but that said, many of our best suppliers do not own inspection equipment, so they often have no idea what they are shipping to us. This shouldn't scare companies away from working with manufacturers based in China as long as they have the proper testing and inspection equipment and know how to use it.

AM&P: How do you ensure the quality of plastics for injection molding, CNC machining, and vacuum casting?

GS: Excellent question because this is a major challenge for everyone. It's important to thoroughly vet and establish a relationship with every supplier. For vacuum casting, we use one supplier, Axson, and we buy directly from them. Most problems with vacuum casting resins are revealed during casting and include excessive bubbling, streaking, under-curing, and discoloration. However, these are the least of our concerns. The real issue is with plastic bar and plate for CNC machining and injection-molding resins. For this, we have found the following tests to be most helpful:

1. Do a visual inspection to make sure the plate or bar looks like the specified material and check for cavities and inclusions. Also make sure that labels and bags are genuine. If in doubt, take a picture of the bag and send it to the original material manufacturer for confirmation.
2. Conduct a melt flow index test. The melt flow rate or index of a plastic depends on its additives, molecular weight, and other factors, all of which can be determined by the test.
3. Use a durometer Shore A/D test, if appropriate, to measure hardness.
4. Run a burn-off test to measure glass content. When burned, most plastics emit characteristic odors, flame colors, and melt patterns that help to identify them.
5. To assess flammability, follow the UL 94 test standard, which classifies plastics based on how they burn in various orientations and thicknesses.

For extreme cases, it may be necessary to engage a third party, an SGS or TÜV for example, that offers materials testing and certification services. Another option, especially for recurring issues, would be to expand your in-house testing capabilities. We recently did that, acquiring a PolyMax plastics analyzer for our quality control department. The PolyMax is a handheld spectrometer that uses laser-induced Raman scattering to confirm the chemical composition of plastics. The operating principle is named after Chandra Raman who discovered that, under the right conditions, molecules in chemical compounds vibrate at a unique frequency and energy, which serves as a sort of fingerprint when measured.

The PolyMax plastics analyzer is used to verify chemical composition.

AM&P: What about metals? How do you test them?

GS: One way we test metals is with an optical emission spectrometer (OES), an instrument that uses a current to electrically charge test samples. The additional energy is released in the form of a plasma, the spectral components of which are unique to each element contained in the sample. By reading the various wavelengths in the plasma, an optical spectrometer can determine the composition of the metal. This is considered a very detailed and accurate test.

Another measurement technology we use on metals is x-ray fluorescence (XRF) analysis. This is a nondestructive test by which materials, such as metals, fabrics, plastics, and ceramics, are exposed to low level, short-wave x-rays, also known as gamma radiation. Thanks to the well-defined order of matter, each element reflects the radiation at a characteristic wavelength that tells a specially calibrated spectrometer what elements are present in the test sample and in what relative concentrations. XRF analyzers can also detect materials banned under the Restriction of Hazardous Substances (RoHS) legislation. The test takes less than 30 seconds.

AM&P: What is the most unique material you've used in a prototype or product?

GS: It would have to be Luvocom 50/CF/10/GF/10/TF/10/BK. It's a polycarbonate—10% carbon filled, 10% glass filled, and 10% PTFE lubricant—used for plastic injection molding. This particular grade of Luvocom was selected because the end product had a variety of conflicting needs. It had to be low friction, resistant to high and repeated impacts by metal objects, and flow easily into an extremely complex geometry. It's truly a bizarre material. Typical applications are sporting goods, medical products, office goods, and industrial parts. We used the material to make components for a coin sorting machine. Flying coins are extremely aggressive, yet machine builders don't want to use metals or ceramics due to potential damage to the coins. **~AM&P**

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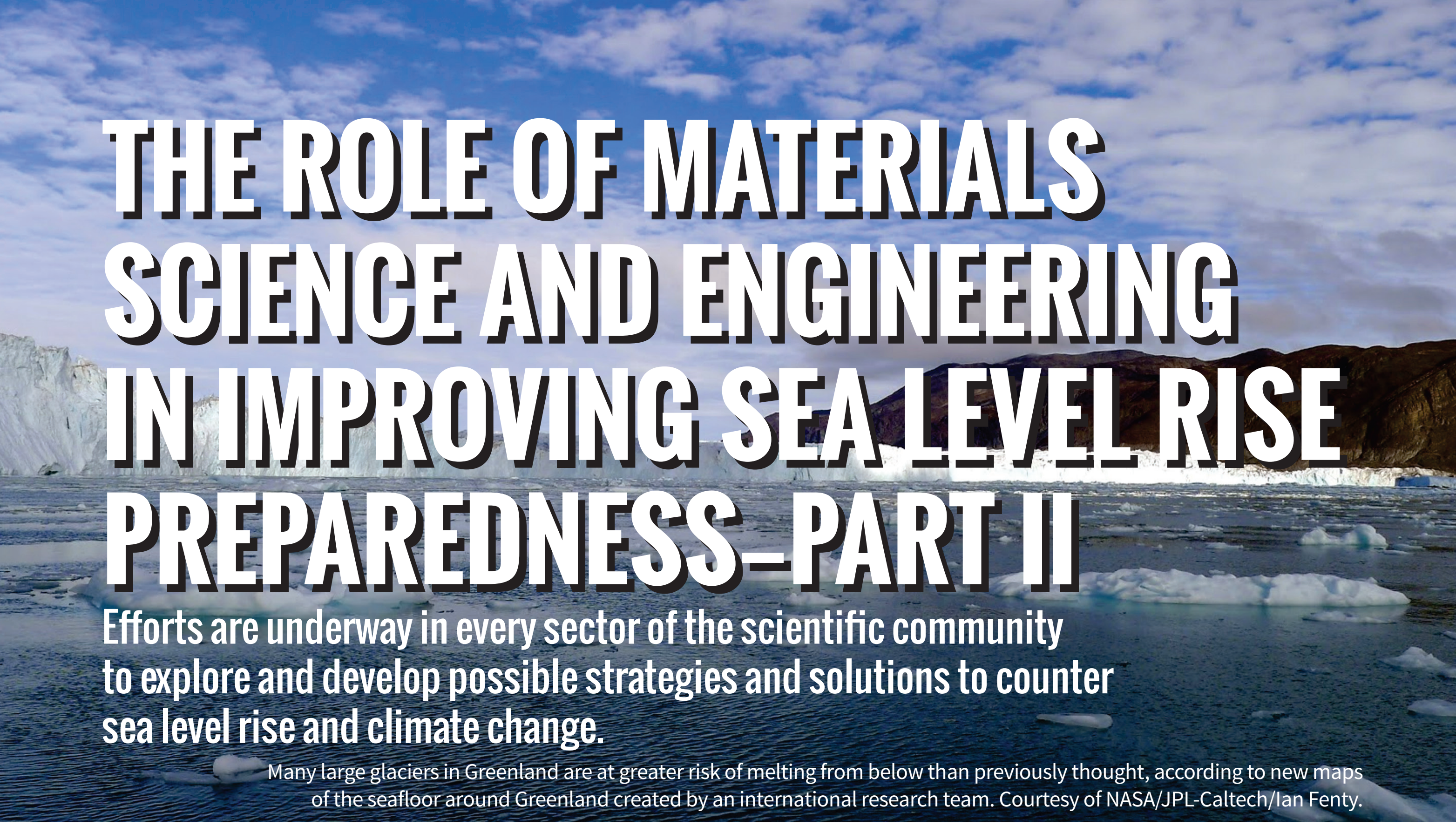

THE ROLE OF MATERIALS SCIENCE AND ENGINEERING IN IMPROVING SEA LEVEL RISE PREPAREDNESS—PART II

Efforts are underway in every sector of the scientific community to explore and develop possible strategies and solutions to counter sea level rise and climate change.

Many large glaciers in Greenland are at greater risk of melting from below than previously thought, according to new maps of the seafloor around Greenland created by an international research team. Courtesy of NASA/JPL-Caltech/Ian Fenty.

Harpreet Sidhar, Benjamin Boesl, and Arvind Agarwal, FASM, Florida International University, Miami*

There is growing international interest in the effects of climate change on the environment, with sea level rise (SLR) anticipated to be the most threatening facet of climate change. Sea level rise is expected to result in the greatest damage to infrastructure in coastal regions around the world, leading to economic losses of up to $50 billion by 2050[1]. Part I of this article (October 2017 *AM&P*) discussed potential solutions and ongoing efforts in the materials science and engineering community to counter SLR and provided a philosophical outlook and direction to push interdisciplinary collaborative materials research to counter and improve SLR preparedness for coastal areas. This article discusses long-term approaches including various methodologies to convert CO_2 greenhouse gas released from burning fossil fuels to other forms of fuel and value-added products, thus mitigating climate change and its associated effects, including SLR.

LONG-TERM APPROACHES

While short-term approaches focus on solutions to counter SLR for the next three to four decades, long-term approaches should focus on mitigating climate change and SLR. Strategies and solutions based on short-term approaches will only provide limited support in the long term. Sea levels are changing due to melting of ice as global temperatures increase due to increasing greenhouse gases in the atmosphere (Fig. 1).

The main cause of SLR must be addressed to completely mitigate the rise. Melting of ice can only be reduced or halted if the concentration of greenhouse gases can be brought to an existing natural level. Thus, long-term planning and approaches are key factors to mitigate climate change and SLR. Consumption of fossil fuels is the major contributor to increased greenhouse gases, and a shift to "green" non-fossil energy sources such as wind, solar, tidal, and geothermal can lower dependence on fossil fuels for energy requirements. However, the industrial revolution was based on fossil fuels and moving away from it will take significant time and effort. In fact, many researchers and governments are wary of completely moving away from fossil fuels, as a major portion of the economy of many countries depends on the production and sale of fossil fuels. Consumption of fossil fuels will continue for the foreseeable future and thus will generate a significant amount of CO_2 and other greenhouse gases. This makes CO_2 inexpensive and abundant in the atmosphere.

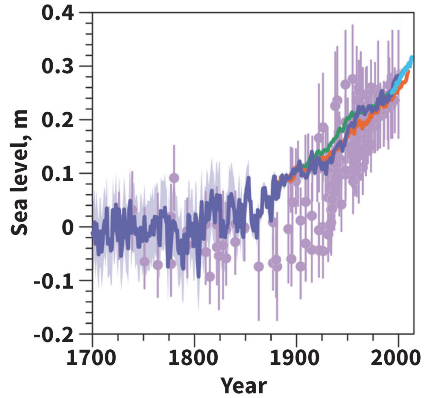

Fig. 1 — Compiled historical data showing increasing sea levels compared to historical rates. Data shown were obtained from different measuring techniques. Purple: salt marshes data; green, orange, and indigo: tide gauge data; and cyan: altimetry data. Courtesy of T.F. Stocker, et al., IPCC 2013.

CO_2 CONVERSION APPROACHES

A crucial area of research is to convert CO_2 greenhouse gas released from burning fossil fuels to other forms of

**Member of ASM International*

fuel and value-added products. Currently, CO_2 is mainly used in the production of chemicals such as salicylic acid, urea, and its derivatives. However, conversion of CO_2 to other long-chain hydrocarbons and potential fuels is difficult due to its thermodynamic stability. Reduction of CO_2 requires high energy, which makes the process economically unviable.

Many researchers have explored the electrochemical conversion of CO_2 to useful products. Metal-based catalysts, such as copper[2], platinum[3], iron, tin, silver, and gold[4], together with carbons such as g-C_3N_4[5], are used to successfully reduce CO_2. Copper, which can convert CO_2 into more than 30 products, is the best metal catalyst known so far. However, efficiency and selectivity of these catalysts for any product with two or more carbons is quite low (often less than a tenth of a percent[6]) and thus cannot be practically implemented. Recently, in two independent studies[7,8], multifunctional catalysts were developed that convert CO_2 to gasoline through direct and indirect hydrogenation, which comprises hydrocarbons with five or more carbon atoms.

In one of these studies, Wei et al.[8] developed a multifunctional catalyst comprising Na-Fe_3O_4 and H-form Zeolite Socony Mobil-5 (HZSM-5) to catalyze the conversion of CO_2 to hydrocarbons. They also used partially reduced magnetite to catalyze the RWGS reaction, producing a high amount of carbon monoxide (CO). Subsequently, some of the Fe_3O_4 sites are converted to Fe_5C_2 sites, which induces the Fischer-Tropsch synthesis resulting in the conversion of CO to α-olefins. In the last step of the process, olefins react to form long-chain hydrocarbons when exposed to HZSM-5 zeolite. Their process shows a CO_2 conversion of 34% and a high selectivity of 73% to C_5-C_{11} hydrocarbons (gasoline range), which increased to 78% when the H_2/CO_2 ratio of feed gas was decreased from 3 to 1. A schematic of the reaction scheme is shown in Fig. 2. By using such conversion methods, CO_2 emissions can be controlled by circulating the carbon to other product forms. In the long term, it could reduce CO_2 concentration in the atmosphere, as it would be converted to other forms of carbon. Reduction of atmospheric CO_2 would reduce global warming, leading to eventual stabilization of SLR.

In another study, Gao et al.[7] developed a bifunctional catalyst containing partially reduced In_2O_3 and HZSM-5 for indirect hydrogenation of CO_2 to gasoline-range hydrocarbons. Cu-ZnO-Al_2O_3 type catalysts are commonly used for methanol production from CO_2 and hydrogen for eventual transformation to longer hydrocarbons, but these catalysts show high selectivity toward formation of CO via the RWGS reaction, which reduces the yield of gasoline-range hydrocarbons. Indium oxide suppresses the RWGS reaction, resulting in higher selectivity towards CH_3OH, which can then be converted to gasoline-range C_{5+} hydrocarbons by the zeolite. The researchers showed a 78.6% selectivity for C_{5+} with a 13.1% CO_2 conversion.

Commercial-scale solutions have been developed in recent years as well. The National Aeronautics and Space Administration (NASA) developed a technology[9] that converts CO_2 into fuel using solar power. It uses metal-oxide thin films to produce a photoelectrochemical cell powered by solar energy. NASA claims its proprietary technology provides a high-efficiency solution to CO_2 conversion. Carbon Clean Solutions Ltd., UK, developed CO_2 capturing solutions and is working with power generation companies in the U.S., UK, and India[10]. Current research and industry trends show that this path could lead to a significant reduction in greenhouse gas emissions, which will help to stabilize rising sea levels. However, these methods and technologies are either at research scale or are too expensive for industrial applications. Therefore, new cost- and performance-efficient methods of CO_2 capture and conversion—which can be combined with other industrial processes to significantly reduce CO_2 concentration in the atmosphere—need to be developed to mitigate climate change and its associated effects, including SLR.

FUTURE OUTLOOK

Climate change and SLR are projected to have a significant impact on the infrastructure and economy, especially in coastal regions around the globe. Lack of necessary and appropriate preparedness could result in huge economic setbacks. A bifurcated approach with short-term and long-term preparedness is needed and would be beneficial for an overall action plan. A more integrated approach is needed both in academia and industry among civil and environmental engineers, materials engineers, and chemical engineers to develop solutions.

The Netherlands and Japan, two low-lying countries, are leading development for SLR preparedness. For

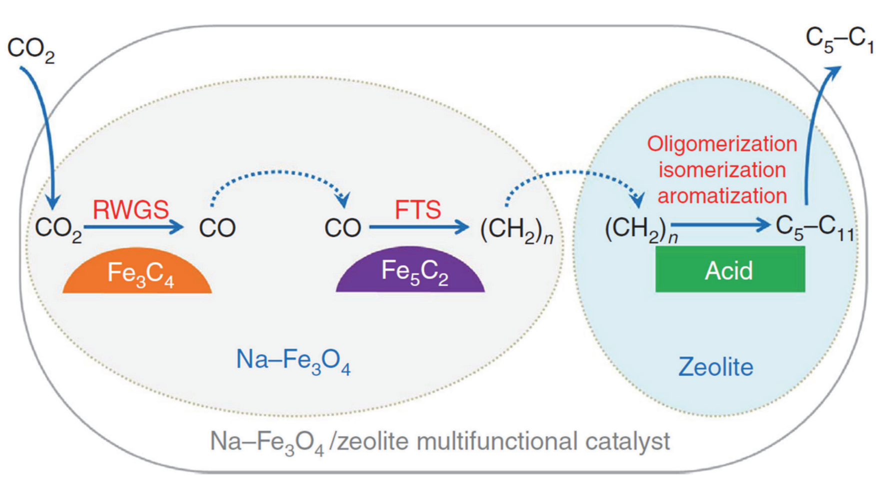

Fig. 2 — Reaction scheme of a process for direct conversion of CO_2 to gasoline-range hydrocarbons[8].

