MARCH 2016 | VOL 174 | NO 3

# ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION


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AUTOMOTIVE MATERIALS

## HIGH-TEMPERATURE ALUMINUM ALLOYS

P.16



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## On The Cover:

The Ford F-150 Raptor features an aluminum body to save vehicle weight. Learn more about Ford and Alcoa working together to produce next-generation automotive aluminum alloys on p. 12. Courtesy of Ford Motor Co., Detroit. ford.com.



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# ADVANCED MATERIALS & PROCESSES

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## FEATURES



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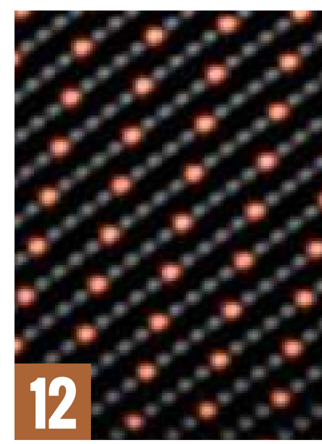

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## TRENDS



## INDUSTRY NEWS



## DEPARTMENTS



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ASM International
9639 Kinsman Road, Materials Park, OH 44073
Tel: 440.338.5151 • Fax: 440.338.4634

**Frances Richards**, *Editor-in-Chief*
frances.richards@asminternational.org
**Julie Lucko**, *Editor*
julie.lucko@asminternational.org
**Ed Kubel and Erika Steinberg**, *Contributing Editors*
**Jim Pallotta**, *Creative Director*
jim.pallotta@asminternational.org
**Kate Fornadel**, *Layout and Design*
**Annie Beck**, *Production Manager*
annie.beck@asminternational.org
**Press Release Editor**
magazines@asminternational.org



# YET ANOTHER REASON TO LOVE MATERIALS SCIENCE

Unless you have been living under a rock or enjoying a tropical vacation, you have no doubt heard the mindboggling news about the detection of gravitational waves, predicted by Einstein 100 years ago. Trying to imagine black holes colliding and ripples in the space-time fabric is, of course, impossible. Nevertheless, incredibly complex scientific instruments made the detection possible. Scientists say these waves contain information about both their origins and the nature of gravity that cannot be gained any other way. From this information, physicists conclude that the waves were produced during the final fraction of a second of the merger of two black holes to create one larger, spinning black hole.

Waves were detected on September 14, 2015, by both of the twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors located in Louisiana and Washington. These observatories are funded by the National Science Foundation (NSF) and operated by the California Institute of Technology and Massachusetts Institute of Technology. Based on the signals, the LIGO team believes the black holes were roughly 29 and 36 times the sun's mass, and that the merger occurred 1.3 billion years ago.

An aerial view of the LIGO detector in Louisiana. Courtesy of LIGO Laboratory.

At each location, a two-and-a-half mile long, L-shaped LIGO device uses laser light split into two beams that travel back and forth down the "arms"—four-foot diameter tubes maintained under nearly perfect vacuum. Beams are used to monitor the distance between mirrors placed at the ends of the arms. According to Einstein, the distance between the mirrors will change by a teensy amount when a gravitational wave passes the detector: A change in the lengths of the arms smaller than one-ten-thousandth the diameter of a proton ($10^{-19}$ meter) can be detected.

Fascinating, yes, but to what end? Some have compared the detection of gravitational waves to Watson and Crick determining the double-helix structure of DNA. This comparison seems extreme to me, at least in terms of practical applications. I'm all in favor of understanding the universe, but I don't foresee any medical breakthroughs or new energy technologies stemming from the wave detection. As one of the LIGO scientists commented, we have entered a new era, in which "the field of gravitational wave astronomy is now a reality." As a pragmatist, I'm thrilled for the scientists who achieved this milestone, but I'd like to think that some earthly innovations could stem from this knowledge.

In many ways, it is this kind of observation that makes me appreciate materials engineering all the more. For example, this issue of *AM&P* focuses on automotive materials—developments such as new aluminum alloys that promise to make our cars lighter to save fuel, and how to test composite materials to determine their mechanical properties. Perhaps not as exciting as ripples in the fabric of space and time, but wonderfully practical and relevant to daily life. If you have an opinion on the matter, we'd love to hear it.

F. Richards

frances.richards@asminternational.org

# MARKET SPOTLIGHT

## IMMIGRANTS PLAY GROWING PART IN U.S. SCIENTIFIC WORKFORCE

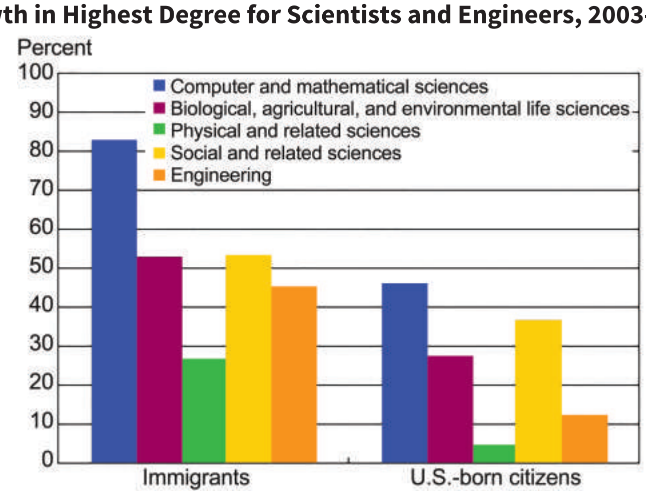
According to new data from the National Science Foundation (NSF), the number of scientists and engineers residing in the U.S. rose from 21.6 million to 29 million between 2003 and 2013. The increase includes significant growth in the number of immigrants, from 3.4 million to 5.2 million. Immigrants went from making up 16% of the science and engineering workforce to 18%, according to a new report from NSF's National Center for Science and Engineering Statistics (NCSES). In 2013, the latest year studied, 63% of U.S. immigrant scientists and engineers are naturalized citizens, while 22% are permanent residents and 15% are temporary visa holders. Birthplaces include:

- 57% born in Asia
- 20% born in North America (excluding the U.S.), Central America, the Caribbean, or South America
- 16% born in Europe
- 6% born in Africa
- Less than 1% born in Oceania

Among Asian countries, India continues its trend of being the top country of birth for immigrant scientists and engineers, with 950,000 out of Asia's total 2.96 million. India's 2013 figure represents an 85% increase from 2003. Also since 2003, the number of scientists and engineers from the Philippines increased 53% and the number from China, including Hong Kong and Macau, increased 34%.

The NCSES report finds that immigrant scientists and engineers were more likely to have earned post-baccalaureate degrees than their U.S.-born counterparts. In 2013, 32% of immigrant scientists report their highest degree was a master's (compared to 29% of U.S.-born counterparts) and 9% report it was a doctorate (compared to 4% of U.S.-born counterparts). The most common fields of study for immigrant scientists and engineers in 2013 include engineering, computer and mathematical sciences, and social and related sciences. More than 80% of immigrant scientists and engineers were employed in 2013: The largest share (18%) worked in computer and mathematical sciences, while the second-largest share (8%) worked in engineering. *For more information, visit nsf.gov/statistics/2015/nsf15328.*

**Growth in Highest Degree for Scientists and Engineers, 2003-2013**




*Source: NSF/Scientists and Engineers Statistical Data System, 2013.*

## FEEDBACK

### LOST IN TRANSLATION

The October issue cover story, "Failure Analysis of a Fractured Pin," is an important topic, but the article was disappointing. The first paragraph states, "Specifically, the owner of the failed pin wanted to determine if inclusions may have caused the failure, if the part had been properly heat treated, and whether or not the steel composition was correct." Three clear questions. Yet nowhere did I find the answer to any of them.

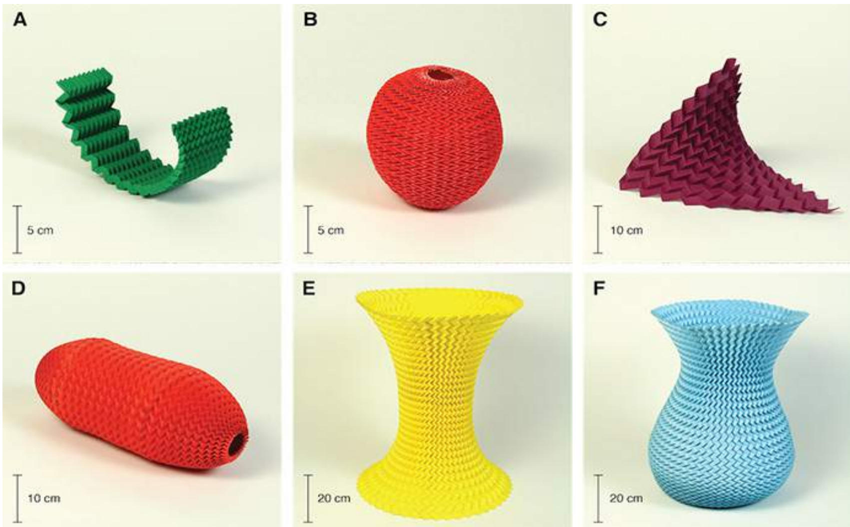
*Irving W. Glater, P.E.*

[The pin was tested for chemical composition and results indicate that the part met the requirements for Werkstoffnummer 1.4057 Alloy X17CrNi16- 2 steel. No anomalies were present in the pin's composition that would contribute to cracking. This information was an unfortunate casualty of the editing process. In the original report, many more metallographic images of the part, in the as polished condition, illustrate that the inclusion content of the steel was low and not a significant contributing factor to the failure. The report makes it clear that cracking progressed longitudinally along the semi-continuous stringers of delta ferrite and it was the presence of delta ferrite, not the inclusions, that resulted in the brittle behavior the pin exhibited in the longitudinal direction. Regarding heat treatment, neither I nor my client had access to the thermal history of the part, as their supplier did not provide this information. In the process of trimming the original report from 4358 words, 63 images, and five tables to an article under 800 words, 10 images, and no tables, important information and details of the investigation were lost.

*—Craig Schroeder, P.E.]*

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

# OMG!
## OUTRAGEOUS MATERIALS GOODNESS



Shapes made from the Miura-ori pattern. Courtesy of Mahadevan Lab.

### ORIGAMI FOLD CREATES COLLAPSIBLE STRUCTURES

A team of researchers at Harvard University, Cambridge, Mass., have characterized a fundamental origami fold, or tessellation, that could be used as a building block to create almost any 3D shape, from nanostructures to buildings. The folding pattern, known as the Miura-ori, is a periodic way to tile the plane using the simplest mountain-valley fold in origami. A folded Miura can be packed into a flat, compact shape and unfolded in one continuous motion. “The collapsibility, transportability, and deployability of Miura-ori folded objects makes it a potentially attractive design for everything from space-bound payloads to laparoscopic surgery,” says graduate student Levi Dudte.

To explore the tessellation’s potential, the team developed an algorithm that can create certain shapes using the Miura-ori fold repeated with small variations. Given the specifications of the target shape, the program lays out the folds needed to create the design, which can then be laser printed for folding. *harvard.edu.*

### FOOD TESTING MACHINE OFFERS TEXTURE ANALYSIS

Ametek Sensors, Test & Calibration, Largo, Fla., developed a machine that quantitatively analyzes the texture of foods. The Lloyd Instruments TA1 performs detailed texture profile analysis (TPA), a process used in the confectionary industry to measure food attributes such as snack bar crispiness, marshmallow springiness, caramel chewiness, and chocolate bar break strength.

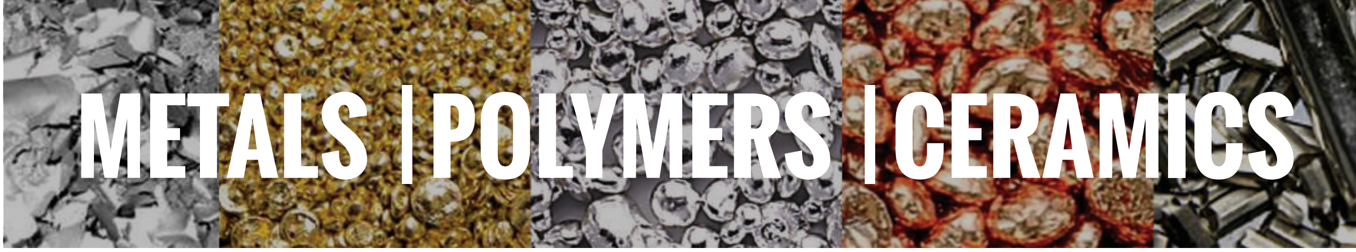
The TA1 has a 102 kgf capacity, and its force measurement is accurate to ±0.5%. Special components are available, such as knife attachments to test butter and cream consistencies and flat ended probes to measure the stickiness of icings and confectionary fillings. The snap strength of crackers, tortillas, and fries can be checked with a modified three-point bend test. Using specialized software, the TA1 can reference a library of international manufacturing standards or incorporate video capture and playback. Once TPA profiles are defined with final testing against human panels, the procedure can be transferred to the production line for standard testing during quality control. Using results from TPA, confectionary manufacturers are able to adjust ingredient ratios, assess baking and production variables, and determine shelf life. *ametektest.com.*


The TA1 analyzes the texture of foods, including confectionary items.

### INTERACTIVE HISTORY OF METAL

Bodycote, UK, launched an “Interactive History of Metallurgy,” a timeline of 10,000 years of metal processing, heat treatment, and surface technology. Containing over 200 high quality images and numerous videos, the interactive infographic pays homage to metallurgy’s Neolithic artisans as well as the scientific innovators of the 20th century and a multitude in between. Starting in 8700 B.C. with the world’s oldest known copper artifacts, the color-coded timeline lets users follow the story of that metal over time. Pathways for bronze, iron, and steel are added as they come into play through the ages. The resource was developed to explore the evolution of metallurgy and heat treating and to acknowledge the collective work of scientists and engineers who have enhanced the properties of metals and alloys throughout human history. *bodycote.com/history-of-metal.*

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





SAC can heal itself and regain its original shape after extreme compression. Courtesy of Jeff Fitlow.

## FLEXIBLE COMPOSITE HEALS ITSELF

Researchers at Rice University, Houston, developed a material called SAC (for self-adaptive composite), a matrix of micron-scale spheres that possesses self-healing and reversible self-stiffening properties. The polymer components, polyvinylidene fluoride (PVDF) and polydimethylsiloxane (PDMS), begin as a powder and a viscous liquid. With the addition of a solvent and controlled heating, the PDMS stabilizes into solid spheres that provide the reconfigurable internal structure.

Other self-healing materials encapsulate liquid in solid shells that leak when cracked, but in SAC, the tiny spheres of PVDF encapsulate much of the liquid, and the viscous PDMS coats the entire surface, making the spheres extremely resilient. Researchers found a maximum 683% increase in the material's storage modulus. SAC could be used as a biocompatible material for tissue engineering or as a lightweight, defect-tolerant structural component, say researchers. *rice.edu*.

## METAL STRENGTHENED WITH NANOPARTICLES

A super-strong, lightweight structural metal was developed by uniformly dispersing silicon carbide nanoparticles into a molten magnesium-zinc alloy. Typically, when used in metal matrices, ceramic particles tend to clump together, reducing strengthening efficiency and plasticity, and making the metals hard to machine. To counteract this, Lianyi Chen, assistant professor of mechanical and aerospace engineering at Missouri University of Science and Technology, Rolla, and his colleagues developed a process that produces a uniform dispersion of 14% nanoparticles in $Mg_2Zn$ metal. The team used scanning and transmission electron microscopy to confirm even dispersion of the nanoparticles. According to Chen, the new metal has greater strength and plasticity than conventional metals and could improve energy efficiency in aerospace, automobile, defense, mobile electronics, and biomedical applications. *mst.edu*.

## METAL NANODROPLETS SEEK AND DESTROY CANCER

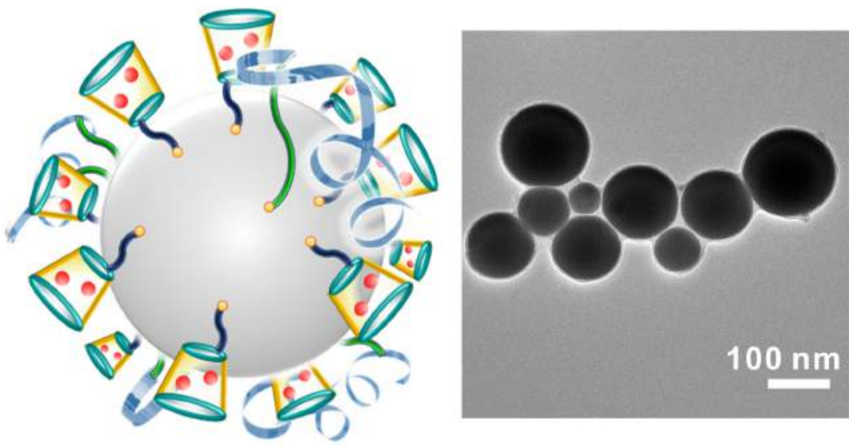
Researchers at North Carolina State University, Raleigh, and the University of North Carolina at Chapel Hill developed a new drug delivery technique using biodegradable liquid metal nanodroplets to target cancer cells. According to Zhen Gu, assistant professor in the joint biomedical engineering program, "The advance here is that we

## BRIEFS

**Norsk Titanium,** Norway, and **Premium Aerotec,** Germany, have taken the initial step in a joint qualification program for additively manufactured titanium aircraft components. The first shipment of Airbus test parts manufactured by Norsk's rapid plasma deposition process was recently finish machined by Premium Aerotec. Following an engineering analysis of the Ti-6Al-4V sample parts, results will be used for the fast-track qualification program. *norsktitanium.com*, *premium-aerotec.com*.


Premium Aerotec Ti-6Al-4V sample part additively manufactured by Norsk Titanium. Courtesy of Business Wire.