Fig. 3 — The Maeslantkering, a storm surge barrier in the Netherlands that automatically closes as needed, is one of the world's largest moving structures. Courtesy of holland.com.

example, the Maeslantkering, a storm surge barrier built in the Rotterdam Port and located at Hoek van Holland on the New Waterway connecting Rotterdam (in the Netherlands) with the North Sea, is an engineering solution against SLR (Fig. 3).

Researchers and governments around the globe can benefit from the collaborative efforts and lessons learned by these countries. From a materials and engineering perspective, tackling corrosion in all forms is a challenge and new protective coating systems, techniques, and methods must be developed for improved performance. Inspired by nature, a biomimicking approach for developing antifouling coating systems could potentially lead to new coatings and improved performance. For example, sharks, dolphins, and whales have skins known to have surface topologies that substantially reduce algae settlement, thereby providing antifouling characteristics. Such examples from nature provide a basis to develop a scientific solution to formulate antifouling coatings.

In the case of electrochemical corrosion of steel and reinforced concrete, major challenges exist due to the multitude of corrosion types in the coastal environment, expensive and complicated preparation and application procedures for large equipment, and inefficiencies in current repair procedures. A combined approach to develop composite and hierarchical coating systems using the principles of different protection mechanisms could result in significant improvement in corrosion protection for steels and concrete structures. Development of portable coating systems for on-site repair work can improve the corrosion protection of existing infrastructure. For example, portable cold-spray systems for applying Zn, Al, and polymeric coatings for steel and concrete bridges can improve the repairability and thus the service life of these structures.

Currently, concrete dikes and flood gates are efficient immediate solutions, and are being used as barriers against storm surges in locales including the U.S. (New Orleans and New England), Germany, and the UK (Thames river). However, these structures have huge construction and maintenance costs associated with them. Microbially induced calcite precipitation (MICP)-based biocement can be used to construct natural dykes to counter SLR. Use of biocement can reduce the cost by a significant amount, as nutrients and bacteria already exist in the biodiversity of sea water. Also, ground improvement using the biocement method can lead the way to strengthen coastal and beachside properties against increased erosion due to SLR.

CAUSES OF SLR

Sea level is rising due to accelerated melting of glacial ice, which is considered a result of the increase in greenhouse gas emissions, which causes a temperature rise. In the future, beyond a certain point, immediate actions such as the construction of dikes and barriers will be rendered inefficient against SLR. Thus, the long-term approach to mitigating and stabilizing climate change will be the key strategy for overall SLR preparedness. Capturing and reusing CO_2 emissions due to transportation and various industries can have a huge positive impact on climate change. CO_2 capture technologies for large emission sources such as fossil fuel power plants, fuel-processing plants, and other industrial plants are already being developed and tested. Fossil fuel-based transportation also emits a substantial amount of greenhouse gases that could be captured. Small-scale systems must be developed for use in vehicles. Development of technologies aimed at reducing greenhouse gases in the atmosphere should be a major research focus into the foreseeable future. **~AM&P**

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iTSSe

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

THERMAL SPRAY R&D

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EDITORIAL OPPORTUNITIES FOR *iTSSe* IN 2018

The editorial focus for *iTSSe* in 2018 reflects established applications of thermal spray technology such as power generation and transportation, as well as new applications representing the latest opportunities for coatings and surface engineering.

February/March: Aerospace and Defense Applications

July/August: Energy and Power Generation

November/December: Emerging Technologies/Applications & Case Studies

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

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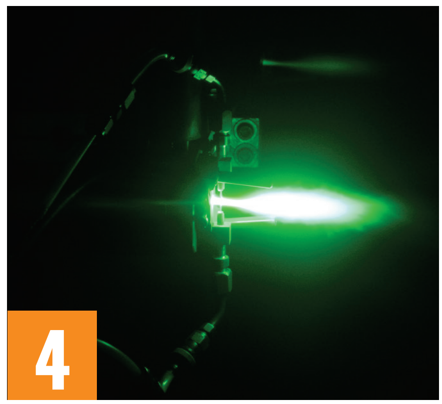

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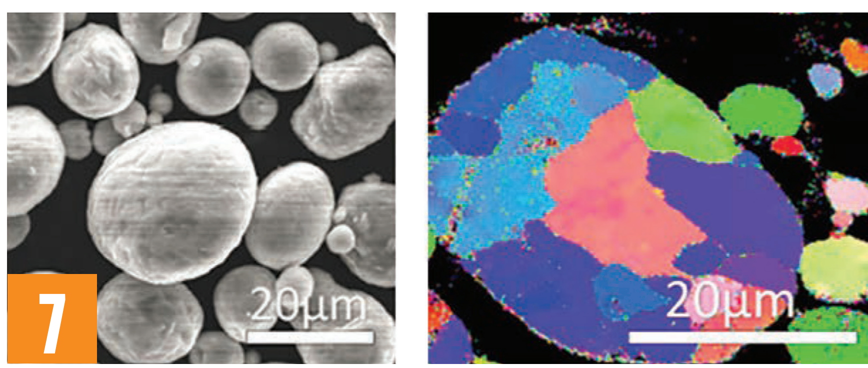

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ABOUT THE COVER

The development of air plasma spray (APS) and suspension plasma spray (SPS) thermal barrier coatings (TBCs) for aerospace and industrial gas turbines is one of the most important R&D themes at Surftec. Courtesy of Surftec.

ITSC AND AEROMAT WILL HEAT UP ORLANDO


McDonald

Next year, the ASM Thermal Spray Society will co-locate the International Thermal Spray Conference (ITSC) with AeroMat in Orlando, Fla., at the Gaylord Palms Resort & Convention Center from May 7-10, 2018. The ITSC 2018 event will once again prove to be the world's foremost international conference and exposition for thermal spray technologists, researchers, manufacturers, and suppliers. The event will feature more than 300 technical presentations, a broad lineup of industry exhibitors, education courses on the fundamentals of thermal spraying and cold spraying, and several unique opportunities for networking and collaborative discussions.

Technical symposia will include fundamental research and development, thermal spray applications, advanced coatings for the aerospace industry, and a session for young professionals. Within each of these sessions there will be keynote addresses, oral presentations, and poster presentations on a variety of topics including deposition spray processes, coating materials characterization, development of next-generation multifunctional coatings, additive manufacturing, biomedical coatings, and much more. Papers that demonstrate novel research and practical results will be selected and invited for submission to the *Journal of Thermal Spray Technology.*

ITSC 2018 will be a nexus event in the thermal spray industry wherein the community will hear from high profile researchers and well known industry movers and shakers through keynote addresses and speeches. The accomplishments of leaders and innovators in the field will be celebrated during special ceremonies that commemorate the Thermal Spray Society Hall of Fame Award, Thermal Spray Society President's Award, ITSC Best Paper Award, *Journal of Thermal Spray Technology* Best Paper Award, Historical Landmark Award, and the Oerlikon Metco Young Professionals Award. These speeches and celebrations will recognize the efforts and advancements that are uniquely pervasive in the thermal spray industry.

The Gaylord Palms Resort & Convention Center was strategically selected to provide attendees with a memorable experience. This upscale resort and convention center includes an 1100-person conference hall, large open concept space for the industry exhibition and poster sessions, and a variety of activities and entertainment for attendees. ITSC attendees will also have access to the technical programming offered through the AeroMat conference at no additional charge. Thus, we expect that co-location with AeroMat will provide experts and practitioners in thermal spraying with an opportunity to learn more about innovative aerospace materials, fabrication and manufacturing methods that improve performance, durability and sustainability of aerospace structures, and engines with reduced lifecycle costs.

Similar to past ITSC events, ITSC 2018 will be of high value to researchers, students, practitioners, and exhibitors. We are very excited and with great anticipation, we look forward to meeting and seeing you in Orlando! To learn more about this exciting event, please visit the event website at asminternational.org/web/itsc-2018/home. Registration will open in January 2018.

André McDonald
University of Alberta
Technical Chair, ITSC 2018

JOURNAL OF THERMAL SPRAY TECHNOLOGY ANNOUNCES 2017 EDITOR'S CHOICE ARTICLES

The *Journal of Thermal Spray Technology* recently announced this year's Editor's Choice articles, showcasing five of the high-quality articles that were published in the journal in 2017. Articles were selected based on the comprehensive nature of the paper, potentially important conclusions, and novelty. Editor's Choice articles are open to all readers and can be shared with colleagues.

- Cold Spraying of Armstrong Process Titanium Powder for Additive Manufacturing by D. MacDonald, R. Fernández, F. Delloro, and B. Jodoin, Vol 26(4), April 2017, p 598-609.
- Additive Manufacturing of AlSi10Mg Alloy Using Direct Energy Deposition: Microstructure and Hardness Characterization by M. Javidani, J. Arreguin-Zavala, J. Danovitch, Y. Tian, and M. Brochu, Vol 26(4), April 2017, p 587-597.
- Environmentally Resistant Mo-Si-B-Based Coatings by J.H. Perepezko, T.A. Sossaman, and M. Taylor, Vol 26(5), June 2017, p 929-940.
- A Guide to Finite Element Simulations of Thermal Barrier Coatings by Martin Bäker and Philipp Seiler, Vol 26(6), August 2017, p 1146-1160.
- Ceramic Top Coats of Plasma-Sprayed Thermal Barrier Coatings: Materials, Processes, and Properties by Emine Bakan and Robert Vassen, Vol 26(6), August 2017, p 992-1010.

THERMAL SPRAY SOCIETY ANNOUNCES NEW BOARD MEMBERS

TSS President **Douglas G. Puerta,** operations manager, Precision Castparts Corp., recently announced new appointments to the TSS Board. **Christopher Dambra,** manager, CSC Americas, Oerlikon Metco, and **Dan C. Hayden,** president, Hayden Corp., were reappointed to the board for a second three-year term. Dan was also reappointed secretary/treasurer for one year. **Friedrich Herold,** chief executive officer, Castolin Eutectic, was appointed to a three-year term.

Gregory Smith, Stoney Brook University, was reappointed student board member and **Alexandre Romao Costa Nascimento,** Concordia University, was also appointed student board member. Both appointments are for one year.


Puerta


Dambra


Hayden


Herold


Smith


Nascimento

NOMINATIONS SOUGHT FOR ASM THERMAL SPRAY SOCIETY BOARD

The ASM TSS Awards & Nominations Committee is seeking nominations to fill three board member positions. Candidates can be from any segment of the thermal spray community. Nominees must be a member of the ASM Thermal Spray Society and must be endorsed by five TSS members. Board members whose terms are expiring may be eligible for nomination and possible reelection on an equal basis with any other nominee. Nominations must be received no later than **February 1, 2018.** Forms can be found at tss.asminternational.org. For more information, contact Christian Moreau, awards & nominations committee chair, at christian.moreau@concordia.ca.


Heinrich

TRIBUTE TO PETER HEINRICH: THERMAL SPRAY PIONEER

Peter Heinrich, FASM, TSS HoF, passed away on October 25 at age 69 after a long and illustrious career in the thermal spray industry. In 1966, he completed a fitter's apprenticeship and later graduated as a mechanical engineer from the University of Applied Science in Munich in 1975. In August of that year, Heinrich began working for Linde AG in Munich, in the R&D department. In 1977, he also became a certified welding engineer at the German Welding Institute (SLV) in Munich and became a member of the German Welding Society (DVS) in 1978. Beginning in 1979, he focused on industrial gases in thermal spray applications at Linde. Heinrich was the cofounder and executive manager of GTS, the Association of Thermal Sprayers (founded in 1992), co-organizer and head of the eight HVOF Spray Colloquia in Munich (1988–2009), ITSC chairman (2001–2010), head of the DVS/DIN standards committee for thermal spraying, and served on the ASM TSS board from 2005 to 2010. A few of Heinrich's most notable achievements include receiving the DVS Ring of Honor Award in 1999, the Plaque of Honor for his work on the DIN Standards Committee for Welding in 2002, election as an ASM Fellow in 2009, and induction into the TSS Hall of Fame in 2011. In addition to TSS Board membership, Heinrich also served on the Society's nominating, program, and safety committees, as well as the *Journal of Thermal Spray Technology* committee.

SEEKING STUDENT MEMBERS FOR TSS BOARD

The ASM Thermal Spray Society is seeking applicants for its two student board member positions. Nominations are due by **April 1, 2018.** Students must be a registered undergraduate or graduate during the 2018-2019 academic year and must be studying or involved in research in an area closely related to the field of thermal spray technology. For more information, visit tss.asminternational.org.

SURFACE TECHNOLOGIES INDUSTRIAL THERMAL SPRAY R&D GROUP

The Surface Technologies Industrial Thermal Spray R&D Group (Surftec) de-risks development of new thermal spray technologies by cost-sharing through memberships and co-funding from the National Research Council of Canada (NRC), along with sponsoring organizations.

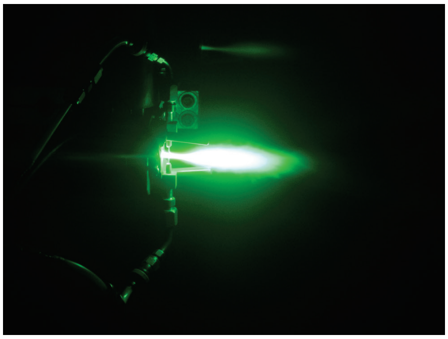
The R&D performed at Surftec is decided on by the industrial members that contribute to the group's R&D roadmap, ensuring continuous alignment with industry needs. Results are presented in biannual meetings, and R&D objectives are proposed and discussed with members on a regular basis. Intellectual property developed within the R&D group is protected and managed by NRC, allowing flexibility for sharing third-party, unbiased results as well as process protection to maintain the competitive advantage of members.

SURFTEC MEMBERS

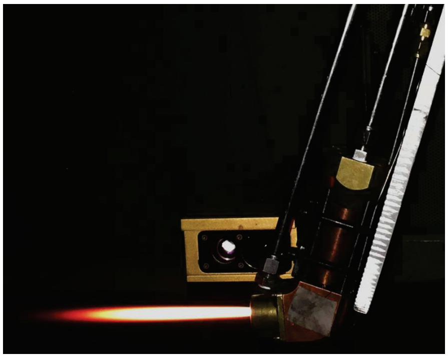
Surftec includes both Canadian and international members from across the thermal spray value chain, from equipment and feedstock suppliers to users and service providers, in addition to OEMs and maintenance organizations. Primary industries targeted by Surftec include aerospace, industrial gas turbines, automotive, and oil & gas. Professionals from other industries are also welcome to join.

WHY JOIN SURFTEC

Surftec provides a vehicle to de-risk R&D investment through cost-sharing among members with significant additional leverage from NRC investment and sponsorship. It also provides an excellent opportunity to network with peers from across the entire value chain in a noncompetitive environment (as opposed to trade shows, for example). Membership includes access to selected NRC background intellectual property and all NRC intellectual property arising as a result of Surftec R&D projects. Surftec also provides a way for members to prove their products against similar or "benchmark" products in an unbiased environment using the latest technologies. In addition, membership provides increased insight into NRC's capabilities in this field with the ability to launch one-on-one spinoff projects to explore the particular needs of any given member for developing an idea into a marketable product.



The development of air plasma spray (APS) and suspension plasma spray (SPS) thermal barrier coatings (TBCs) for aerospace and industrial gas turbines is one of the most important Surftec R&D themes.



Protective coatings sprayed via internal diameter–high velocity oxygen fuel (ID-HVOF) and internal diameter–high velocity air fuel (ID-HVAF) is a new R&D theme being implemented at Surftec.

CURRENT R&D PROJECTS

The roadmap of Surftec R&D projects is currently being expanded and developed in collaboration with members. Broad themes include:

- Aerospace and industrial gas turbines
- Internal diameters via ID-HVOF and ID-HVAF
- General thermal spray development
- Thermal spray 4.0
- Technology watch & IP management

For more information: The next Surftec meeting will be held at the NRC Boucherville site (17 km/11 miles from downtown Montreal) in June 2018. Interested companies are invited to contact the organizers: Polly-Lee Moore, Surftec Project Manager, 450.641.5919, polly-lee.moore@cnrc-nrc.gc.ca or Rogerio S. Lima, Senior Research Officer and Surftec Research Lead, 450.641.5150, rogerio.lima@cnrc-nrc.gc.ca. **~iTSSe**

***Note:** An article highlighting the Cold-Spray Additive Manufacturing Consortium (CSAM) of the NRC will appear in the February/March 2018 edition of iTSSe.*

SST COLD SPRAY TECHNOLOGY RESTORES HIGH-VALUE PRECISION GAUGING FIXTURES

REASON TO CONSIDER RESTORATION

Precision gauges and fixtures used to dimensionally check automotive components are typically made of heat-sensitive aluminum alloys using a variety of subtractive and/or additive manufacturing techniques. Due to the required precision, machining and finishing costs are often very high, and consequently any machining mistake can become cost prohibitive. In addition, recurrent use of the tool leads to unavoidable wear and tear, which eventually renders the tool unacceptable for the job, even though there may be considerable value remaining.

ISSUES

Aluminum alloys used to fabricate these components are specially heat treated. These materials are intrinsically sensitive to any process or procedure, such as welding or conventional thermal spray, which create a heat affected zone (HAZ) on the substrate. Not only would the material properties in the HAZ become substandard, but the dimensional accuracy of the tool would be compromised due to thermal distortion.

Fig. 1 — Subtractive machining of a geometrically complex aluminum gauging tool for checking automobile polymeric shapes.

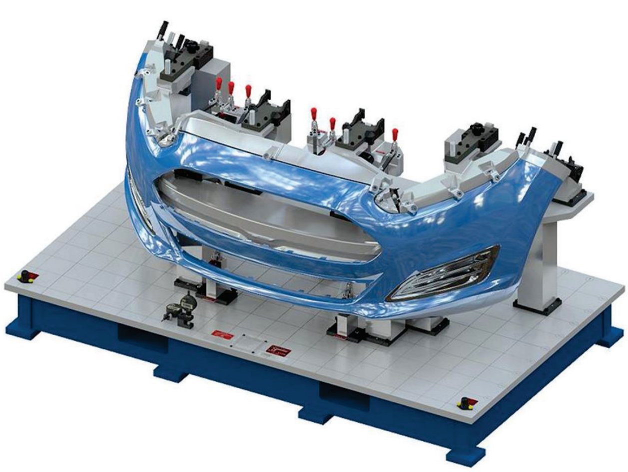


Fig. 2 — Finished check fixture for dimensionally validating a plastic front bumper.

OPTION

Supersonic spray technology (SST) cold spray enables metal consolidation that can dimensionally restore these tools with minimal or no thermal effects. Therefore, SST manual and robotic cold spray technology, which is operated at low pressures and temperatures, has become a reliable and effective tool in the industry (Fig. 3).

Fig. 3 — Commercial SST cold spray system. Courtesy of CenterLine Windsor Ltd.

Cold spray is a solid-state metal consolidation process that uses a high-speed gas jet to propel metal and other powder particles against a substrate where particles plastically deform and consolidate upon impact. The term *cold spray* refers to the relatively low temperature involved in the process, which is typically much lower than the melting point of the spray material and substrate. In the SST cold spray equipment, air can be used as a propellant gas and temperatures will be low enough not to thermally disturb the substrate material. After low-temperature dimensional restoration of the area, the newly consolidated material can be effectively machined back to tolerance using standard machining techniques.

BENEFITS

Since adhesion of the metal powder to the substrate and deposited material is achieved in the solid state, the characteristics of cold spray deposits are quite unique, making cold spray suitable for depositing well bonded, low porosity, oxide-free coatings. These attributes make cold spray uniquely suitable for depositing a range of temperature-sensitive materials in this application. The following tool issues can easily be fixed with SST cold spray technology:

Machining errors – Quite often, there can be irreparable errors in the machining operation that render the tool useless. In these cases, it is possible to cold spray an equivalent material to dimensionally restore functionality and then re-machine to proper tolerance (Fig. 4).

Wear and/or snap-offs – Wear and/or snap-offs are another potential issue that can be easily repaired by SST cold spray technology: Simply fill in by cold spray with the appropriate material, then re-machine back to tolerance (Fig. 5).

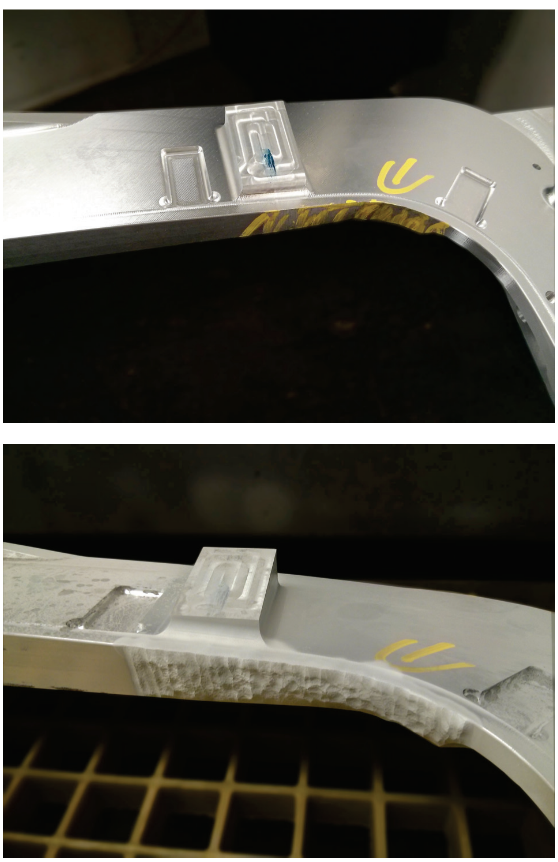


Fig. 4 — Machining errors dimensionally repaired with SST cold spray, before (top) and after (bottom).

Fig. 5 — Snap-off defect dimensionally repaired with SST cold spray, before (top) and after (bottom).

A local manufacturer of high-precision aluminum gauging fixtures saved thousands of dollars by using the SST cold spray technology to salvage a number of high-value fixtures that were either incorrectly machined or simply worn beyond their useful life. **~iTSSe**

For more information: Julio Villafuerte is a corporate technology strategist at CenterLine (Windsor) Ltd., 595 Morton Dr., Windsor, ON N9J 3T8, 519.734.8464, julio.villafuerte@cntrline.com, www.cntrline.com or www.supersonicspray.com.

COLD SPRAY: ADVANCED CHARACTERIZATION METHODS—ELECTRON BACKSCATTER DIFFRACTION

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

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

Electron backscatter diffraction (EBSD) is a characterization technique that enables determination of crystal orientations, texture, boundary misorientations and deformation behavior, and bonding mechanism in cold spray coatings. Although transmission electron microscopy (TEM) provides adequate crystallographic information, EBSD is a microstructural crystallographic characterization technique performed by means of a scanning electron microscope (SEM) that is able to examine large areas of samples and provide statistically significant data along with image quality. Especially in the case of cold spray coatings with a nonuniform deformation, this technique is highly suitable for providing valuable information on the nature of bonding. Pattern quality maps obtained by the Kikuchi pattern qualities show local defect density and lattice strain. Sample preparation for EBSD involves metallography of the sample to yield a highly polished flat surface. Typical SEM accelerating voltages of 20 kV are used with step sizes of 50 to 500 nm to scan the coating with different grain sizes. Euler angle maps indicate locations with differing orientation by different colors (Fig. 1).

Figure 1 (b) is a typical EBSD map showing the grain or crystallite size from aluminum feedstock powders to assess the initial crystallite size, taken from the work of Zou. In the EBSD map, each point is colored according to its crystal orientation. In this case, red corresponds to the [001] direction, blue to [111], and green to [101]. Characterization of the thermomechanical behavior of cold spray coatings has been carried out extensively using EBSD.

Electron backscatter diffraction, in conjunction with field-emission gun SEM, provides insights into large areas of samples to elucidate the particle bonding, porosity, and other qualities. As such, it provides statistically significant

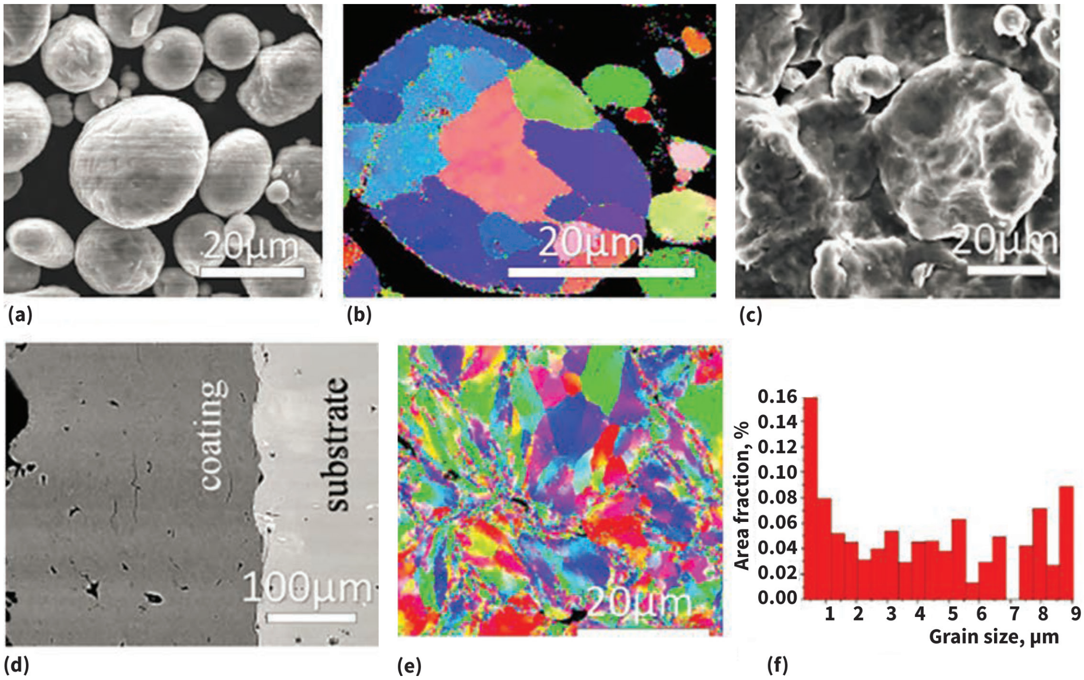


Fig. 1 — (a) Scanning electron micrograph and (b) EBSD map of feedstock aluminum powder particles showing polycrystalline powder; (c) scanning electron micrograph of top surface of cold spray coating; (d) coating cross section; (e) EBSD map of top surface; (f) grain size distribution.

information on crystal orientation, including splat-boundary misorientation that can help elucidate the bonding mechanism and complex thermomechanical history of the metal powder particles during cold spray. Starting with the atomized powders, EBSD enables an understanding of the crystallite size as the lattice strain in the starting powder, by means of a Euler angle map. The as-sprayed coating (Fig. 1 c, d) reveals a nonuniform deformation pattern, with some grains showing an equiaxed structure while others appear elongated. Regardless of whether the particles remain equiaxed or are heavily deformed, the particle-particle boundaries reveal ultrafine grains of <100 nm. EBSD is also able to reveal the occurrence of nonuniform fine-grained structure, which can be attributed to dynamic—rather than static—recrystallization.

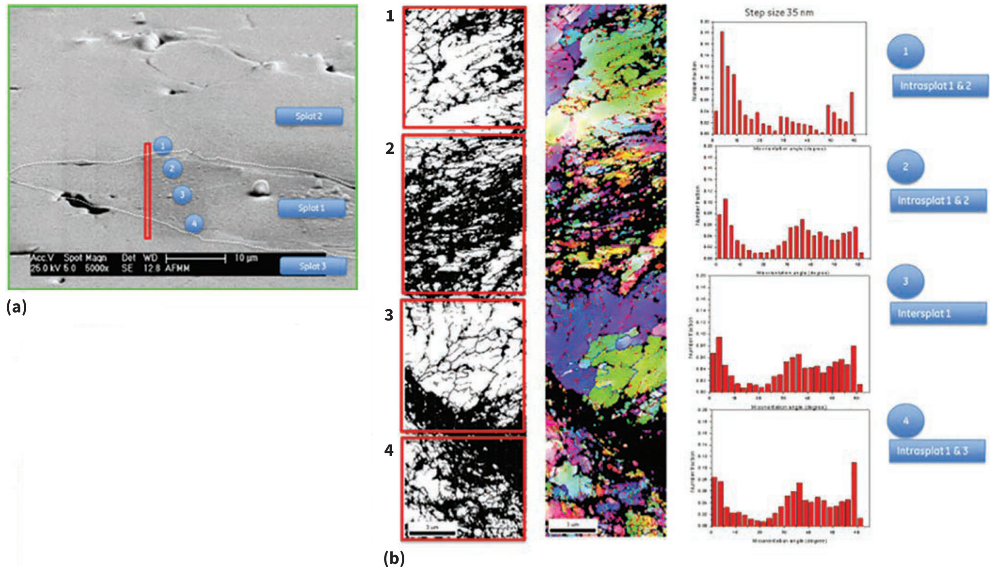


Fig. 2 — (a) Scanning electron micrograph indicating boundary between two splats in an IN625 cold spray coating; (b) series of Euler images and image quality maps showing the nature of deformation in inter and intrasplat locations.

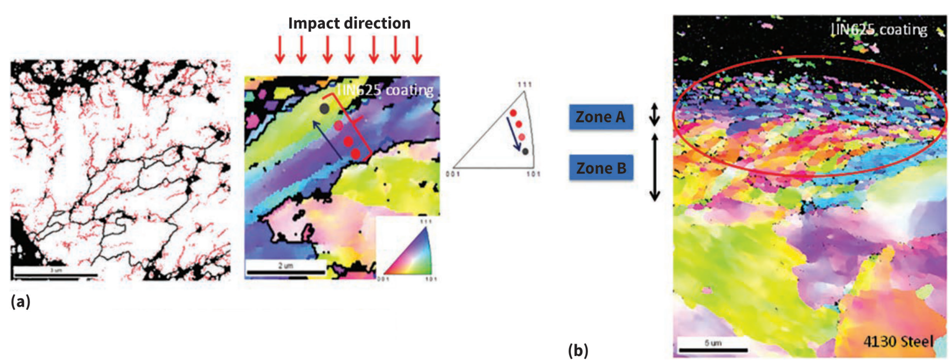


Fig. 3 — (a) End-pattern quality maps from IN625 coating showing the change in orientation of the grain with respect to powder impact direction, indicative of the nature of deformation in these coatings; (b) EBSD pattern from AISI 4130 steel substrate, indicating two distinct deformation zones in the as-sprayed condition.

EBSD characterization of an IN625 cold spray coating reveals several insights as to the nature of deformation within the splats, as shown in Fig. 2. Figure 2 (a) is a high-magnification SEM micrograph focusing on both inter and intrasplat locations, labeled 1 to 4 in the figure. Figure 2 (b) is a series of Euler images as well as image quality maps taken from all the locations to indicate the degree of deformation that takes place in an IN625 coating. Figure 3, taken from the same coating, reveals details of the change in grain orientation in response to the deformation, by way of the Euler angle map, which shows a change from the [110] to the [111] direction on impact. Figure 3 (b) is an EBSD pattern from an AISI 4130 steel substrate showing two distinct deformation zones in the substrate, in the vicinity of the coating-substrate interface, in the case of hard particles on a hard substrate.