**Orbital ATK Inc.,** Dulles, Va., was awarded a contract from **United Launch Alliance** (ULA), Centennial, Colo., for large composite structures as part of the current United States Air Force Evolved Expendable Launch Vehicles program. Orbital will produce the hardware for ULA from 2016–2019, supporting Atlas V and Delta IV vehicle launches through 2021. The order will include fairings, payload adapters and diaphragms, interstages, nose cones, and structures providing main engine thermal/aerodynamic protection. *orbitalatk.com*.




Left, a schematic illustration of liquid-metal nano-terminators. Red spheres are Dox. Right, a representative TEM image of liquid-metal nano-terminators. Courtesy of Yue Lu.

have a drug delivery technique that may enhance the effectiveness of the drugs being delivered, can help doctors locate tumors, can be produced in bulk, and appears to be wholly biodegradable with very low toxicity."

In this technique, 100-nm-diameter droplets of a liquid gallium-indium alloy are introduced into the bloodstream. One type of polymeric ligand binds the anticancer drug doxorubicin (Dox) to the droplets' surface while a second type seeks out cancer cells and causes them to absorb the nanodroplets. Inside the cells, higher acidity levels dissolve the nanodroplets' oxidized skin, releasing the Dox along with gallium ions that enhance the drug's performance. Without the oxidized skin, the nanodroplets fuse into larger drops that can be detected with diagnostic techniques, aiding in tumor detection. Because the metal degrades in this process, toxicity is minimized. *ncsu.edu, unc.edu*.

## ADJACENT FACTORIES TO PRODUCE CMC COMPONENTS

GE Aviation, Evendale, Ohio, will begin construction on two adjacent factories in Huntsville, Ala., to produce silicon carbide (SiC) ceramic fiber and unidirectional ceramic matrix composite (CMC) components used in jet engines and land-based gas turbines. One plant—the first of its kind in the U.S.—will make the SiC ceramic fiber, and the adjacent factory will apply proprietary coatings and form the fiber into a matrix, producing CMC tape. GE Aviation plans to use the tape in CMC shrouds for the LEAP engine's high-pressure turbine section. Additionally, GE Power and Water is testing CMC components as replacements for superalloys in large gas turbines. Ultra-lightweight CMCs have one-third the density of metal alloys, and are far more heat resistant, increasing engine efficiency. Production is slated to begin in 2018. *geaviation.com*.

# TESTING | CHARACTERIZATION


LIFT's latest project aims to reduce the cost of designing and testing titanium parts.

## LIFT ANNOUNCES TITANIUM PROJECT

The third technology project announced by LIFT (Lightweight Innovations for Tomorrow), Detroit, will focus on titanium, which has significant potential for expanded use in aircraft engines and other aerospace needs if new technologies can reduce the cost of designing and testing new parts. Lead partners on the project—GE Aviation and The Ohio State University—will initially focus on advancing computer analytics to better understand and predict the performance of titanium alloys.

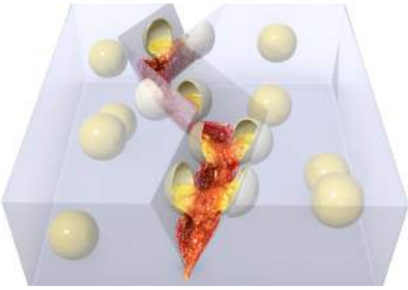
"Titanium is expensive, and engineers have to make and break a lot of test parts before they can be sure the design is right for a critical component of an airplane engine," says Alan Taub, LIFT's chief technology officer. "If we can advance the abilities of our computer models to better predict how a particular design will perform, we can test less. That cuts material and testing costs, and the lead time for developing new designs."

Boeing and Scientific Forming Technologies Corp. are the other industry partners on the project. In addition, EWI, Purdue University, Southwest Research Institute, University of Michigan, and the University of North Texas will contribute as research participants. This project differs from two earlier ones in its focus on integrated computational materials engineering (ICME) that could apply across several related manufacturing processes. "This project aims to develop computer models that will reduce by 50% both the time and cost for materials development, component design, and manufacture," says Taub. *www.lift.technology.*

## NEW SYSTEM INDICATES POLYMER DAMAGE

Researchers at University of Illinois at Urbana-Champaign developed a new polymer damage indication system that automatically highlights areas in a material that are cracked, scratched, or stressed, allowing engineers to address problem areas in a timely manner. The early warning system could be particularly useful in applications such as petroleum pipelines, air and space transport, and automobiles. Materials science and engineering professor Nancy Sottos and aerospace engineering professor Scott White are leading the project.

The team embedded tiny microcapsules of a pH-sensitive dye in an epoxy resin. If the polymer forms cracks


When cracks form, microbeads embedded in the material break open and cause a chemical reaction that highlights the damaged area. Courtesy of Nancy Sottos.

## BRIEFS

**Thermo Fisher Scientific Inc.,** Waltham, Mass., acquired **Inel Inc.,** France, a provider of real-time x-ray diffraction (XRD) systems. The business will be integrated into Thermo Fisher's analytical instruments segment. Inel offers a range of XRD equipment, from simple benchtop instruments to sophisticated platforms for analysis of nanomaterials, coatings, and other advanced materials. *thermofisher.com.*

**King Tester Corp.,** King of Prussia, Pa., now features the full range of Ernst hardness testers from **Ernst S.A.,** Switzerland. The two companies are offering testers previously sold by Newage Testing Instruments under trade names like Versitron and AutoBrinell. All products meet ASTM standards for hardness and King provides warranty and support throughout North America. *kingtester.com.*

or suffers a scratch, stress, or fracture, the capsules break open. The dye reacts with the epoxy, causing a dramatic color change from light yellow to bright red—with no additional chemicals or activators required. The deeper the scratch or crack, the more microcapsules are broken and the more intense the color. The team is now exploring further applications for the indicator system, such as applying it to fiber-reinforced composites, as well as integrating it with previous work in self-healing systems. *illinois.edu.*

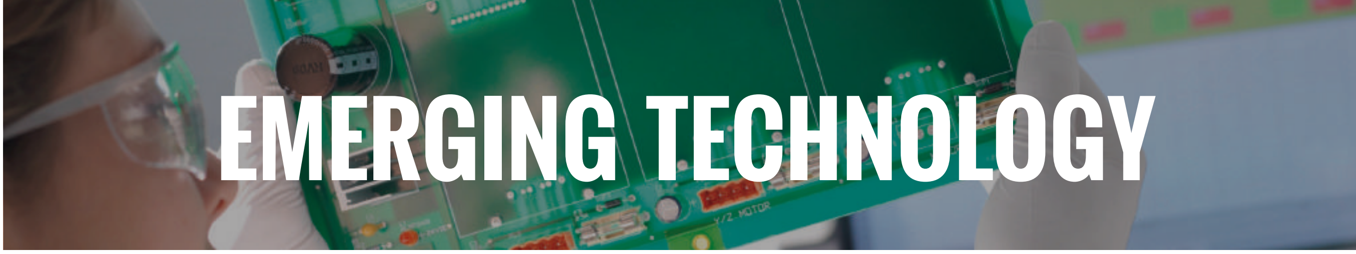
## FINAL MIRRORS INSTALLED ON JAMES WEBB SPACE TELESCOPE

In February, the 18th and final primary mirror segment was installed on the James Webb Space Telescope at NASA's Goddard Space Flight Center in Greenbelt, Md. Using a robotic arm, the team installed all of Webb's primary mirror segments onto the telescope structure. Each hexagonal-shaped segment measures just over 4.2 feet across and weighs approximately 88 pounds.

Inside a massive clean room at NASA's Goddard Space Flight Center, a robotic am is used to install the 18th mirror segment onto the Webb telescope structure. Courtesy of NASA/Chris Gunn.

Once in space and fully deployed, the segments will work together as one large 21.3-foot-diameter mirror.

Mirrors were built by Ball Aerospace & Technologies Corp., Boulder, Colo., the principal subcontractor to Northrop Grumman for the optical technology and optical system design. The new telescope is the scientific successor to NASA's Hubble Space Telescope and will be the most powerful space telescope ever built. Webb is targeted to launch from French Guiana aboard an Ariane 5 rocket in 2018. *nasa.gov.*



# EMERGING TECHNOLOGY

Alcoa's Micromill technology reduces the time to transform molten metal into aluminum coil from 20 days to 20 minutes.