Electron backscatter diffraction is also an indispensable tool in understanding the mechanical behavior of cold spray coatings on different substrates, such as enabling an understanding of the fatigue response. The fatigue behavior of cold spray coated materials is not well understood. In the case of hard metallic coatings, such as titanium and nickel-base alloys, fatigue debits have been observed, whereas for soft materials such as aluminum and copper, it is reported that the compressive stress results in enhancing the fatigue properties. Here, EBSD enables a detailed understanding of the deformation behavior in the substrate and is therefore able to substantiate the fatigue behavior. **~iTSSe**

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

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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 October and December issues, as selected by *JTST* Editor-in-Chief Armelle Vardelle, are highlighted here. The October issue contains a special focus on "Cold Spray," organized by guest editors **Jean-Gabriel Legoux, Amadeu Concustell, Michel Jeandin, Thomas Klassen, Heli Koivuluoto, and Julio Villafuerte.** The first three articles highlighted below are from this special focus. In addition to the print publication, *JTST* is available online through springerlink.com. For more information, visit asminternational.org/tss.

COLD SPRAY DEPOSITION OF FREESTANDING INCONEL SAMPLES AND COMPARATIVE ANALYSIS WITH SELECTIVE LASER MELTING

Sara Bagherifard, Gianluca Roscioli, Maria Vittoria Zuccoli, Mehdi Hadi, Gaetano D'Elia, Ali Gökhan Demir, Barbara Previtali, Ján Kondás, and Mario Guagliano

Cold spray offers the possibility of obtaining almost zero-porosity buildups with no theoretical limit to the thickness. Moreover, cold spray can eliminate particle melting, evaporation, crystallization, grain growth, unwanted oxidation, undesirable phases, and thermally induced tensile residual stresses. Such characteristics can boost its potential to be used as an additive manufacturing (AM) technique. Indeed, deposition via cold spray is recently finding its path toward fabrication of freeform components since it can address the common challenges of powder-bed AM techniques including major size constraints, deposition rate limitations, and high process temperature. Herein, we prepared nickel-base superalloy Inconel 718 samples with a cold spray technique and compared them with similar samples fabricated by selective laser melting. The samples fabricated using both methods were characterized in terms of mechanical strength, microstructural and porosity characteristics, Vickers microhardness, and residual stress distribution. Different heat treatment cycles were applied to the cold spray samples in order to enhance their mechanical characteristics. The obtained data confirm that the cold spray technique can be used as a complementary AM method for fabrication of high-quality freestanding components where higher deposition rate, larger final size, and lower fabrication temperatures are desired (Fig. 1).

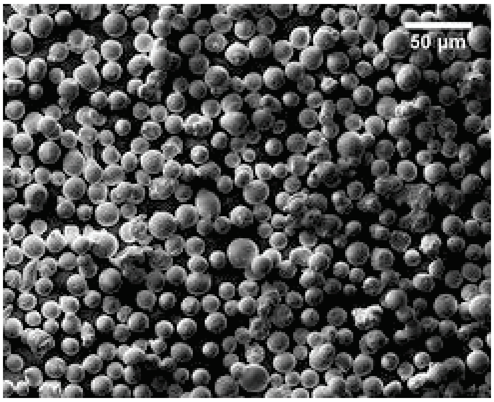


Fig. 1 — SEM micrograph of Inconel 718 powder used for fabrication of both cold spray and selective laser melting samples.

ASSESSING RELIABILITY OF COLD SPRAY SPUTTER TARGETS IN PHOTOVOLTAIC MANUFACTURING

Kedar Hardikar, Johannes Vlcek, Venkata Bheemreddy, and Daniel Juliano

Cold spray has been used to manufacture more than 800 Cu-In-Ga (CIG) sputter targets for deposition of high-efficiency photovoltaic thin films. It is a preferred technique since it enables high deposit purity and transfer of non-equilibrium alloy states to the target material. In this work, an integrated approach to reliability assessment of such targets with deposit

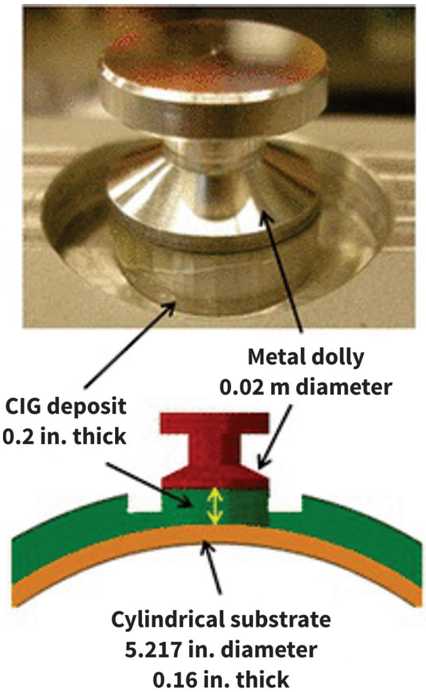


Fig. 2 — Stud-pull testing for adhesion and adaptation for cylindrical surface: adaptation for cylindrical substrate.

weight in excess of 50 lb. is undertaken, involving thermal-mechanical characterization of the material in as-deposited condition, characterization of the interface adhesion on cylindrical substrate in as-deposited condition, and developing a means to assess target integrity under thermal-mechanical loads during the physical vapor deposition (PVD) sputtering process. Mechanical characterization of cold spray deposited CIG alloy is accomplished through the use of indentation testing and adaptation of Brazilian disk test. A custom lever test was developed to characterize adhesion along the cylindrical interface between the CIG deposit and cylindrical substrate, overcoming limitations of current standards. A cohesive zone model for crack initiation and propagation at the deposit interface is developed and validated using the lever test and later used to simulate the potential catastrophic target failure in the PVD process. It is shown that this approach enables reliability assessment of sputter targets and improves robustness (Fig. 2).

MACHINABILITY OF AL 6061 DEPOSITED WITH COLD SPRAY ADDITIVE MANUFACTURING

Barry Aldwell, Elaine Kelly, Ronan Wall, Andrea Amaldi, Garret E. O'Donnell, and Rocco Lupoi

Additive manufacturing techniques such as cold spray are translating from research laboratories into more mainstream high-end production systems. Similar to many additive processes, finishing still depends on removal processes. This research presents the results from investigations into aspects of the machinability of aluminum 6061 tubes manufactured with cold spray. Through the analysis of cutting forces and observations on chip formation and surface morphology, the effect of cutting speed, feed rate, and heat treatment was quantified, for both cold sprayed and bulk aluminum 6061. High-speed video of chip formation shows changes in chip form for varying material and heat treatment, which is supported by the force data and quantitative imaging of the machined surface. Results shown in this paper demonstrate that parameters involved in cold spray directly impact machinability and therefore have implications for machining parameters and strategy (Fig. 3).

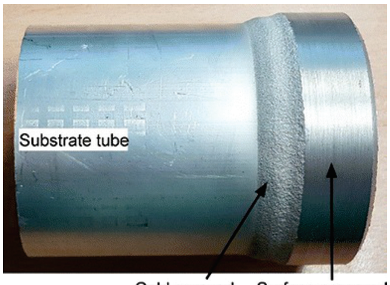


Fig. 3 — Sample prepared for machining test.

MECHANICAL PERFORMANCE OF COLD-SPRAYED A357 ALUMINUM ALLOY COATINGS FOR REPAIR AND ADDITIVE MANUFACTURING

K. Petráčková, J. Kondás, and M. Guagliano

Cold spray coatings made of A357 aluminum alloy, a casting alloy widely used in aerospace, underwent a set of standard tests as well as a newly developed fatigue test to gain information about the potential of cold spray for repair and additive manufacturing (AM) of loaded parts. With optimal spray parameters, coating deposition on substrates with a smooth surface resulted in relatively good bonding, which can be further improved by application of grit blasting on the substrate's surface. However, no enhancement of adhesion was obtained for shot-peened surfaces. Process temperature, which was set either to 450° or 550°C, was shown to have an effect on adhesion and cohesion strength, but it does not influence residual stress in the coating. To assess cold spray perspectives for AM, flat tensile specimens were machined from the coating and tested in the as-sprayed and heat-treated (solution treatment and aging) condition. Tensile properties of the coating after treatment correspond to properties of cast A357-T61 aluminum alloy. Finally, the fatigue specimen was proposed to test overall performance of the coating and the coating's fatigue limit, and is compared to results obtained on cast A357-T61 aluminum alloy (Fig. 4).

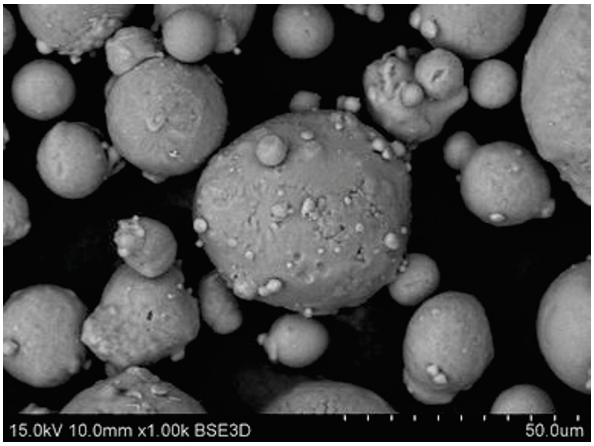


Fig. 4 — BSE image of powder feedstock.

OVERVIEW ON RECENT DEVELOPMENTS OF BONDCOATS FOR PLASMA SPRAYED THERMAL BARRIER COATINGS

D. Naumenko, R. Pillai, A. Chyrkin, and W.J. Quadakkers

The performance of MCrAlY (M=Ni,Co) bondcoats for atmospheric plasma sprayed thermal barrier coatings (APS-TBCs) is substantially affected by the contents of Co, Ni, Cr, and Al as well as minor additions of Y, Hf, Zr, etc., but also by manufacturing related properties such as coating thickness, porosity, surface roughness, and oxygen content. The latter properties depend in turn on the exact technology and set of

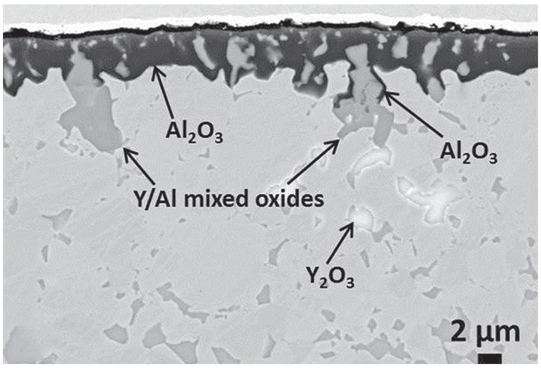
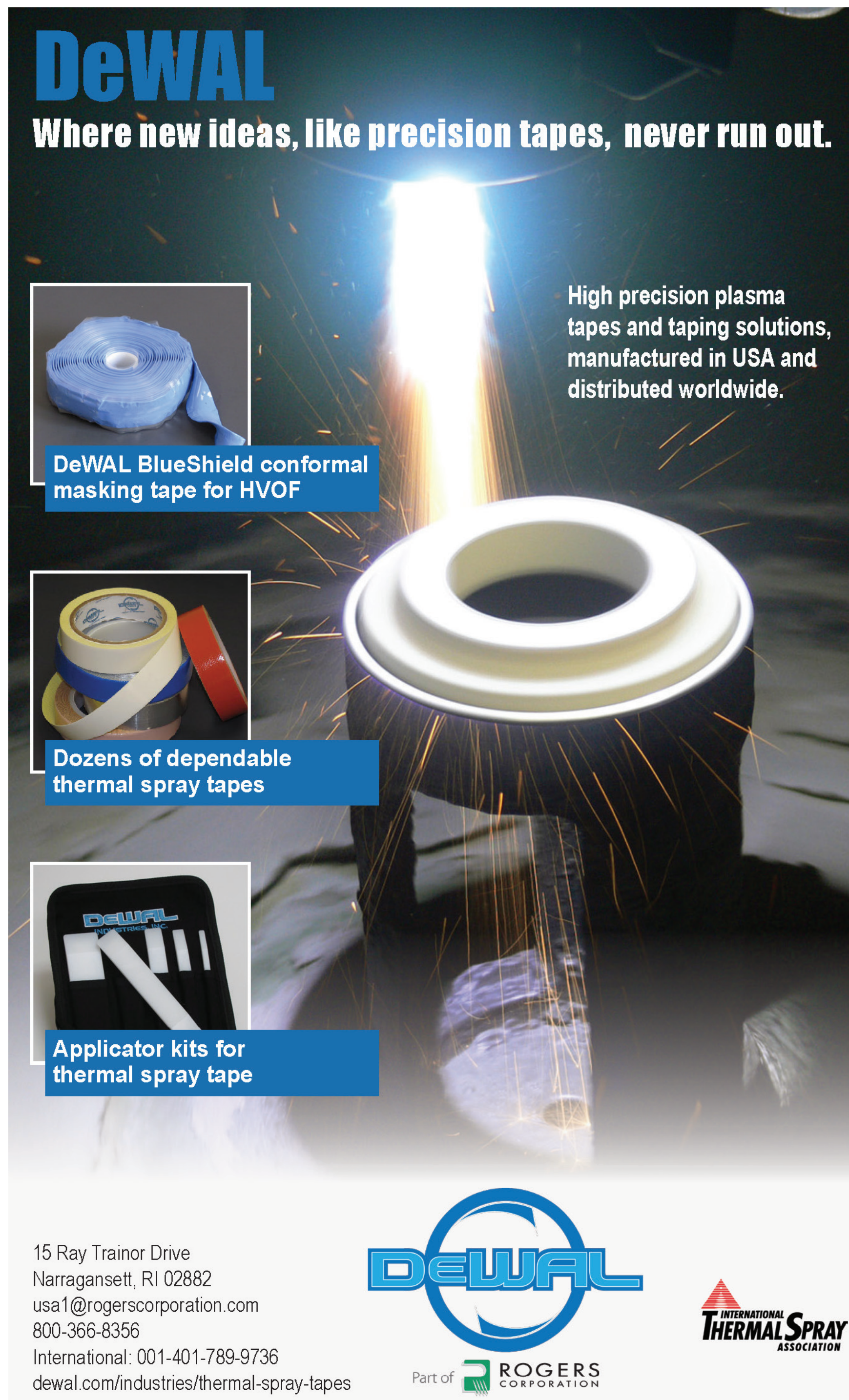
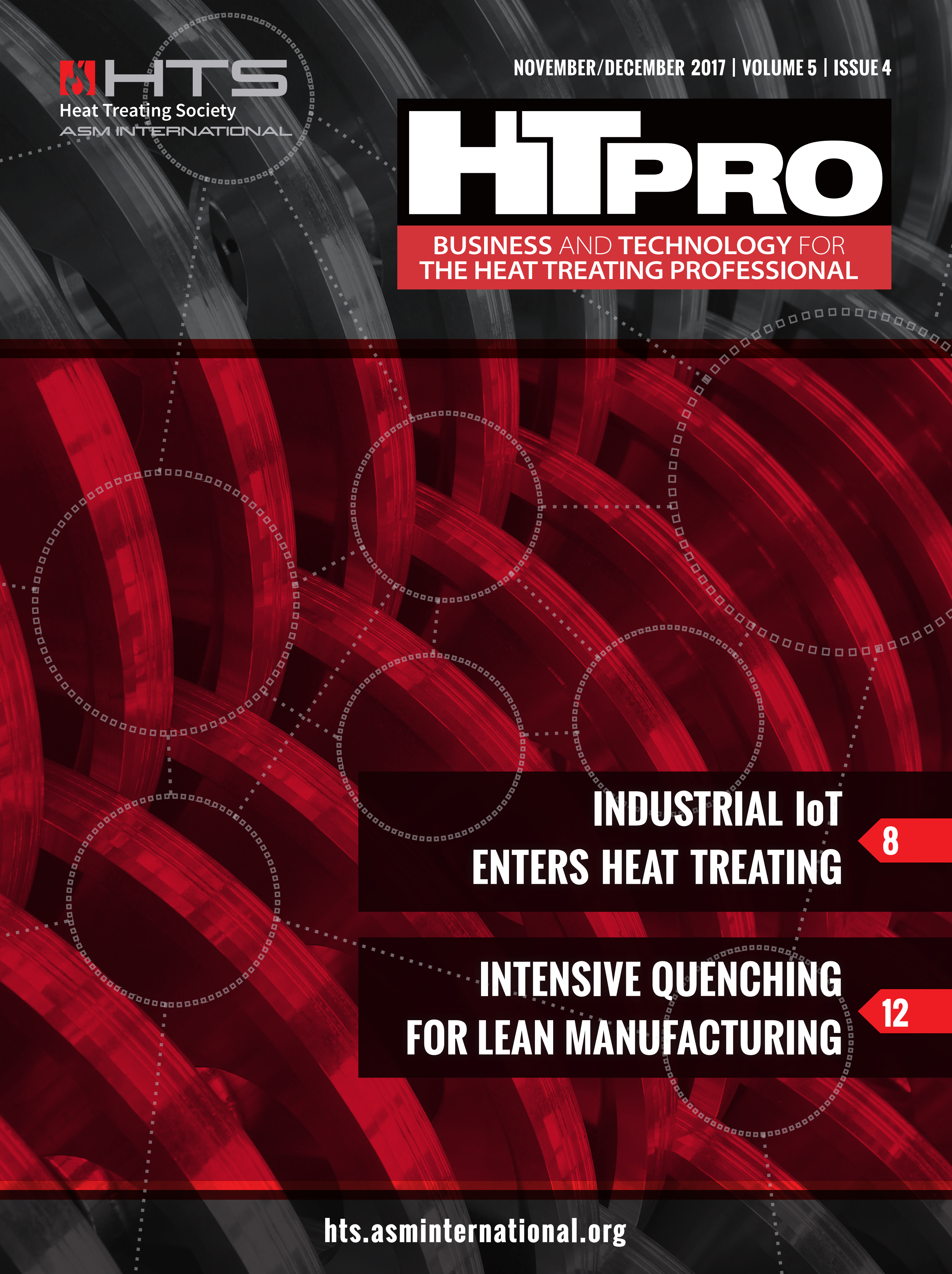


Fig. 5 — BSE images of metallographic cross sections showing 2-mm-thick freestanding CoNiCrAlY coatings after 1100°C exposure in synthetic air for 72 hours: LPPS coating.

parameters used for bondcoat deposition. The well-established LPPS process competes nowadays with alternative technologies such as HVOF and APS. In addition, new technologies have been developed for bondcoat manufacturing such as high-velocity APS or a combination of HVOF and APS for application of a flashcoat. Future developments of bondcoat systems will likely include optimization of thermal spray methods for obtaining complex bondcoat roughness profiles required for extended APS-TBC lifetimes. Introduction of the newest generation of single crystal superalloys possessing low Cr and high Al and refractory metals (Re, Ru) contents will require definition of new bondcoat compositions and/or multilayered bondcoats to minimize interdiffusion issues. The developments of new bondcoat compositions may be substantially facilitated using thermodynamic-kinetic modeling, the vast potential of which has been demonstrated in recent years (Fig. 5).