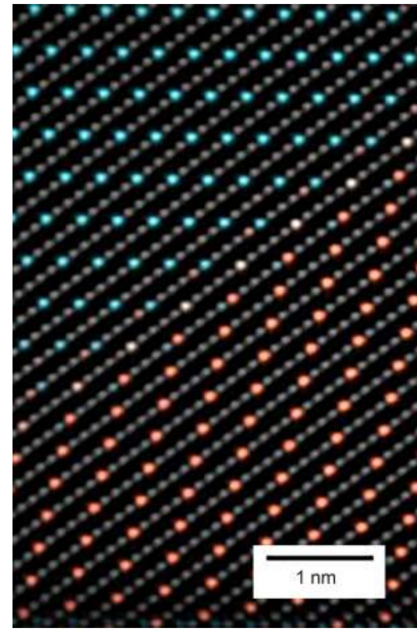
## FORD AND ALCOA DEVELOP NEXT-GEN ALUMINUM

Ford Motor Co., Dearborn, Mich., and Alcoa Inc., New York, are collaborating to produce next-generation automotive aluminum alloys that are more formable and design-friendly than previous versions. Ford will use Alcoa's Micromill material in multiple components on the 2016 F-150, becoming the first automaker to commercially use the advanced aluminum. Alcoa's Micromill technology produces an aluminum alloy that is 40% more formable than today's automotive aluminum. The increased formability makes it easier to shape into intricate forms, such as the inside panels of automobile doors and external fenders. Increased strength enables use of thinner aluminum sheet without compromising dent resistance. Micromill is reportedly the fastest, most productive aluminum casting and rolling system in the world combining multiple technologies into a streamlined production system. While a traditional rolling mill takes around 20 days to turn molten metal into coil, Micromill does it in 20 minutes.

Ford began using Micromill material in 2016 F-150 production in late 2015, and plans to increase its use over the next several years on a range of vehicle components and future platforms. By using the highly formable material, parts constructed of multiple pieces can be manufactured as a single part, reducing complexity and assembly time. Target applications include critical strength structural parts as well as exterior panels that must meet strict surface quality requirements. *corporate.ford.com, alcoa.com.*

## KECK FOUNDATION AWARDS $1 MILLION TO STUDY ANTI-THERMAL BEHAVIOR

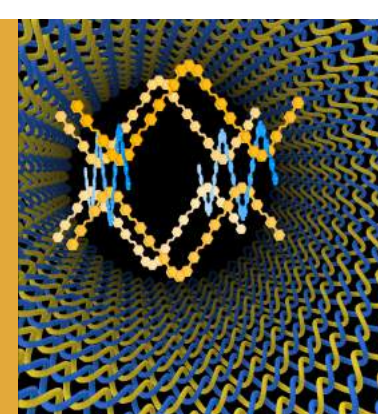
The W.M. Keck Foundation, Los Angeles, awarded a $1 million grant to Lehigh University, Bethlehem, Pa., to study the mechanisms that govern anti-thermal processes that appear to reverse nature. The work has potential to revolutionize the basic understanding of thermal processes and inform development of new materials that could withstand higher temperatures. A breakthrough in this area could lead to significant increases in engine efficiency, for example, saving billions of dollars in fuel costs, say researchers. The grant was awarded to principal investigator Martin Harmer, Alcoa Foundation Professor of Materials Science and Engineering. Harmer's collaborators are Elizabeth Holm and Gregory Rohrer, both professors of materials science and engineering at Carnegie Mellon University, Pittsburgh. *lehigh.edu.*



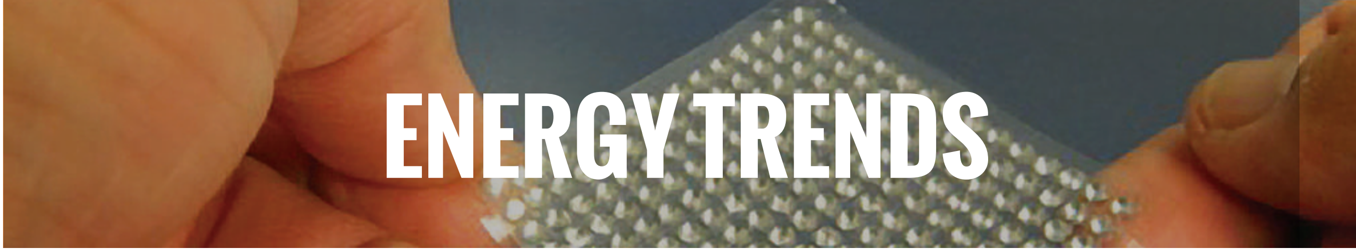

High magnification image shows how atoms are arranged on both sides of the twin boundary, represented by yellow atoms in the center. Courtesy of Martin Harmer and Christopher Marvel, Lehigh University.

## BRIEF

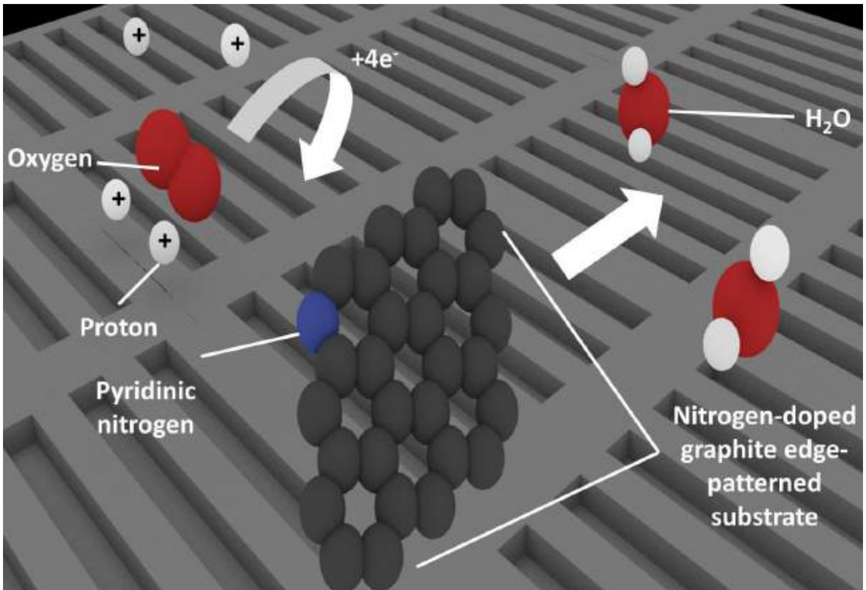
An international team led by scientists at the DOE's **Lawrence Berkeley National Laboratory** and the **University of California, Berkeley** reports weaving the first 3D covalent organic frameworks (COFs) from helical organic threads. The woven COFs display advantages in flexibility, resiliency, and reversibility over previous COFs—materials prized for their potential to capture and store $CO_2$ then convert it into valuable chemical products. *lbl.gov.*



COF-505 is the first 3D covalent organic framework to be made by weaving together helical organic threads.



# ENERGY TRENDS




Patterning nitrogen-doped graphite to create multiple edges increases the amount of pyridinic nitrogen present. Courtesy of University of Tsukuba.

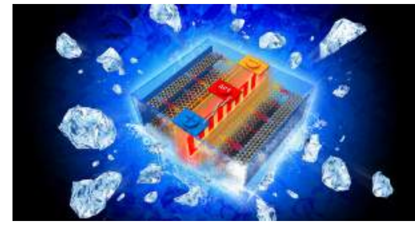
## CARBON-BASED CATALYST DECODED

Carbon-based catalysts with added nitrogen are among the most promising alternatives to the expensive precious metals currently used for oxygen reduction in fuel cells. A team of researchers from the University of Tsukuba, Japan, identified the arrangement of nitrogen and carbon that provides the catalytic effect in these materials, and proposed a mechanism by which the reaction works.

To determine whether the nitrogen in the carbon-based catalyst was pyridinic or graphitic—a question unanswered until now—the team fabricated four model catalyst substrates and analyzed their reaction performance. Because pyridinic nitrogen occurs mainly at the edges of the material, the team manipulated the number of edges on the samples to adjust these nitrogen levels, then measured how it affected catalytic performance. The results? Active catalytic sites were associated with pyridinic nitrogen. After learning that it was actually the carbon atom next to the nitrogen that was the active site rather than the nitrogen atom itself, investigators were able to hypothesize the various stages of the reaction mechanism. This will enable future research to focus on ratcheting up catalyst performance. *www.tsukuba.ac.jp/english.*

## BATTERY HEATS UP, DOESN'T POWER DOWN

Researchers at Pennsylvania State University, University Park, Pa., and EC Power, State College, Pa., developed a lithium-ion battery that self-heats if the temperature is below 32°F. The most



An all-climate battery that rapidly self-heats battery materials and electrochemical interfaces in cold environments. Courtesy of Chao-Yang Wang/Penn State.

significant impact of this technology could be reducing winter "range anxiety" for electric vehicle owners—one of the major barriers to large-scale adoption of all-electric cars.

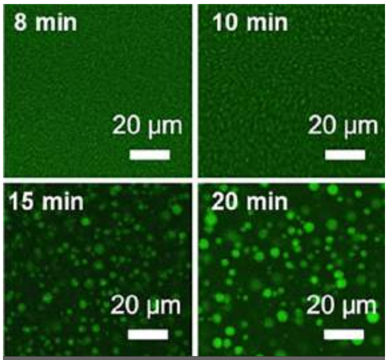
At below-freezing temperatures, conventional batteries suffer severe power loss, leading to slow charging, restricted regenerative breaking, and reduction of cruise range by as much as 40%. Larger battery packs, which could supply adequate power in the cold, are significantly heavier and more expensive. The all-climate battery, however, is designed to weigh only 1.5% more and cost just 0.04% of the base battery. It can heat from 22°F to 32°F in 30 seconds, consuming only 5.5% of the cell's capacity.

In the all-climate battery, one end of a 50-µm-thick nickel foil is attached to the negative terminal while the other end extends outside the cell, creating a third terminal. A temperature sensor attached to a switch causes electrons to flow through the nickel foil when it is cold, completing the circuit and rapidly warming the foil through resistance heating. Once the battery reaches 32°F, the switch turns off, and electric current flows normally. *psu.edu*.

## BRIEF

Scientists at the **Energy Department's National Renewable Energy Laboratory** (NREL) and the **Swiss Center for Electronics and Microtechnology** (CSEM) jointly set a new world record for converting non-concentrated sunlight into electricity using a dual-junction III-V/Si solar cell. The team achieved conversion efficiency of 29.8% by using a top cell made of gallium indium phosphide developed by NREL, and a bottom cell made of crystalline silicon developed by CSEM using silicon heterojunction technology. *nrel.gov, www.csem.ch.*

# SURFACE ENGINEERING




Harvard scientists created a new technology for fluid secretion and self-healing behavior. Courtesy of Jiaxi Cui and Joanna Aizenberg.

## SELF-HEALING SYSTEM USES SECRETION

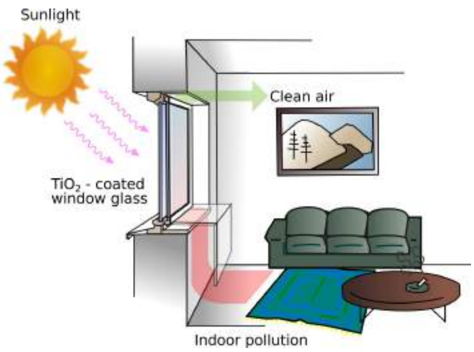
Researchers at Harvard University, Cambridge, Mass., developed a new system of material self-healing that uses a fluid secretion process inspired by biological wound healing. The system consists of liquid droplets inside a supramolecular polymer gel with a thin layer of liquid on its surface. When the surface liquid is removed or depleted, the droplets spontaneously release only enough fluid to replace what is lost on the surface. Current fluid secretion technologies generally use one-time-only release mechanisms where fluid continues flowing at a consistent rate until the supply is exhausted. Unlike these static models, the new system is out of equilibrium, like systems in nature, making it unstable enough to respond to its environment.

The supramolecular polymers are reversibly bonded to each other, meaning they can detach to allow liquid to filter through the matrix, then reattach and adapt to the shrinking liquid reserves. When the system is cut down the middle, the newly exposed polymer surface signals droplets to secrete liquid, quickly filling in the crack between the ends of broken polymers. Over time, polymer strands swim through the liquid and stitch themselves back together. The system even self-reports its liquid levels: As fluid is secreted, the gel becomes more and more transparent over time. *harvard.edu*.

## NANOSTRUCTURED COATINGS CLEAR THE AIR

Bozhidar Stefanov, a graduate student at Uppsala University, Sweden, developed an improved method for depositing nanostructured surface coatings onto window glass used to clean indoor air of organic pollutants. Through a process called photocatalysis, these titanium dioxide coatings absorb ultraviolet light from the sun and use that energy to destroy molecules of pollutants in the air when it is passed between two window panes. However, as pollutant decomposition products bind to the coating surface and block active sites, photocatalytic activity diminishes. To address this problem, Stefanov adapted the industrial process of magnetron sputtering to apply these coatings.

Only about 10% of the crystalline facets of titanium dioxide nanoparticles are significantly photocatalytic, so when nanoparticles are randomly deposited, it is unlikely that a large proportion of the film surface will be highly reactive. Stefanov's application process increases the probability that very reactive titanium dioxide facets are exposed. These preferentially oriented coatings exhibit higher activity against air pollution, and their activity is less dependent on external conditions such as humidity and temperature. *www.uu.se/en*.

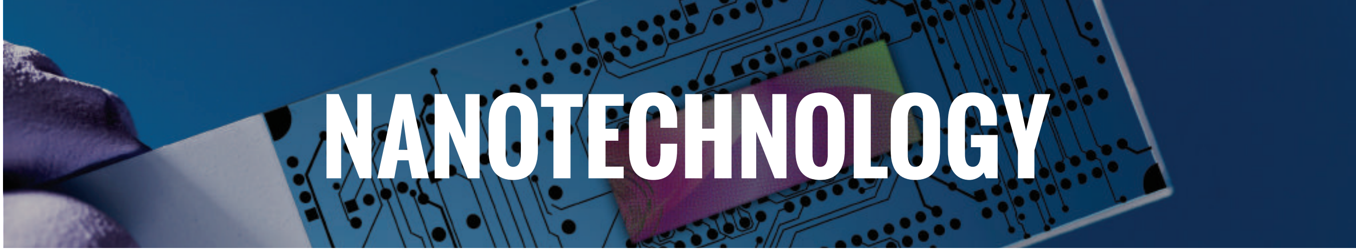



Window glass with a nanostructured coating based on titanium dioxide.

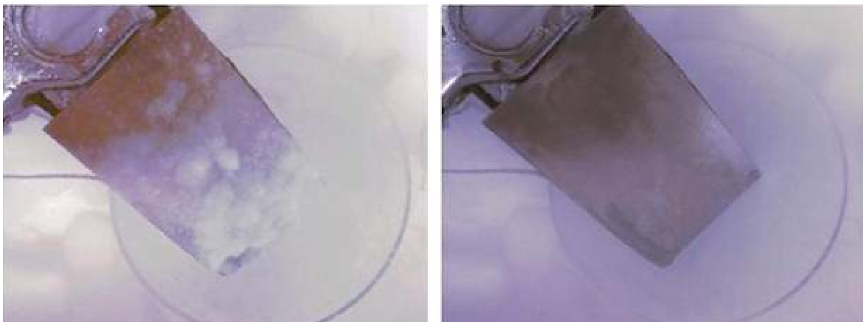
## BRIEFS

**GE Aviation,** Evendale, Ohio, and **Praxair Surface Technologies Inc.,** Indianapolis, formed a joint venture for the development, support, and application of specialized coatings. Formulas will be tailored to current and future engine models produced by GE Aviation and **CFM International,** Cincinnati, including the GE9X and LEAP engines. *ge.com/aviation*, *praxairsurfacetechnologies.com*.

**IHI Hauzer Techno Coating,** the Netherlands, acquired the intellectual property rights and trademarks for the Cromatipic ecological chroming system, formerly owned by **Sidasa Engineering,** Spain. Hauzer will supply consumables to all Cromatipic users. The chroming system is an environmentally friendly technology that can replace electroplating on various plastic substrates and aluminum alloys. *www.hauzer.nl*.



# NANOTECHNOLOGY



Graphene nanoribbon-infused epoxy embedded into a helicopter blade. Courtesy of the Tour group.

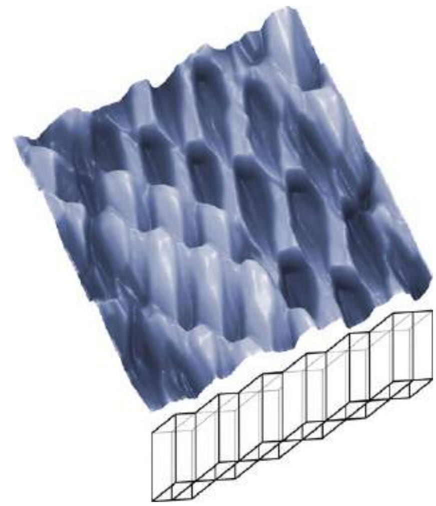
## NANORIBBON COMPOSITE MELTS ICE

Researchers at Rice University, Houston, developed a thin, conductive coating that can serve as a real-time de-icer for aircraft, transmission lines, and other surfaces exposed to winter weather. The coating consists of an epoxy laced with interconnected graphene nanoribbons that conduct electricity across the material, heating the surface and melting ice. The team spread a thin coat of the composite—consisting of no more than 5% nanoribbons—on part of a helicopter rotor blade, then replaced the thermally conductive nickel abrasion sleeve used as a leading edge. When a small voltage was applied, the coating delivered electrothermal heat, or Joule heating, raising the composite's temperature to more than 200°F. This was enough to melt 1-cm-thick ice on a static blade in a -4°F environment.

For surfaces in motion, the thin layer of water that forms on the surface after heating begins should be enough to loosen and dislodge ice before it is completely melted. "Applying this composite to wings could save time and money at airports where the glycol-based chemicals now used to de-ice aircraft are also an environmental concern," says chemist James Tour. Additionally, the coating could help protect aircraft from lightning strikes and provide an extra layer of electromagnetic shielding. *rice.edu.*

## NEW NANOSTRUCTURE DISCOVERED

A previously unknown, 3D nanostructure consisting of graphene sheets was discovered by a staff scientist at the Institute of Physical Problems, Russian Federation. The new nanostructure is a multilayer system of parallel hollow channels with a quadrangular cross section extending along the surface. Though this structure is unlike anything previously observed in graphite, the wall thickness of less than 1 nm and the quadrangular cross section of the channels clearly indicate that the channel walls/facets are graphene planes. It is hypothesized that the structure was formed from a series of mechanical deformations of graphite, which is layered by nature. Because the nanochannels have a quadrangular cross section, the newly detected structure is called *box-shaped graphene* (BSG). Preliminary analysis indicates that the nanostructure could be used in applications such as ultrasensitive detectors, high-performance catalytic cells, nanochannels of microfluidic devices, high-performance heat-sink surfaces, enhanced rechargeable batteries, and high-capacity sorbents for safe hydrogen storage. *www.niifp.ru.*



Box-shaped graphene—a 3D nanostructure consisting of graphene sheets. Courtesy of Rostislav Lapshin.