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ABOUT THE COVER

The potential for predictive processes, maintenance, and productivity will be fully realized when the heat treat industry embraces the Industrial Internet of Things and its data gathering and analytics capabilities.

EDITORIAL OPPORTUNITIES FOR HTPro IN 2018

The editorial focus for *HTPro* in 2018 reflects some key technology areas wherein opportunities exist to lower manufacturing and processing costs, reduce energy consumption, and improve performance of heat treated components through continual research and development.

February/March Thermal Processing in Aerospace

May/June Testing & Process Control

September Thermal Processing in On/Off Highway Applications

November/December Atmosphere & Vacuum Heat Treating

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

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

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HEAT TREATING SOCIETY GOING STRONG

First, I would like to say thank you to those who have given me the opportunity to be part of the leadership team for the ASM Heat Treating Society. Thank you also to the HTS board members, ASM leadership, all of our committees, and all of our members for their time and effort in making the heat treating industry a better place.

As I write this, we are less than a week away from Heat Treat 2017 in Columbus and are looking forward to a successful conference and expo. Heat Treat 2017 has attracted more than 2000 attendees, 100 technical presentations, several keynote presentations, three days of exhibits, educational courses, student and young professional sessions, and boundless networking opportunities. Thank you to everyone involved. Over the next two years, HTS will be involved in other great events in Spartanburg, South Carolina; Querétaro, Mexico; and Detroit. Our technical content at such events is top notch and our committees are focused on continuing to make these conferences best in class, with so much to offer to attendees.

During 2017 to 2019, ASM International will transform its technology infrastructure to provide improved content accessibility, searchability, collaboration, improved customer experience, and a myriad of other capabilities. This digital infrastructure upgrade is complemented by the reengineering of our content and educational offerings to meet the electronic access and delivery demands of today.

As a younger generation embarks on a career in heat treating and manufacturing, we must ensure that they understand the value HTS provides to our industry with its rich content and knowledge. Over the next two years as HTS president, I hope to continue connecting heat treat professionals and organizations with the resources necessary to solve problems, predict behavior, and grow professionally. I am excited about the investments being made at ASM and I want to be sure industry professionals look to HTS for these resources.

During the years that I have served on the HTS board, a consistent theme has been to engage younger professionals. I look forward to being part of the leadership team as HTS and ASM find ways to capture the interest of this cohort—those just beginning careers in heat treating and those whose work depends on heat treating services. To do this, we must continue to articulate the value of membership, both the content we deliver to the industry and the education we provide to individuals.

Today's technology is changing at an incredibly fast pace and manufacturing is seeing this on many fronts. I look forward to our committees and our content and education teams taking a deeper dive into additive manufacturing and other emerging technologies, and the potential impact they will have on the heat treating industry.

This is an exciting time with the current team of professionals on the HTS board, our committees, and at ASM headquarters. I am very excited to be part of the team.

Jim Oakes
HTS President
Vice President Business Development
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HTS NAMES NEW OFFICERS AND BOARD MEMBERS

James P. Oakes, vice president business development, Super Systems Inc., succeeds as president of the Heat Treating Society (HTS), while **Stephen G. Kowalski,** president, Kowalski Heat Treating Co., remains on the board as immediate past president and treasurer. **Eric L. Hutton,** director of North American sales and marketing, Bodycote, is elected vice president. Officers serve a two-year term.

In addition, the following members were elected to the HTS board for a three-year term: **Chuck Faulkner,** marketing manager, heat treatment, Houghton International; **Marc Glasser,** director of metallurgical services, Rolled Alloys; and **Thomas Wingens,** consultant, Wingens International Industry Consultancy. **Joseph T. Fignar,** heat treat process engineer, Honda Transmission Manufacturing, was appointed emerging professional board member and **Jonah Klemm-Toole,** graduate student, metallurgical and materials engineering, Colorado School of Mines, was appointed student board member. Both appointments are for one year.


Oakes

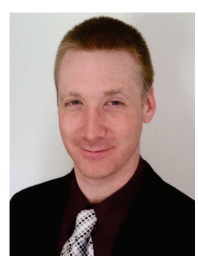

Kowalski


Hutton


Faulkner


Glasser


Wingens


Fignar


Klemm-Toole

SOLICITING PAPERS FOR ASM HTS/BODYCOTE BEST PAPER IN HEAT TREATING CONTEST

The ASM HTS/Bodycote award was established by HTS in 1997 to recognize a paper that represents advancement in heat treating technology, promotes heat treating in a substantial way, or represents a clear advancement in managing the business of heat treating. The award is endowed by Bodycote Thermal Process-North America.

The contest is open to all students, in full-time or part-time education, at universities (or their equivalent), or colleges. It is also open to students who have graduated within the past three years and whose paper describes work completed while an undergraduate or post-graduate student. The winner receives a plaque and check for $2500. To view rules for eligibility and paper submission, visit hts.asminternational.org, Membership & Networking, and Society Awards. **Paper submission deadline is March 1, 2018.** Submissions should be sent to Mary Anne Jerson, ASM Heat Treating Society, 9639 Kinsman Rd., Materials Park, OH 44073, 440.338.5151 ext. 5539, maryanne.jerson@asminternational.org.

HEAT TREATING SOCIETY SEEKS BOARD NOMINATIONS

The HTS Awards and Nominations Committee is seeking nominations for three directors, a student board member, and an emerging professional board member. Candidates must be an HTS member in good standing. Nominations should be made on the formal nomination form and can be submitted by a chapter, council, committee, HTS member, or an affiliate society. The HTS Awards and Nominations Committee may consider any HTS member, even those who have previously served on the HTS Board. **Nominations for board members are due February 1, 2018.**

For more information and the nomination form, visit the HTS website at hts.asminternational.org and click on Membership and Networking and then Board Nominations; or contact Mary Anne Jerson at 440.338.5151 ext. 5539, maryanne.jerson@asminternational.org.

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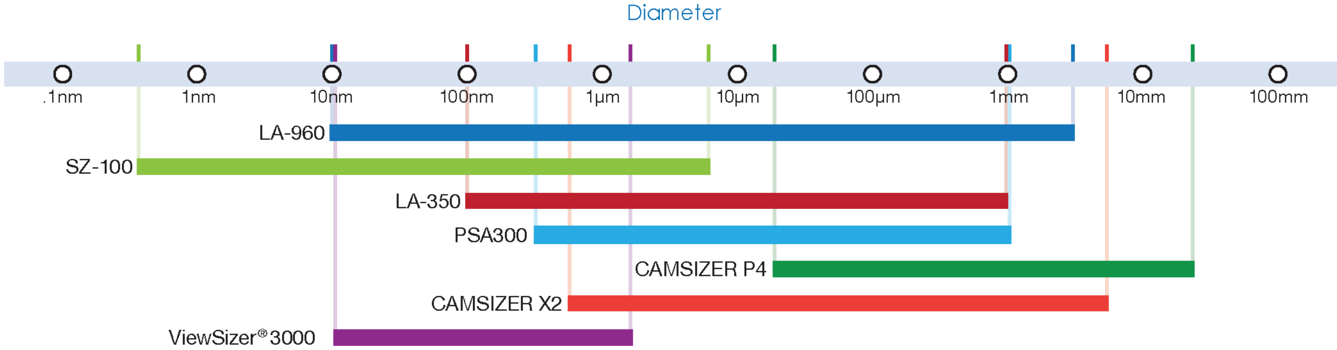

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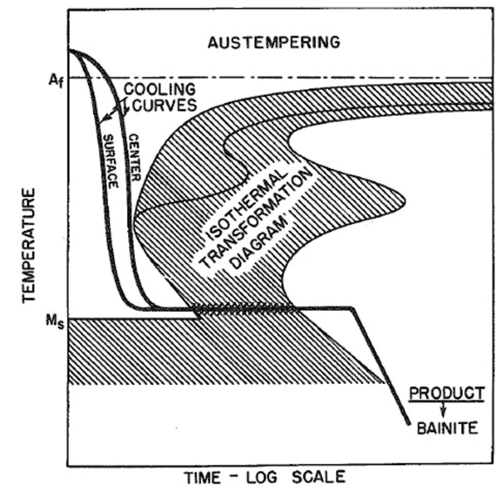
EXPLORING NEW WAYS TO ENHANCE THE AUSTEMPERING PROCESS FOR STEELS

In the 1920s, Edgar Collins Bain, an American metallurgist and member of the National Academy of Sciences, along with his colleague E.S. Davenport, discovered a microstructure that forms in steels at temperatures of 250° to 550°C. While it resembled martensite in outward appearance, it was actually quite different. In Bain's honor, this newly identified microstructure was named bainite.

Today, bainite is used in a wide variety of critical materials applications—military, railway, and automotive—but there is growing pressure to find new ways to enhance performance of the microstructure while perfecting the cooling process. This is critical because the preferred cooling method of salt bath quenching is raising environmental questions.

In August 2017, the Center for Heat Treating Excellence (CHTE) at Worcester Polytechnic Institute (WPI), Mass., announced it is conducting a three-year research project that will help the heat treat industry better understand process parameters related to austempering of steels. This research will help the industry to identify the potential strength, toughness, and cost benefits of bainitic steels over martensitic steels. Further, it will provide furnace manufacturers and commercial heat treat shops with knowledge and experience in the design, validation, and control of heat treating processes designed to produce bainitic microstructures in steels.



As shown in this time-temperature diagram, austempering involves heating to above the austenitizing temperature, cooling to just above Ms temperature, holding at that temperature until the transformation is complete, and then cooling further to room temperature. Source: Vander Voort, George F., ed., Atlas of Time-Temperature Diagrams for Irons and Steels, ASM international, 1991.

RESEARCH OBJECTIVES

Under the direction of Richard Sisson, George F. Fuller Professor of Mechanical Engineering at WPI and director of CHTE, the center's latest research project aims to answer the following questions:

- How can bainite be formed without quenching in liquid salt, which is currently raising environmental concerns?
- What alternative quenching media can be used?
- How can cooling rates be optimized and controlled?
- What temperature should the part be held at—and for how long—to provide the desired properties?

According to Sisson, "We are looking into alternative quenching media, other than liquid salt, that can be used in the cooling process and still maintain strength, ductility, and toughness of the heat treated part. And we are exploring how precisely we need to hold the temperature. What's the range that we can live with?"

The belief is that others have attempted to do this type of research, but to date the results are proprietary and the data is not being shared. "This is an opportunity for CHTE to provide necessary answers to our members on a subject of critical importance," says Mei Yang, assistant research professor at WPI and associate technical director of CHTE.

Since 1999, CHTE, a university-industry collaborative, has helped industry to better understand the relationship of heat treated parts and the processes they undergo. It has demystified induction tempering, studied gas quenching, analyzed nondestructive testing, and explored how to extend the service life of parts and fixtures, to mention a few, always with the goal of furthering innovation in the heat treating industry. Now CHTE is applying its expertise and research ethic to its latest research project—optimizing the austempering process to form bainite.

STUDY PARAMETERS AND TIMELINE

CHTE is currently in the early phases of research development. Following is a rough timeline for how the research will be done:

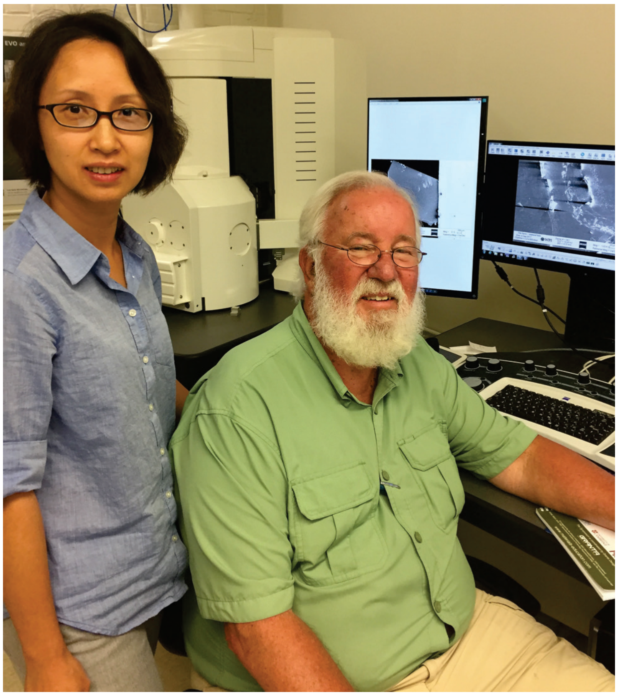
Year One—Conduct literature review to obtain austempering related information such as Ms, TTT, and CCCT diagrams for each alloy. Determine which materials to test. Apply computational thermodynamics to calculate T_0 and Ms temperatures. The austempering temperature should be below T_0 and above Ms. Compare the literature data and calculation results to determine the temperature range for the isothermal bainitic transformation. Choose three transformation temperatures for the austempering trials. In each trial, three different transformation times will be chosen to investigate the transformation kinetics. Review preliminary results with research team. Prepare for mechanical testing.

Year Two—Conduct austempering process at CHTE labs. Characterize the austempered samples using optical microscopy, SEM microscopy with EDS and EBSD, and possibly TEM analysis to determine bainite plate thickness. Meet with research focus group to review results and prepare for mechanical testing. Prepare project brief for members.

Year Three—Mechanical testing on austempered samples begins. Conduct microhardness testing, tensile testing, impact toughness testing, and possibly fatigue testing. Analyze and assess what additional research needs to be done. Share findings with members. Train and teach as needed.

At this time, CHTE researchers expect to conduct austempering experiments to determine the bainite transformation kinetics by heating to a temperature within the austenitizing range; quenching in salt bath/fluidized bed and maintaining at a constant temperature (bainite transformation temperature); holding for a time to allow transformation to a bainite microstructure; cooling to room temperature; and characterizing the austempered samples to investigate the bainite transformation kinetics.

For more information about CHTE, email Rick Sisson at sisson@wpi.edu.



At WPI, Richard Sisson, director of CHTE, and Mei Yang, assistant research professor, are working on optimizing the austempering process to form bainite.

INDUSTRIAL INTERNET OF THINGS ENTERS HEAT TREAT WORLD

The Industrial Internet of Things (IIoT) has tremendous potential in many areas of industry, and the opportunities in heat treating cannot be overlooked.

James P. Oakes*
Super Systems Inc., Cincinnati

The Industrial Internet of Things (IIoT) is extremely broad in definition. It exists in virtually all areas of industry, covering all sectors of business. It is proving to be a huge benefit to organizations that can seize the data that provides them with an opportunity to benefit from this information. Many organizations now have fast access to information, helping them to make quick decisions based on data derived from minute levels. With so much hype around *big data* and IIoT, what does this mean for the heat treating industry?

The heat treating industry has been capturing process-related data ever since paper recorders were introduced. In addition to process data, many other data points from the shop floor are available to provide business intelligence. What drives data capture requests in heat treating can be broken out into two areas—process data and operational data. Requests for proof of process are common when manufacturing parts or providing a heat treating service to a customer. Several process parameters are captured during heat treating, which are critical to the metallurgical results of the part. Time, temperature, and atmosphere are the most common. Operational reporting can come from an ERP/shop management system or a supervisory control and data acquisition (SCADA) system. This reporting can be used to address operational benefits by understanding the overall status of the manufacturing floor along with information about customers and parts. Large amounts of process and operational data can be gathered, but in the end, this data is commonly underutilized by the industry.

INDUSTRIAL DATA SOURCES

IIoT data comes from many sources and is traditionally stored in silos, meaning it tends to be segregated and not shared between different areas of an organization. The heat treating industry is no different when it comes to the challenges of bringing data together to form a holistic view of the operation. Control systems, shop floor management, and SCADA systems are not usually integrated with one an-

To fully realize the benefits of IIoT, it is important to have a system that not only captures data efficiently, but also provides the information in an easily digestible format.

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other, leaving valuable data unshared across these different business systems. In many cases, each is providing exactly what is intended, but with gaps in data—gaps that may very well be filled in by a different system with valuable data just waiting to be shared.

Field devices provide valuable process data and machine status. The good news about data capture in heat treating is that it has been gathered for years. Process data from field devices comes from microprocessor controllers, programmable logic controllers (PLCs), and discrete instruments. Even field devices without communications provide feedback to data collection systems in the form of discrete I/O or 4-20 mA signals. An example of this is a door with a simple limit switch tied to a PLC, providing a count of the number of times the door has been opened; this information is then used to coordinate planned maintenance instead of facing an unexpected outage.

There is no right or wrong way to slice through data for decision-making processes. What one operation identifies as beneficial, another may not. In fact, many manufacturing and heat treating operations do not fully utilize the data they already have. In many cases, there is simply not enough time to sort through the information. In other cases, the expertise is not available to present data in a format that would enable decision-making. Quick analysis of real-time data is standard operating procedure when it comes to heat treating. However, the challenge becomes real-time analysis of process data used for operational analysis that can be *acted on*. In many cases, a gap exists between the time data is produced and the time it is used for something actionable.

INTELLIGENT HEAT TREATING

Several years ago, Pete Hushek from Phoenix Heat Treat coined the term “intelligent heat treating.” What Hushek envisioned was taking full advantage of the data that was available to him to create a predictive process for cycle development and an opportunity to improve operational performance with his SCADA and automated process controllers. Keeping operators informed about load status gives them a heads-up on equipment coming available, allowing labor to shift to load preparation to ensure equipment use is maximized.

According to Hushek, “We are constantly mining data to look at quality and operational improvements. We have had an opportunity to refine cycle times and adjust ramps, preheats, and soaks that incorporate data from our temperature uniformity surveys. This provides our team with visual information related to sufficient load temperature uniformity, meeting industry specifications and customer requirements.”

This is just one example of information in heat treating being used to help with quality, cost, and performance. IIoT is bigger than real-time machine information and plant-wide SCADA. But the definitions of IIoT are really based on how companies put the information to use. Companies like General Motors use IIoT as the foundation for their Industry 4.0 initiatives and to achieve zero downtime on their manufacturing lines.

DATA ANALYTICS

Because heat treating is an additional treatment performed on a manufactured part, it also impacts overall product flow. The significance of delivery time is escalated when the parts being heat treated are a component of a finished good. Transparency of timelines and updates about parts status are what many industrialists benefit from with IIoT, whether dealing with customer service from an outside heat treat service provider or workflow in a captive shop, for example. Gathering data from field devices collectively provides information on equipment status and remaining time, while using historical statistics can predict completion time.

Data analytics is the future of automation in manufacturing. Autonomous machines using established metrics combined with real-time and historical information allow for the highest level of productivity by predicting and preventing potential problems in pursuit of a zero-downtime operation. Employees armed with smartphones can quickly deliver information relevant to their job responsibility. The key is providing relevant content to the end user. If too much information is presented to someone, it becomes background noise and loses its benefit.

It is important to have a system that not only captures data efficiently, but also provides the information in an easily digestible format. Visualization often helps, providing a familiar format for quickly reviewing data and an opportunity to react swiftly and make well-informed decisions. One of the major hurdles in using this information is making it accessible in a timely and actionable manner. Delivering the right data in a summarized format to the right individual is where benefits start to be realized.

IIoT has tremendous potential in so many areas of industry, and the opportunities in heat treating cannot be overlooked. The potential for predictive processes, maintenance, and productivity will be fully realized as the heat treat industry combines data from multiple sources and focuses on evaluating—and acting on—both real-time and historical data that is readily available. **~HTPro**

For more information: Jim Oakes is vice president of business development, Super Systems Inc., 7205 Edington Dr., Cincinnati, OH 45249, 513.772.0060, joakes@supersystems.com, www.supersystems.com.

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INTENSIVE QUENCHING FOR LEAN MANUFACTURING OF STEEL PARTS

Intensive quenching enables manufacturers to improve part performance at a lower cost than other available methods.

Michael Aronov,* Nikolai Kobasko, FASM,* Joseph Powell,* and William Andreski,
IQ Technologies Inc., Akron, Ohio

Jon Tirpak, FASM,*
Advanced Technology International, Summerville, S.C.

To accomplish lean manufacturing of steel parts, companies should consider potential cost savings throughout the entire manufacturing chain—including steelmaking, forging and casting, machining, and heat treatment. As one approach, the intensive-quenching (IQ) process[1] is an effective cost-saving step in the lean manufacturing of steel products.

IQ offers an alternative way to quench steel parts. It is an interrupted quench method conducted in highly agitated water, which eliminates the random film-boiling process in quenching and enables the quench process to be consistent at the part surface for every part, every time. Very high "current" surface compressive stresses developed in the part's shell from the beginning of the IQ process hold the part during quenching, preventing cracking and reducing distortion. Beneficial compressive stresses remain in the part surface layer after the quench. The IQ process known as *direct-from-forge IQ* (DFIQ), is implemented immediately after forging, while the IQ process known as *IntensiQuench* is used as a final heat treatment after machining is complete. Because the quench is consistent, all part properties—including distortion—are the same for each part at each part location. This consistency is what permits the part manufacturer to achieve lean manufacturing.

This article describes how using DFIQ and IntensiQuench can significantly reduce the cost of manufacturing steel products when engineered into the lean part-making value stream.

DFIQ REDUCES MANUFACTURING COSTS

The effect of quenching immediately after plastic deformation of steel parts (hot forging) was first studied in the former Soviet Union in the 1960s and later in Japan in the 1980s[2-4]. It was demonstrated that rapid cooling immediately after hot forging improves mechanical properties (tensile and yield strength, elongation, and reduction in area) by more than 20% compared with those obtained using conventional post-forging heat treatment where parts are cooled to room temperature, then reheated and normalized prior to further quench and temper heat treating. Mechanical properties improve due to both the "freezing" of dislocations in steel grains created during plastic deformation of the part, and formation of finer grains (finer martensitic microstructure) in the material. By comparison, in conventional plastic deformation processes, parts are air cooled after forging, allowing dislocations to relax.

Two reasons that quenching immediately after forging was not commercialized were that conventional quenching in oil is not suitable in forging operations due to potential fire hazard, and conventional water quenching is applicable only to forgings made of water-quench steel grades and simple shapes due to the high probability of cracking. Because IQ can use water as a quenchant, it overcomes these two hurdles.

In an ongoing project funded by the U.S. Department of Defense, IQ Technologies Inc. (IQT) designed and built a portable 600-gallon DFIQ system (patent pending) to quench forgings immediately after plastic deformation (Fig. 1). The main DFIQ system components include a steel tank; pump; special quenchant-agitation system to provide the hot forging with a suitably intensive, uniform heat extraction rate

Fig. 1 — Portable 600-gallon DFIQ system (patent pending) for quenching forgings.

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required by the IQ process; conveyor to transport parts through the quenchant; loading/unloading table; sludge buster to clean forging scale from the quenchant; chiller to maintain quenchant temperature within an allowable range; and system controls. Environmentally friendly Daphne Genuine IntensiQuench quenchant, a low concentration solution of organic salt in plain tap water jointly developed by IQT and Idemitsu Kosan Co., Japan, is used for the DFIQ system. The combination of the uniform, intensive delivery of the quenchant to the hot part surface with the unique cooling properties of the quenchant minimizes the duration of the initial film-boiling stage of cooling. This in turn results in more uniform cooling of the forging, drastically reducing the probability of part cracking.

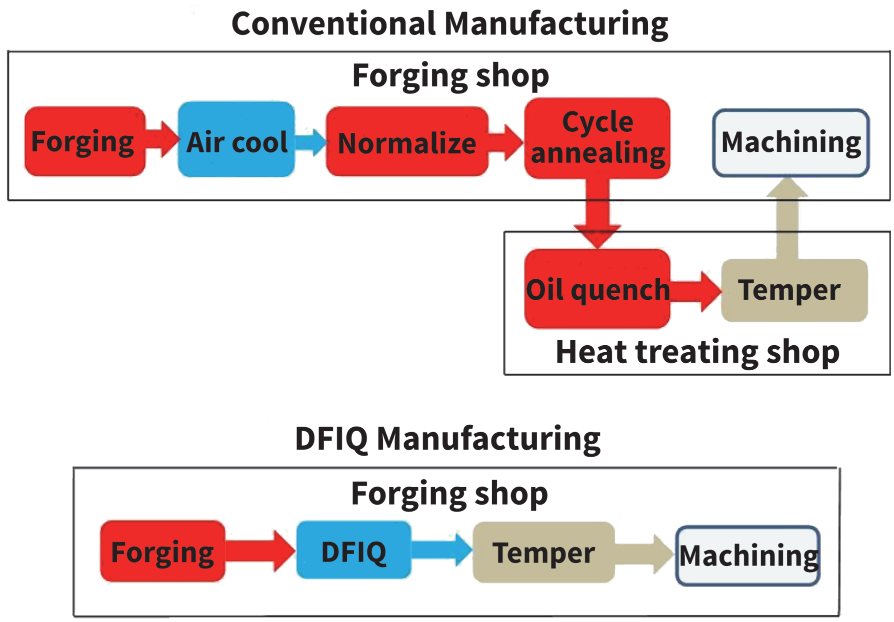

Fig. 3 — Production flow diagrams for conventionally and DFIQ processed pintle adapter forgings.

DFIQ trials with actual forgings in production conditions were conducted at Bula Forge and Machine (Cleveland), Welland Forge (Canada), and Clifford Jacobs Forge (Champaign, Ill.). Figure 2 shows some processed forgings including keys, pindle adapters, tines, and lugs. Forgings were made of AISI 1045, 4140, 4340, and 8640 steels for materials characterization studies. One set of keys was processed using DFIQ followed by a self-tempering process only, i.e., the part surface layer was tempered by residual heat from the hot core. Another set of keys was heat treated using traditional methods: air cooled after forging, reheated, quenched

Fig. 2 — Examples of forgings processed using DFIQ.

in oil, and tempered for two hours at 700°F. Keys from both sets had the same hardness of 50-51 HRC[5].

The studies illustrated that DFIQ significantly improves material mechanical properties compared with those obtained using conventional heat treatment. For example, the tensile strength of 4140 alloy steel after conventional heat treatment was 222,000 psi, and increased to 287,000 psi after DFIQ, while impact strength improved from 5 to 14 ft-lb. Tensile and impact strength for 4140 after DFIQ are even higher than those for conventionally heat treated higher alloy 4340 steel (i.e., 262,000 psi and 8 ft-lb). This illustrates the possibility of substituting a less expensive, lower alloy steel for a higher alloy steel using DFIQ, and still obtaining the same or better mechanical properties—achieving both easier machinability and lower material cost. DFIQ can also eliminate the need for normalizing, or both normalizing and annealing processes after forging, resulting in a significant reduction of production lead times, energy consumption, and overall cost of the heat treatment process.

Additional savings from DFIQ come from eliminating shipping costs and lead time between forging and heat treating shops. For example, the DFIQ-processed pintle adapters followed by furnace tempering met customer specifications without being normalized, annealed, reaustenitized, and oil quenched and tempered. Production flow diagrams comparing pintle adapters made using conventional manufacturing and DFIQ are shown in Fig. 3.

In addition, DFIQ forgings have very little surface scale, because the parts are not reheated two times after the initial billet heating, and the intensive water quench actually blasts off any forging scale, eliminating the need for blast cleaning. Because DFIQ consistently quenches the part, it aids in the production of a more near-net-shape part after hardening.

INTENSIQUENCH REDUCES COST OF MANUFACTURING

Three types of IQ processes used for final heat treatment of steel parts include:

- *Batch IQ*—parts are batch furnace heated and intensively quenched in an IQ water tank
- *Continuous IQ*—parts are heated in a continuous furnace and intensively quenched in a continuous IQ water tank
- *Single-part quenching*—an individual part is quenched in high-velocity water-flow IQ system after furnace or induction heating

IQT has conducted hundreds of IQ demonstrations for a variety of steel parts using batch and single-part processing IQ equipment installed at Akron Steel Treating Co. and at Euclid Heat Treating Co. in Cleveland. Proven IQ process benefits include:

- Increased surface and core hardness with a deeper hardened layer (up to 50%) resulting in stronger parts or lighter parts with a higher power density.
- Use of less expensive, lower alloy steels producing the same mechanical properties as higher alloy materials that are conventionally quenched in oil and water-based polymers. This is in contrast to material selection by part designers using traditional heat treatment where added strength usually requires selection of steels containing additional alloying elements for higher hardenability.
- High residual surface compressive stresses in parts made of through-hardening steels (in contrast to tensile stresses after convectional quenching) resulting in stronger parts with longer fatigue life.
- Up to two times greater residual surface compressive stresses in parts made of carburized steels compared with conventional quenching in oil, without mechanical shot peening.
- Low, repeatable part distortion (as low as 50 μm) for predictable part size change after hardening. Distortion is so predictable, the green part can be purposely machined out of tolerance and will consistently distort to fit after IQ hardening.
- Reduced heat treatment cost due to a reduction in furnace carburization cycle times by 30-40%, which results in higher furnace production rates, lower energy costs, cleaner parts, and no hazards or environmental concerns associated with oil quenching. For a given alloy's inherent hardenability, the "hardenability" built into the IQ process requires less carbon content in the case gradient to achieve an effective case depth hardness of 50 HRC compared with oil and water-base polymer quenching.
- Enables the elimination of carburizing with the use of optimum hardenability steels[1], and also enables single-part flow in the manufacture and heat treatment of case-hardened parts in the manufacturing cell. This in turn allows for lower work-in-process inventories, as well as faster, more flexible throughput for case-hardened parts.

IQ Technologies recently shipped a $1.1 million, fully automated turnkey IntensiQuench system for hardening gear products consisting of a rotary hearth, controlled-atmosphere furnace for austenitizing parts prior to quenching, a single-part processing IQ unit, and a pick and place device to transfer parts from the furnace to the IQ unit and from the IQ unit to the unloading area (Fig. 4). The system enables the manufacturer to use plain carbon steel instead of an alloy steel; to reduce the carburizing cycle time by up to 30%; to eliminate the environmental costs of oil quenching; and to minimize straightening operations for its gear products. In addition, shot peening can be eliminated for some parts.