## BRIEF

**Defense Advanced Research Projects Agency** (DARPA), Arlington, Va., launched its *Atoms to Product* program to develop technologies and processes for assembling nanometer-scale pieces into systems, components, or materials that are at least millimeter-scale in size. DARPA recently selected 10 companies to tackle this challenge: Zyvex Labs, Richardson, Texas; SRI, Menlo Park, Calif.; Boston University; University of Notre Dame, South Bend, Ind.; HRL Laboratories, Malibu, Calif.; PARC, Palo Alto, Calif.; Embody, Norfolk, Va.; Voxtel, Beaverton, Ore.; Harvard University, Cambridge, Mass.; and Draper Laboratory, Cambridge, Mass. The program calls for closing the assembly gap in two steps—from atoms to microns and from microns to millimeters. *darpa.mil.*

# HIGH-TEMPERATURE ALUMINUM ALLOYS FOR AUTOMOTIVE POWERTRAINS

**Cast aluminum alloys were developed with high-temperature tensile and fatigue strengths to withstand elevated-temperature applications in modern engines.**

*Frank Czerwinski and Wojciech Kasprzak, CanmetMATERIALS, Natural Resources Canada, Hamilton, Ontario*

*Dimitry Sediako, Canadian Neutron Beam Centre, Canadian Nuclear Labs, Chalk River, Ontario*

*Darius Emadi, CanmetENERGY, Natural Resources Canada, Ottawa, Ontario*

*Sugrib Shaha, Jacob Friedman, and Daolun Chen,* Ryerson University, Toronto*

**Member of ASM International*

The use of aluminum alloys in automotive applications continues to grow because they offer an economically viable way to improve vehicle performance and efficiency, ensuring safety and durability, enhancing fuel consumption, and reducing harmful emissions. The U.S. Environmental Protection Agency and U.S. Department of Transportation issued 2017-2025 corporate average fuel economy (CAFE) targets for both passenger cars and light trucks calling for more than 50% improvement compared with current targets. Substantial improvements in fuel economy can be achieved by increasing engine performance and by replacing large engines with smaller ones in the same vehicle class. Smaller engines require lighter support, which means additional weight reduction. Computer simulations of a diesel engine show that a 60% increase in power and torque requires an increase in maximum cylinder-head pressure of 180 to 300 bar, an increase in peak temperature on the head combustion face of 215° to 275°C, and of 150° to 190°C on the water-jacket face[1]. These goals require significant technological changes in engine materials.

Cast aluminum alloys are attractive structural materials for a number of automotive applications including strategic powertrain components, such as engine blocks and cylinder heads, where permanent-mold casting and high-pressure die casting are cost-effective mass production methods (Fig. 1). The most versatile casting aluminum alloys are Al-Si alloys, accounting for the majority of automotive cast parts. The maximum operating temperature of 180°C for existing Al-Si casting grades (Al-Si-Cu and Al-Si-Mg) is too low for new combustion-engine designs, where an improvement in performance requires both increasing service temperature and internal pressure. This article describes research aimed at developing cast aluminum alloys with the necessary high-temperature tensile and fatigue strengths to withstand the modern automotive engine environment.

## INCREASING THERMAL STABILITY

The strengthening mechanism of current Al alloy grades becomes ineffective at the service temperature of new engine designs due to rapid coarsening and dissolution of their microstructure controlling phases. This requires modifying the base composition of aluminum alloys. Elements investigated for this purpose include Ni, Fe, Cr, Mn, Co, Zr, Gd, Hf, Y, Sc, Nb, and V. When alloyed with Al, some elements form incoherent dispersoids, such as in the Al-Fe-Ce, Al-Fe-V-Si, Al-Fe-Ce-W, and Al-Cr-Zr-Mn systems. Alloying Al with Sc forms coherent dispersoids, where their low fraction is effective in preserving high-temperature properties. Strengthening is also induced through incoherent oxide particles such as in Al-Mg and Al-Ti systems, but resulting alloys have low ductility and fracture toughness. For effective improvement of the high temperature performance of Al, alloying elements should[3]:

- Be capable of forming thermally stable strengthening phases
- Have low solid solubility in the Al matrix
- Have low diffusivity in the Al matrix
- Retain the ability for the alloy to be conventionally solidified

Transition metals, which form thermally stable and coarsening-resistant precipitates, are promising candidates to achieve this. Phase diagrams and crystallographic data indicate that some transition metals crystallize with Al to form stable $Al_3M$-trialuminides. Trialuminide intermetallic compounds ($Al_3X$) are good candidates for dispersoids and precipitates in high-temperature aluminum alloys. High symmetry cubic $L1_2$ and related tetragonal $D0_{22}$ and $D0_{23}$ structures are prevalent among some transition metals. This work focuses on Zr, V, and Ti combined with the Al-Si-Mg-Cu cast matrix[4-7].

The best results were generated for simultaneous micro-additions (0.1-0.5 wt%) of Zr, V, and Ti to the hypoeutectic Al-7Si-1Cu-0.5Mg (wt%) base. The alloy's chemical composition is listed in Table 1.

## ALLOYING IMPACT ON MICROSTRUCTURE

Al-Si-Cu-Mg base alloys have a complex microstructure consisting of a number of phases including dendritic α-Al, modified eutectic silicon, blocky-type copper base θ-$Al_2Cu$ phase, ternary eutectic Al-$Al_2Cu$-Si phase, Mg-rich Chinese script-like Q-phase $Al_5Cu_2Mg_8Si_6$, and Fe-rich needlelike π-phase $Al_8FeMg_3Si_6$[8]. Additions of transition metals make this microstructure much more complex (Fig. 2a). For example, the presence of Ti leads to an additional needlelike phase $(AlSi)_3Ti$, while additions of Ti and Zr form needlelike phase $(AlSi)_3(TiZr)$. The simultaneous presence of Zr-Ti-V leads to new unique $(AlSi)_x(TiVZr)$-type phases with $D0_{22}/D0_{23}$ tetragonal crystal structure and

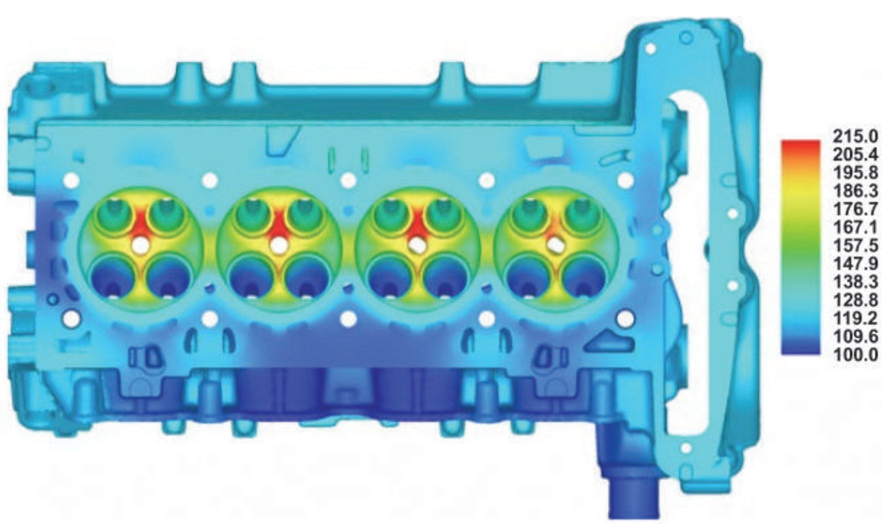



**Fig. 1 —** Modeled temperature distribution within a combustion engine[2].

**TABLE 1—CHEMICAL COMPOSTIONS OF COMMERCIAL A380 AND RESEARCH AL ALLOYS, WT%**

| Alloy | Si | Cu | Mg | Fe | Sr | Mn | Zr | Ti | V | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| New | 7.02 | 0.95 | 0.48 | 0.09 | 0.012 | 0.005 | 0.47 | 0.21 | 0.30 | Bal |
| A380 | 9.5 | 3.4 | 0.07 | 0.90 | <0.001 | 0.18 | 0.0073 | <0.001 | 0.0087 | Bal |

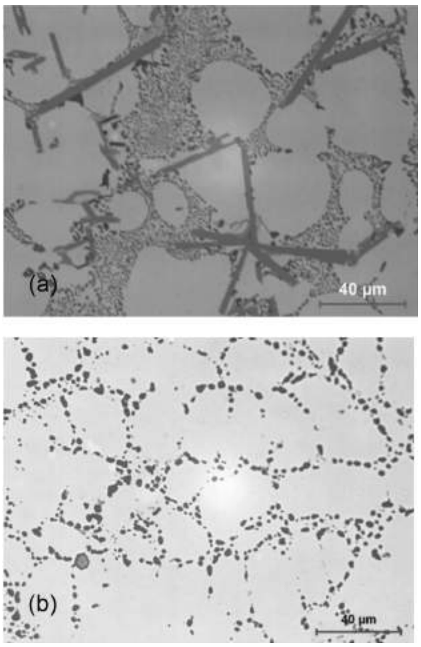



**Fig. 2 —** (a) As-cast microstructure of research alloy; (b) microstructure after T6 heat treatment. Chemical composition listed in Table 1.

different lattice parameters. They include $Al_{6.7}Si_{1.2}TiZr_{1.8}$, $Al_{21.4}Si_{4.1}Ti_{3.5}VZr_{3.9}$, and $Al_{2.8}Si_{3.8}V_{1.6}Zr$, which are designated in the literature as $(AlSi)_3(TiZr)$, $(AlSi)_3(TiVZr)$, and $(AlSi)_2(VZr)$, respectively.