Fig. 4 — Fully automated, single-part processing IntensiQuench system for hardening gears.

CONCLUSION

Lean manufacture of parts requires that each step in the manufacturing value stream be concurrently engineered to eliminate waste wherever and whenever possible. Each processing step, including heat treating, should be fully integrated into the part design and material selection process with the objective of lowering overall costs and maximizing value-added benefits. In addition, the proper order of processing should be considered to eliminate hidden costs between various processing steps. **~HTPro**

Note: Direct from forge IQ (DFIQ) is a trademark and Intensi-Quench is a registered trademark of IQ Technologies Inc.

For more information: Joseph Powell is president, Akron Steel Treating Co., IQDI Products Ltd., and IQ Technologies Inc., 336 Morgan Ave., Akron, OH 44311, 330.773.4850, joepowell@akronsteeltreating.com, www.intensivequench.com.

Acknowledgment

IQ Technologies acknowledges the support of Logistics Research and Development Program at Defense Logistics Agency Headquarters, Fort Belvoir, Va., and Advanced Technology International, Summerville, S.C., under the Procurement Readiness Optimization-Forging Advanced Systems and Technologies (PRO-FAST) Program.

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ASM INTERNATIONAL

ASMNEWS

ASM AFFILIATE SOCIETIES ANNOUNCE NEW OFFICERS AND BOARD MEMBERS

In accordance with their Rules of Governance, five ASM Affiliate Societies have completed their elections for officers and board members beginning in fall 2017. Please join us in welcoming the following appointments.

Electronic Device Failure Analysis Society

Zhiyong Wang, executive director, Maxim Integrated and EDFAS president, announced the appointment of **Efrat Moyal,** co-founder, LatticeGear LLC, to a two-year term on the Board in her role as general chair of ISTFA.

Failure Analysis Society

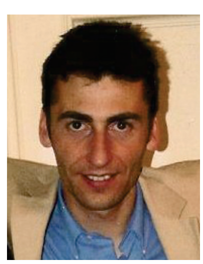
Pierre Dupont, key account manager – industry, Schaeffler Belgium Sprl/bvba, succeeds as president of FAS, while **Burak Akyuz,** team lead – metallurgy and failure analysis, Applied Technical Services Inc., remains as immediate past president. **James Lane,** senior engineer, Professional Analysis and Consulting Inc., succeeds to vice president, while **Daniel P. Dennies, FASM,** principal, DMS Inc., was elected secretary. **Roch Shipley, FASM,** principal engineer, Professional Analysis Consulting Inc., was reelected treasurer. Officers' terms are two years.

Craig J. Schroeder, senior engineer, metallurgy, Element, and **Thomas D. Traubert,** consulting engineer, EDT Engineering, were both elected to the board for a three-year term. **Steven A. Bradley, FASM,** research fellow, UOP, was elected to the board for a two-year term filling the unexpired term of Daniel Dennies.

Daniel Grice, senior materials engineer, Materials Evaluation and Engineering, was reappointed emerging professional board member and **Rachel Stewart,** Colorado School of Mines, was appointed student board member. Both positions are one-year terms.


Wang


Moyal


Dupont

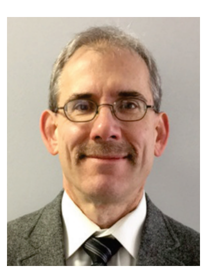

Akyuz


Lane

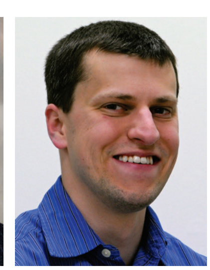

Dennies


Shipley


Schroeder


Traubert


Bradley


Grice


Stewart

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ASM INTERNATIONAL

Submit news of ASM and its members, chapters, and affiliate societies to Joanne Miller, editor, ASM News | ASM International
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HIGHLIGHTS AFFILIATE OFFICERS/BOARD MEMBERS

Heat Treating Society

The HTS Board elected a vice president and three members to the board. See page 4 of *HTPro* in this issue for the full story.

International Metallographic Society

James E. Martinez, materials scientist, NASA, succeeds as president of IMS, while **Jaret J. Frafjord,** laboratory director, IMR Test Labs-Portland, remains on the board as immediate past president. **Daniel P. Dennies, FASM,** principal, DMS Inc., was elected vice president. **David Rollings,** vice president, sales and marketing, Ted Pella Inc., was reelected finance officer and **George Abraham IV,** manager, technical services, Allied High Tech Products, was elected secretary. Officers serve two-year terms.

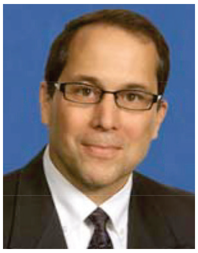
Laura Moyer, lab manager, Lehigh University, **Steven J. Gentz,** NESC chief engineer, NASA, and **Michael Keeble,** U.S. labs and technology manager, Buehler, were elected directors for a three-year term. **Don Zipperian,** vice president, Pace Technologies, was elected to a two-year term filling George Abrahams' unexpired term; and **Frank Muecklich,** professor, Saarland University, was elected to a two-year term filling the unexpired term of Dan Dennies. **Mary O'Brien,** graduate student, Colorado School of Mines, was appointed student board member for one year.

Thermal Spray Society

TSS reelected two members to the board and elected one new member; and the TSS executive committee reappointed the secretary/treasurer and two student board members to the board. See page 3 of *iTSSe* in this issue for the full story.


Martinez


Frafjord


Dennies


Rollings


Abraham


Moyer


Gentz


Keeble


Zipperian


Muecklich


O'Brien

NOMINATION DEADLINES

ASM Nominating Committee Nominations

Nominations for the ASM Nominating Committee are due **December 15, 2017.** Contact leslie.taylor@asminternational.org, 440.338.5151, ext. 5500, or visit asminternational.org/about/governance/nominating-committee.

2018 ASM Class of Fellows Nominations: Deadline Fast Approaching

The honor of Fellow of the Society was established to provide recognition to members for distinguished contributions in the field of materials science and engineering, and to develop a broadly based forum for technical and professional leaders to serve as advisors to the Society.

Criteria for the Fellow award are:

- Outstanding accomplishments in materials science or engineering
- Broad and productive achievement in production, manufacturing, management, design, development, research, or education
- Five years of current, continuous ASM membership

Deadline for nominations for the class of 2018 is **November 30, 2017.**

View rules and past recipients at asminternational.org/membership/awards. To receive a unique nomination form link contact Christine Hoover at christine.hoover@asminternational.org.

Annual ASM Award Nominations

The deadline for the majority of ASM's awards is **February 1, 2018.** We are actively seeking nominations for these awards, a few of which are listed below:

- Edward DeMille Campbell Memorial lectureship
- Distinguished Life Membership
- William Hunt Eisenman Award
- Gold Medal
- Silver Medal

View rules and past recipients at asminternational.org/membership/awards. To receive a unique nomination form link, contact Christine Hoover at christine.hoover@asminternational.org.

CEO CORNER

ASM Renewal on Track for 2017

As I write this column at the beginning of October, fall is starting to reach Northeast Ohio and encircle the Dome with color. We are now entering the 10th month of the 36-month timeline of the ASM Renewal.

Our full view of 2017 achievements and outcomes, as well as challenges for the rest of the year and into 2018 and 2019, is taking clearer shape. Through three quarters of 2017, ASM has been able to achieve its year-to-date financial and program objectives, and remain substantially on track against both the 2017 Annual Operating Plan objectives and 2016 and 2017 Strategic Plan initiatives. Veterans on both the Dome team and in member leadership roles tell me that this on-plan performance by the ASM operating company has not been seen in many years. We expect it to continue.

We have had some disappointments during 2017, most notably the delay from November until February of the go-live date for our new eCommerce backbone, which we covered in this column in the October issue. We also have been challenged to scale our educational line of business, despite significant needs for our curricula in the marketplace. After taking corrective actions—including forming courseware resale relationships with technical colleges and continuing education programs at universities—we are confident that we will surmount those challenges moving into 2018.

Mahoney

The fourth quarter of this year is a busy time for ASM conferences, most notably MS&T, Heat Treat, and ISTFA. Our events team has done a highly professional job of planning and executing those meetings, and the attendance and financial projections from those events are exceeding both our Annual Operating Plan forecasts and prior actuals.

We hope that, as members, the professional development and improved materials performance objectives you set for attending these fourth quarter 2017 meetings are achieved. Please feel free to contact me and share feedback about your experience at these fall events.

Last year at MS&T 2016, we asked our members to join the ASM Renewal, and you have done so. Thank you. This year, we are asking for your help to advance and grow the Renewal. Please join me in the 2018 phase of our transformational journey.

William T. Mahoney, CEO, ASM International
bill.mahoney@asminternational.org

HIGHLIGHTS MS&T17

Materials Standards and Specifications Workshop

In early August, ASM International hosted a cross-industry materials standards and specifications workshop at its headquarters, on behalf of the Boeing Company. The goal was to discuss the current state of product standards, specifications, and best practices, and make suggestions for an improved future state.

Seventeen people from more than a dozen companies attended the meeting, which was chaired by Bob Kiggans (pictured left), an independent consultant, and facilitated by Jeff Grabowski (on right) of QuesTek Innovations LLC. The companies included airframe and aero engine builders, automotive manufacturers, and materials suppliers.

The general consensus is that the meeting generated some useful outputs and identified several areas for development. One of the resulting actions is that ASM is now creating a training course on specifications writing.

PHOTO GALLERY: HIGHLIGHTS FROM MS&T17

Pittsburgh's rivers and beautifully engineered bridges, as seen from the Convention Center.

A team from Virginia Polytechnic Institute and State University secured first place in the 2017 Undergraduate Design Competition.

Kishor M. Kulkarni presents his namesake Distinguished High School Teacher Award to Todd Bolenbaugh.

At the ASM Leadership Luncheon, Emily Stover DeRocco from LIFT receives the ASM Foundation Pacesetter Award from Diran Apelian, FASM, and Glen Daehn, FASM.

Rachel Pry of The Ohio State University, a George A. Roberts Scholarship winner, is recognized by the ASM Foundation's Glenn Daehn, FASM.

MS&T17 HIGHLIGHTS

Nate Eisinger, chair of the Pittsburgh Chapter, gives opening remarks at the ASM Annual Meeting.

William Lee of ACerS, Alexander King, FASM, and ASM leaders Frederick Schmidt, FASM, and William Frazier, FASM, at the opening plenary session.

Jon Tirpak, FASM, starts the ASM Awards Dinner with levity using a cell phone gag.

The team from The Timken Co. earns the 2017 ASM Engineering Materials Achievement Award.

Dan Dennies, FASM, (left) and George Vander Voort, FASM, helped organize a special symposium celebrating the 50th anniversary of IMS.

FAS and IMS Board members hamming it up at the photo booth at the IMS Ice Breaker and Canada Council Suite.

John Perepezko, University of Wisconsin, Madison, gives his Gold Medal Award acceptance speech.

William Frazier, FASM, shows off his newly acquired pin for past presidents with Gern Mauer, FASM, Frederick Schmidt, FASM, Bill Mahoney, and Ray Decker, FASM, looking on.

Kip Findley and Michael Marucci proudly display their ASM Silver Medal Award.

HIGHLIGHTS MS&T17

2017 Class of ASM Fellows.

Lesley Frame gives remarks after accepting the ASM Bronze Medal Award.

Gwynne Shotwell, president and COO of SpaceX, receives the ASM Medal for the Advancement of Research from William Frazier, FASM.

Thomas Glasgow, FASM, accepts the George A. Roberts Award from William Frazier, FASM, and Aziz Asphahani, FASM.

Students visiting the ASM booth get excited about the 2020 ASM Annual Event to be held in Cleveland.

Contestants from Arizona State University make their pitch to the judges at the DomesDay competition.

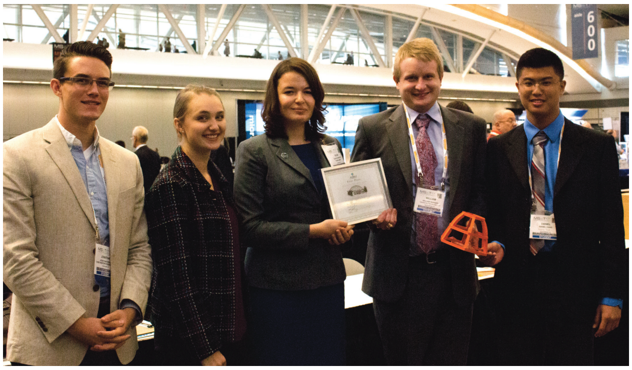
2017-2018 ASM Board of Trustees.

STUDENT BOARD MEMBER SOUND BITES

DomesDay 2017 Crushes It

Established in 2014 by the ASM Student Board Members, DomesDay is intended to familiarize Material Advantage students with a piece of ASM culture—the Dome—by involving them in a design and materials selection competition. Each team is required to create a Dome structure, reminiscent of ASM's Headquarters and National Historic Landmark, while also accounting for mechanical strength and cost of production. A poster presentation is included to describe the innovation process from ideation to final fabrication.

This year, 11 teams competed to claim the title of DomesDay 2017 Champion. Three teams rose to the top after judging each entry's poster presentation, Dome aesthetics, and mechanical strength. In first place was VT Dome (Virginia Tech), second place was awarded to Tree Killers (Arizona State University), and in third place was Miner Domeination (Missouri University of Science and Technology). For a full list of teams, photo gallery, and video, visit asminternational.org/students/domesday-competition.



ASM Student Board Members congratulate Virginia Tech's winning team members, William Wenger and Daniel Ching for their DomesDay first place entry.

Thanks to all the teams that participated in this year's competition, as well as the sponsors, NSL Analytical and MTS. We look forward to seeing you at DomesDay 2018 in Columbus!

FROM THE FOUNDATION

Year in Review: Much Accomplished, More to Do

Campana

As the year comes to a close, I would like to take this opportunity to thank you for your support, belief, and commitment to the ASM Materials Education Foundation. As you know, the Foundation aims to serve its mission to excite young people in materials, science, and engineering careers. A special thanks goes to all of our stakeholders, partners, Board of Directors, volunteers, staff, and most importantly, the teachers and students we serve!

In reflecting upon this year, the Foundation has much to be proud of and should celebrate the many accomplishments that were realized. For example, we conducted two specialty Materials Camps, one focused on additive manufacturing, the other on the Materials Genome Initiative. In addition, the Materials Camp for teachers program has been operating for 15 years—providing education and inspiration to students and teachers alike.

This year also provided the opportunity to review our past successes and begin to plan for a desired future state. The Board embarked on developing a new strategic plan, expected to be complete early next year, which includes a full assessment of the Foundation's programs. Through the planning process, we will be evaluating our Materials Camp programming to see where improvements can be made in content, delivery, and operational logistics to provide the most engaging curriculum to as many people as possible, in a cost effective manner.

While the Foundation was an early pioneer of hands-on science learning, we are now in an increasingly crowded space where everyone is competing for funding. The Foundation needs to be sure we are providing a product that captures the attention of educators, appeals to the goals of funders, and continues to serve the Foundation's mission. We are particularly excited to look at new ways that we might reach and inspire even more youth to join STEM fields.

As we approach the end of the year, I send my very best to each of you. I am proud to serve this organization and look forward to working with you in the coming year to make the ASM Materials Education Foundation the best it can be. Without your support, none of this would be possible.

Nichol Campana
Director of Development & Operations
ASM Materials Education Foundation

VOLUNTEERISM COMMITTEE

Profile of a Volunteer

Cummings

Jessica Cummings, Manager, Engineering Partnership Programs, Rolls-Royce

Jessica Cummings was adept at chemistry and she loved her research opportunity using anodic aluminum oxide at the University of Chicago during her high school years. She intended to become a chemical engineer until a visit to Georgia Tech, where she stumbled onto the materials science and engineering department. "I thought, 'Hey that research I really enjoyed falls under materials science!' I decided that was much cooler and what I wanted to do."

Graduating from Georgia Tech in 2013, Jessica entered the graduate rotational program at Rolls-Royce jet engine business in Indianapolis. In 2015, she accepted a role as materials application engineer, supporting design, service, and production groups. In 2016, she became manager for the company's graduate rotational, co-op, and high school internship programs.

Jessica decided to join the ASM Indianapolis Chapter when her professional mentor at Rolls-Royce, Ann Bolcavage, encouraged her. "A personal invitation is important. It can be as simple as saying 'come hear this talk or join us on this tour.'" Jessica is now Chapter chair and a member of the Emerging Professionals Committee. "There's no substitute for personal interaction. I've met people at Haynes and now I call them when I have a question about a specific alloy," says Cummings. "At chapter meetings, we learn about technical topics I didn't even know existed. My favorite part is touring other facilities. We've gone to Alcoa, the Indianapolis Museum of Art analysis lab, and a composites manufacturing facility."

At 25, Jessica is confident taking a leadership role. "If you've never been involved before, don't be afraid. I even convinced my husband to get involved—he's a materials scientist too! You'll feel more connected to ASM and the gamut of what you can do—from Teacher Camps to training courses. You see what's going on and the difference you can make."

CHAPTERS IN THE NEWS

Don Bosco Hosts Teachers Camp

Twenty-four high school teachers participated in the 2017 Materials Camp for Teachers at Don Bosco Technical Institute in Rosemead, Calif. The Camp was organized by the Los Angeles Chapter and Don Bosco Tech, with financial support from the Los Angeles Chapter, Orange Coast Chapter, Northrop Grumman Corp., National Association of Corrosion Engineers, and Lightweight Innovations for Technology, as well as the in-kind support of Don Bosco Tech.

Chapters of Excellence Awards

Each year, ASM administers the Chapters of Excellence (COE) Award Program on behalf of the Material Advantage Student Program. This competition judges the student chapters across programming, career development, service, social activities, chapter management, and overall report quality. Congratulations to this year's winning schools!

Most Outstanding Chapter (receiving an award plaque and $750 prize):

- Colorado School of Mines

Chapters of Excellence Awards (receiving an award plaque and $450 prize):

- The University of Illinois at Urbana-Champaign
- Missouri University of Science & Technology
- Iowa State University
- Suez University
- Rensselaer Polytechnic Institute

Runner-Up (receiving a certificate of achievement):

- Penn State

Minnesota Explores Proto Labs

On September 20, the ASM Minnesota Chapter toured Proto Labs in Plymouth. Approximately 40 members attended the tour and learned about Proto Labs' capabilities in CNC machining, injection molding, and 3D printing.

Seal Wins Grant for UCF

The National Science Foundation has awarded the University of Central Florida (UCF) a grant to help fund the purchase of a $900,000 imaging device that will do everything from design nanoparticles of the future to delve into our civilization's past. Rather than siloed in one department's lab, the state-of-the-art x-ray photoelectron spectrometer with ultrafine imaging capability will be used by researchers from physicists to anthropologists. **Sudipta Seal, FASM,** led the effort to acquire the technology. Seal is chair of the department of materials science and engineering and an ASM trustee. His collaborators on the grant application included **Yongho Sohn, FASM,** professor in the department of materials science and engineering and **Amit Kumar,** associate director of research programs at Florida's Bridging the Innovation to Development Gap.

Seal

MEMBERS IN THE NEWS

Ravindran Lectures in Support of IIM-ASM Partnership

ASM reinforces global partnerships with sister societies and materials communities. As part of an ongoing partnership with the Indian Institute of Metals (IIM), **Prof. Mukhopadhyay** (IIM coordinator) invited **Prof. Ravi Ravindran, FASM,** (ASM coordinator) to the Indian Institute of Technology at Banares Hindu University (IIT-BHU), Varanasi, India. On August 19, Prof. Ravindran delivered a talk there on "In-situ Analysis of Incipient Melting of Al Casting Alloys." Initiated in 2012, the ASM-IIM North America Lectureship is a joint program of IIM and ASM, enabling the visit of two high-profile Indian materials engineers to North America to deliver lectures on leading edge technologies and research.

Pictured seated (left to right) are Prof. Shanthi Srinivas, Prof. Vikas Jindal, Prof. Ravi Ravindran, Prof. Shrikant Lele, and Prof. Kaushik Chattopadhyay. Standing are graduate students.

Tarkanian's MIT Contest Breeds Innovations

Michael Tarkanian, senior lecturer in MIT's department of materials science and engineering, is the competition organizer for the annual MADMEC contest. MIT students present oral and poster demonstrations explaining inventions they designed over the summer to solve a range of sustainability issues. This year's winning team called A Salt Solution won $10,000 for a model of a simple, low-cost hydrogel for uranium mining in seawater. A number of former MADMEC competitors have started companies based on their inventions. Clear Motion (formally Levant Power), the third-place winner at the first MADMEC in 2007, later raised $130 million to build shock absorbers that enhance vehicle handling while producing electricity to improve efficiency. Embr Labs, 2013 winner, sold nearly half a million dollars' worth of preorders for its marketable thermoelectric wristband that cools and heats the body.

Michael Tarkanian (center) with MADMEC 2017 competitors, Team Dumbledore (left) and Team Geoworks (right).

IN MEMORIAM


Donahue

Raymond "Ray" Joseph Donahue, FASM, and ASM Life member, passed away on October 10 at age 76. He was a graduate of the Illinois Institute of Technology in Chicago where he obtained a Ph.D. in metallurgical engineering. He was a professor of metallurgical engineering in Connecticut before working at Brunswick Corp. in Glenview, Ill. Brunswick brought him to Mercury Marine Corp. in Fond du Lac, Wisc., where he worked as a technical fellow until the time of his death. He was an employee with Brunswick for 45 years. Donahue was a member of the ASM Milwaukee Chapter where he served on the executive committee (2009-2017). He was also chairman of the ASM Chapter Council in 2009. Donahue held more than 60 U.S. and foreign patents for innovations in metallurgy and die casting. His co-workers recall his wise expression, "From our mistakes come the next great breakthroughs." One of these breakthroughs led him to co-invent MercAlloy, which helped elevate Mercury Marine's reputation in the industry.


Lawley

Alan Lawley, FASM, emeritus professor, Drexel University, Philadelphia, passed away on October 17 at the age of 84. He made significant contributions to the research and development of power metallurgy and particulate materials in his career. Lawley received a B.Sc. in physical metallurgy and Ph.D. in metallurgy from the University of Birmingham, UK. He worked at the University of Pennsylvania's School of Metallurgical Engineering as a post-doctoral fellow and at Franklin Institute's Solid State Research Laboratory. He joined Drexel in 1968 where he initiated the powder metallurgy program. While at Drexel, he was appointed department head of materials engineering and the A.W. Grosvenor Professor of Metallurgy. Lawley published over 300 articles in archival journals, conference proceedings, and books. He was editor-in-chief of APMI International's *International Journal of Powder Metallurgy* from 1985 to 2015. A long-time member of the Metal Powder Industries Federation technical board, Lawley was among the first class of fellows of APMI International in 1998, and was elected to the National Academy of Engineering that same year. Lawley was recipient of the ASM Gold Medal (1996) and the ASM Albert Easton White Distinguished Teacher Award (1982). He served as chair of the Philadelphia Chapter from 1991 to 1992.

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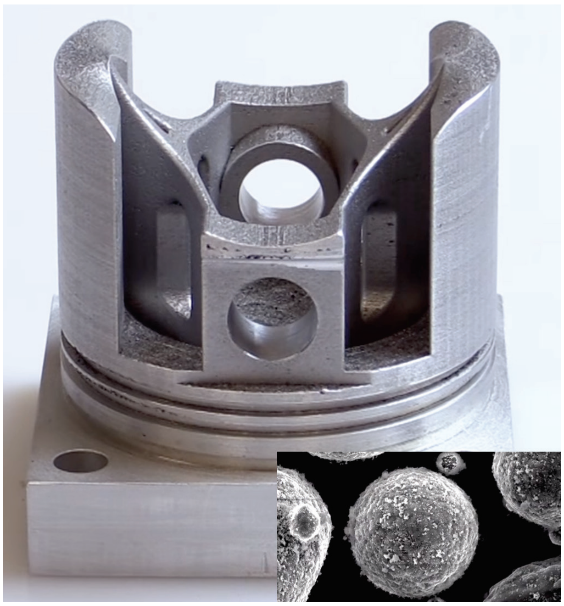
3D PRINTSHOP



An aluminum piston made with nano-functionalized 6061 powder (inset) shows no signs of cracking or shrinkage, a problem that currently prevents thousands of alloys from being used in additive manufacturing.

NANO-FUNCTIONALIZED POWDERS SOLVE HOT CRACKING PROBLEM

Engineers at HRL Laboratories LLC, Malibu, Calif., developed a way to eliminate hot cracking in 3D-printed parts made of high-strength aluminum, including 6061 and 7075. Uncontrolled cracking during solidification currently prevents thousands of commercial alloys from being used in additive manufacturing. The ingenious fix developed by HRL engineers alters the solidification dynamics of the alloy by adding nanoparticles to the powder. The particles act as nucleation sites, optimizing lattice alignment between adjacent grains and enabling formation of uniform, crack-free, fine-grained microstructures, comparable in strength to wrought materials. Besides aluminum, the method also applies to high-strength steels and nickel-base superalloys as well as other metals that are difficult to weld or print. *hrl.com.*

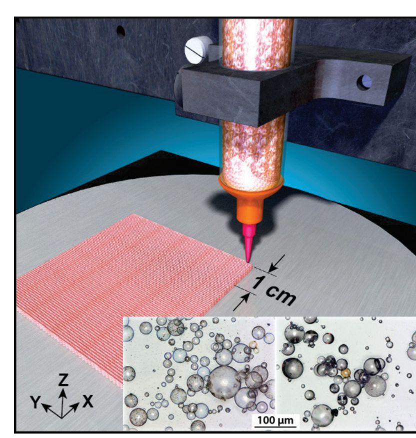
AIRBUS INSTALLS FIRST 3D-PRINTED TITANIUM PART ON COMMERCIAL FLEET

Airbus, France, is installing 3D-printed titanium brackets on production units of its A350 XWB, the first such use of additively manufactured parts in the aerospace industry. The brackets are part of the pylons that hold the engines to the wings, and their use on a commercial airframe represents a significant advancement in the qualification of printed metal components for aerospace applications. The structurally critical parts are manufactured by Arconic, New York, a long-time Airbus supplier of titanium and nickel components made using laser powder bed and electron beam technology. *airbus.com.*

A production specialist works on a 3D-printed titanium bracket, part of a pylon assembly designed for the Airbus A350 XWB.

RESEARCHERS PRODUCE 4D-PRINTED MATERIAL

Researchers at Lawrence Livermore National Laboratory, Calif., developed a printable silicone ink that possesses shape memory properties. The activating mechanism, discovered by accident while testing porous materials, is an expanding gas trapped in polymer-lined pores embedded in the ink. The polymer has a glass transition temperature, below which it is rigid and glassy, and above which it becomes soft and malleable. As a result, objects made from the ink can be compressed at elevated temperatures and will remain in that state as they cool. When reheated, however, the gas expands in the tiny balloons, forcing the overall structure to return to its original shape. Researchers envision applications in athletic equipment, such as helmets, braces, and shoes, and potential large-scale uses in packaging, transportation, and load stabilization. *llnl.gov.*



A direct-write 3D printer dispenses a silicone ink infused with gas-filled pores (inset) that expand when heated and contract when cooled. Developed by LLNL researchers, the ink may one day be used to create formfitting cushioning activated by body heat.

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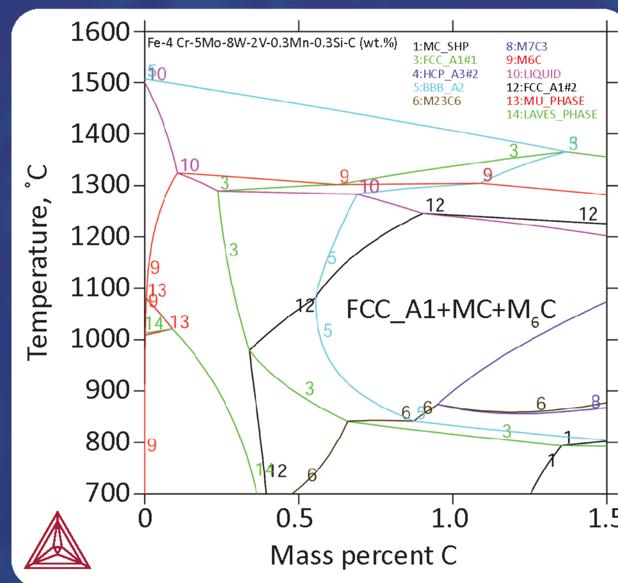

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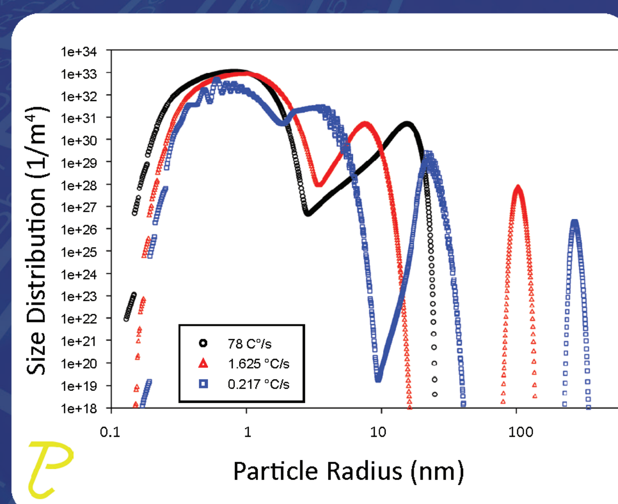

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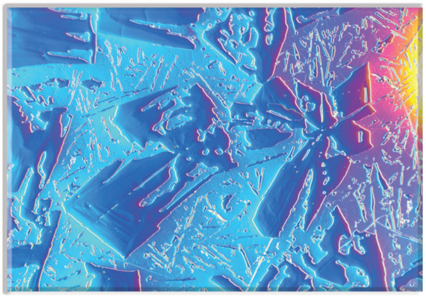
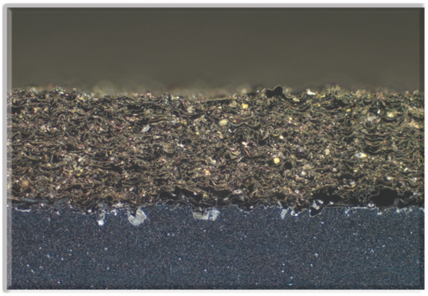
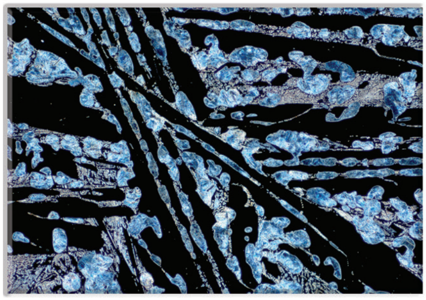
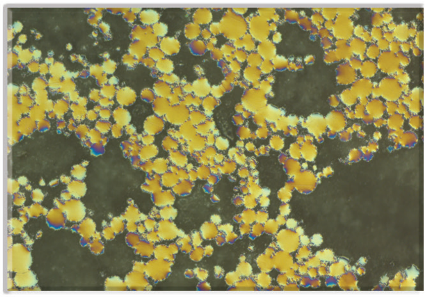
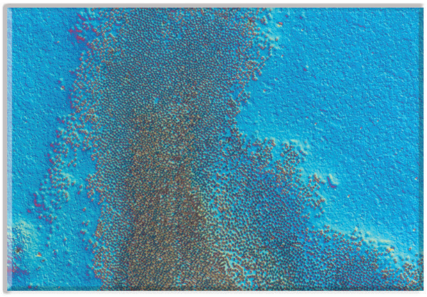
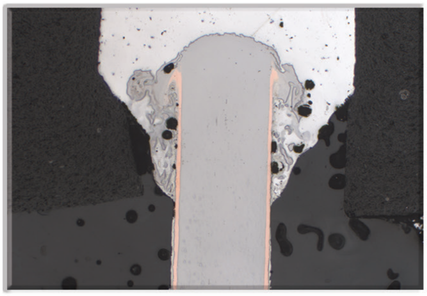


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