Another positive modification of the alloy microstructure occurs in the Fe-containing β-$Al_5FeSi$ phase, which is generally needlelike in shape and detrimental for alloy strength and ductility. As a result of alloying with Zr-Ti-V, the Fe-containing β-$Al_5FeSi$ phase converts into the $Al_{5.1}Si_{35.4}Ti_{1.6}Zr_{5.7}Fe$ phase with a general formula of $(AlSi)_2(TiZr)Fe$. Zr always forms complex intermetallics. The intermetallic phases are distributed most often in interdendritic regions.

## TESTING HIGH-TEMPERATURE PERFORMANCE

To test high-temperature performance, alloys were subjected to various heating cycles. Test results were compared with properties of commercial A380 alloy, currently the industry choice for targeted automotive applications. As-cast hardness of A380 alloy (83 HRF) was over 10 units higher than that of the research alloy. Results of isochronal aging at temperatures up to 500°C show that the research alloy achieved peak aging hardness at approximately 200°C, and a hardness difference existed at the peak between the research alloy and A380 grade[9]. For temperatures up to 150°C, A380 experienced a hardness reduction compared with an increase for the research alloy.

Temperatures of phase stability were identified using electron microscopy, electron backscatter diffraction, and high-temperature x-ray diffraction. During the solutionizing step of the T6 heat treatment at 510°C followed by 525°C, the research alloy primarily experienced dissolution of Cu-containing phases (Fig. 2b). Some other phases including eutectic silicon experienced only partial dissolution. Some phases were not affected by the solutionizing temperature, indicating their high stability. In-situ x-ray diffraction of bulk material at room and elevated temperatures is useful to directly test alloy phase stability. For the research alloy, increasing the temperature from 200° to 400°C led to dissolution of the Si eutectics in the Al matrix. Also, $Al_2Cu$ and Q phases dissolved with increasing temperature from 300° to 500°C, and were not detected by x-ray above 500°C. In contrast, phases containing transition metals V, Ti, and Zr remained present up to temperatures between 695° and 705°C, i.e., after reaching liquid state, indicating their high stability.

## STATIC MECHANICAL PROPERTIES

Microstructural modifications through alloying additions affect work hardening and texture, tensile and compressive deformation behavior, hot deformation, and movement of dislocations during deformation at increasing temperatures. In automotive engine applications, Al alloys are subjected to complex stress scenarios. The component typically undergoes compression during heating and is under tension during subsequent cooling. Therefore, hot tensile and compressive behavior are relevant for good material performance.

The as-cast research alloy had a yield strength (YS) of 162 MPa, an ultimate tensile strength (UTS) of 252 MPa, and an elongation of 3.9% in monotonic loading at room temperature. Properties improved substantially after the T6 heat treatment, resulting in 287 MPa YS, 343 MPa UTS, but lower elongation of 2.6% (Fig. 3a). Compression properties were 312 MPa YS, compressive strength of 418 MPa, and a compressibility value of 52.2% (Fig. 3b). It was established during compression experiments that decreasing deformation temperature in the range of 200° to 400°C, and to a lesser extent increasing the strain rate in the range of $10^{-3}$ – 1 $s^{-1}$, led to higher flow stress.

During hot compression deformation, fracturing and reorientation of the second phase particles occur, and both phenomena are influenced by temperature and strain rate. For both the research and A380 alloys, intermetallic precipitates experience substantially more frequent cracking than the eutectic silicon. Although second phase particles in both alloys have a similar morphology, there is a difference in their performance during hot compression. In the research alloy, eutectic silicon and intermetallics were more resistant and experienced less frequent fracturing. Also, both the eutectic silicon and intermetallic particles of complex chemistry are more resistant to rotation within the matrix during hot deformation.

## CREEP PROPERTIES

Creep-rupture tests provide relevant information when considering

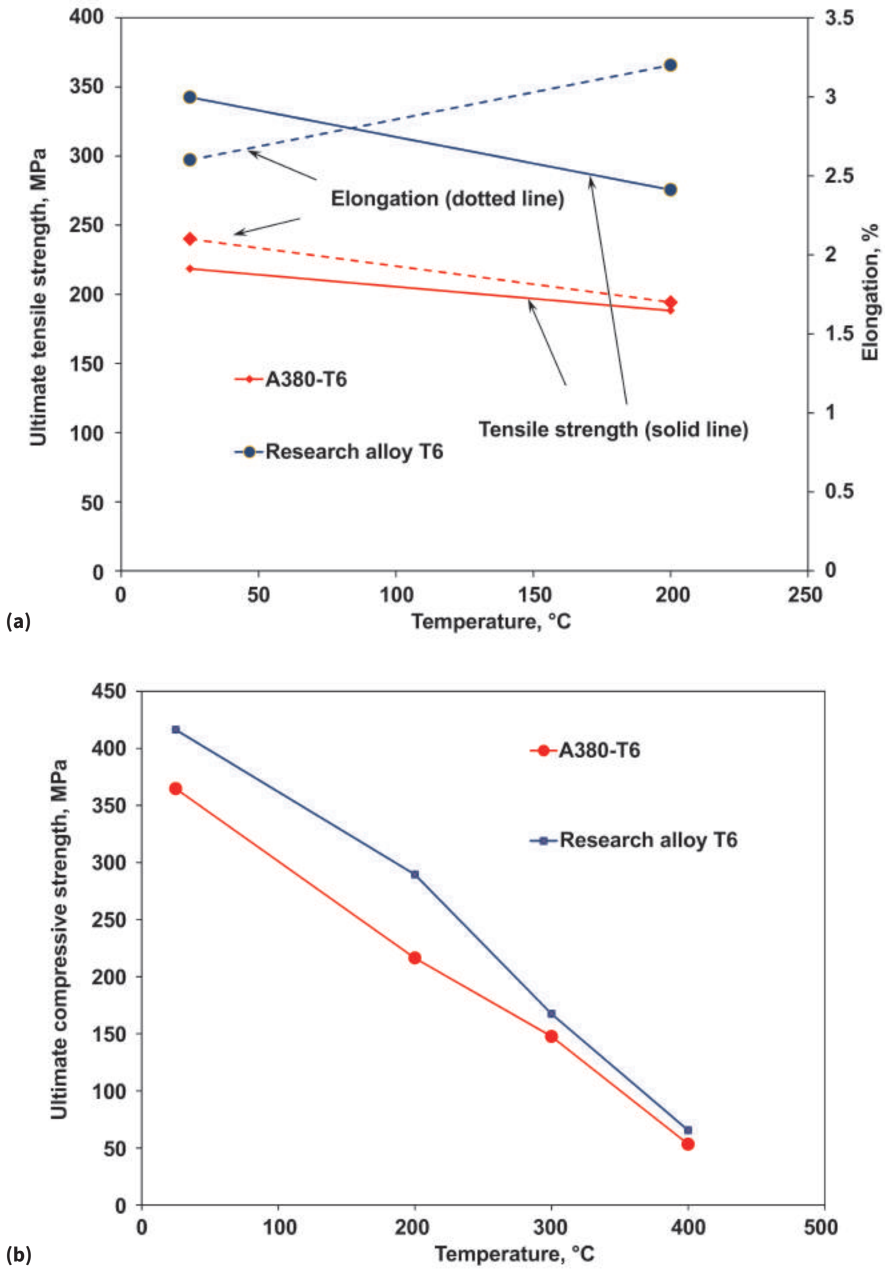



**Fig. 3 —** (a) Ultimate tensile strength and (b) compressive strength of research and A380 alloys after T6 heat treatment tested at room and elevated temperatures.

durability of materials for use in powertrain applications. Creep deformation is slow, continuous, and time dependent. In contrast to elastic/plastic deformation where strain is mainly a function of stress and temperature, creep strain is a function of time as well. In-situ neutron diffraction was used for an in-depth analysis of creep evolution in the alloys under elevated temperatures of 200° and 250°C[10]. The focus of this experimental research includes elastic and plastic tensile creep properties near the yield strength of the material, typical in automotive powertrain applications. Test data enabled defining creep mechanisms characteristic for each stage of incremental loading. The research alloy exhibited considerable improvement in creep resistance over that of A380 grade at 200° and 250°C in terms of ultimate strength and total (plastic and elastic) creep. The improvement was explained by profiles of elastic microstrains, which indicate that additional crystallographic planes were activated in supporting the applied load.

Test results showed that the main mechanism is dislocation creep, which initiates at the lower load setting associated with power law-governed creep. The creep mode shifted to the power-law breakdown as the applied load was incrementally increased; this was dominant for most testing conditions. Crystallographic planes (111) and (311) were typically the main planes that supported most of the applied load during testing of both alloys. Activation of the additional crystallographic planes, such as (200) and (220) in the research alloy to support the load at the higher load settings and at the higher temperature of 250°C was due to accumulation of dislocations through the loading stages and by thermal activation.

## FATIGUE BEHAVIOR

The failure mechanism in automotive powertrain components subjected to high pressure, changing high loads, and thermal gradient is often fatigue related. Load cycling between low and high stress leads to a shorter lifetime than a static load at high stress. Fatigue is of special importance for cast alloys due to a variety of casting defects, which serve as sources of crack initiation. Combined analysis of creep and fatigue provides valuable input into the alloy performance. The response of cyclic stress amplitude as a function of the number of cycles at different strain amplitudes was measured for the research alloy. Fatigue life decreased and stress amplitude increased with increasing strain amplitude for the T6 temper condition. At lower total strain amplitudes in the range of 0.1-0.2%, cyclic stress amplitude remained essentially constant throughout the entire fatigue life. At higher total strain amplitudes in the range of 0.4-0.6%, cyclic hardening occurred from the beginning and continued to failure for the T6 tempered samples as cyclic deformation progressed[11].

Fatigue lifetime S-N curves for both alloys in the T6 tempered condition are shown in Fig. 4[6]. Fatigue life increased with decreasing total strain amplitudes for all alloys, and fatigue life of the research alloy is significantly longer at all levels of total strain amplitudes. According to the testing regime, if alloy

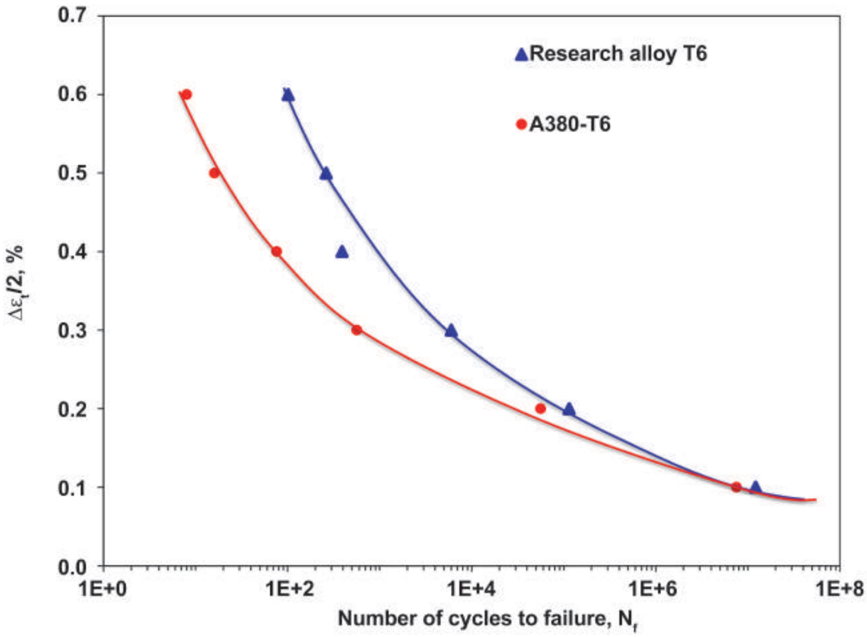



**Fig. 4 —** Fatigue life of research and A380 alloys after T6 heat treatment.

fatigue life reaches $10^7$ cycles without failure, the alloy passes the fatigue test. Therefore, the research alloy passed the fatigue test at a strain amplitude of 0.1%. Figure 5 shows that the improved fatigue resistance exhibited by the new alloy at higher amplitudes was mainly attributed to the composite-like strengthening and precipitation strengthening by trialuminide phases created as a result of Zr-V-Ti additions.

## SUMMARY

CanmetMATERIALS developed a new Al cast alloy for high-temperature applications. Micro-additions of Ti, V, and Zr to the Al-7Si-1Cu-0.5Mg cast alloy led to formation of $(AlSi)_x(TiVZr)$ phases that increase stability at high temperatures, positively affecting alloy strength. The improvement in tensile and compressive strength is preserved to temperatures over 200°C, with a more positive effect in the T6 condition. Moreover, creep rapture strength is higher, and fatigue life of the new alloy at strain amplitudes exceeding 0.1% is substantially longer than that of A380 reference grade. **~AM&P**

**For more information:** Frank Czerwinski is group leader, senior research scientist, CanmetMATERIALS, 183 Longwood Rd. South, Room 259C, Hamilton, Ontario L8P 0A5 Canada, 905.645.0887, frank.czerwinski@canada.ca, www.canmetmaterials.nrcan.gc.ca.

**Acknowledgments**

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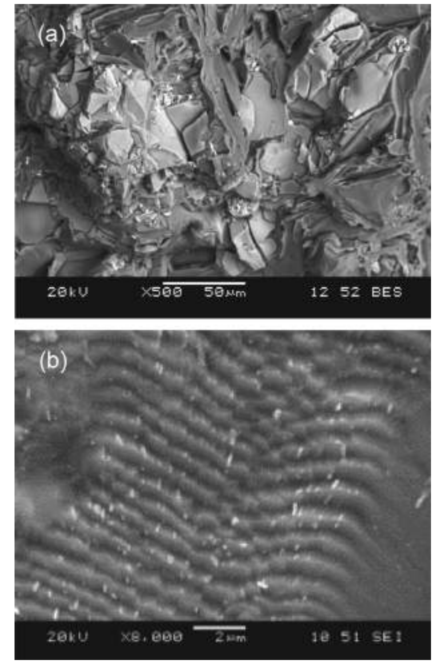


**Fig. 5 —** Effect of alloying on fracture mechanism during cyclic loading: (a) Brittle fracture of particles in alloy without Zr, V, and Ti additions; (b) fracture propagation path shows ductile nature of particles in alloy modified with additions of Ti-V and Zr, which lead to improved fatigue life.

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TECHNICAL SPOTLIGHT

# MECHANICAL TESTING OF AUTOMOTIVE COMPOSITES

## Successful use of composite materials requires a thorough understanding of their mechanical properties.

Automotive manufacturers are employing a wide range of new materials to decrease the weight of their vehicles and reduce emissions. These materials include new, high-strength steel and aluminum alloys, and a huge range of plastics and composites. Of these materials, continuous carbon fiber polymer composites offer the greatest potential for lightweight structures, yet many barriers inhibit their widespread adoption. Currently, the cost and process times of composite parts are significantly higher than traditional metals. This is being addressed by the development of new matrix materials and manufacturing processes. Recycling of composite materials is being investigated and progress is being made with new thermoplastic matrix composite materials, which are easier to recycle than thermoset matrix materials. Finally, the unique nature of composite materials presents designers and engineers with new challenges, and the successful use of composite materials requires a thorough understanding of their mechanical properties.

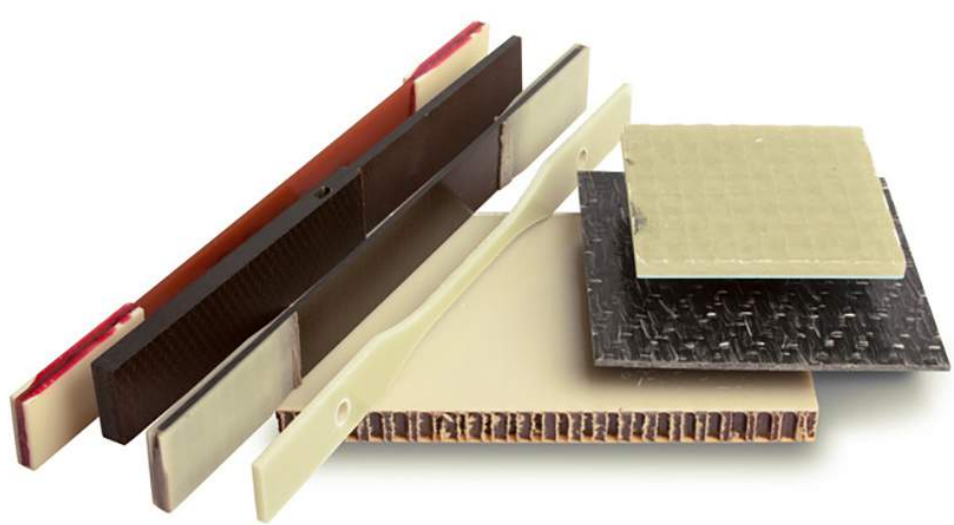
## MECHANICAL PROPERTIES AND TESTING

The properties of most metals and plastics are more or less isotropic (i.e., independent of direction) and homogenous (i.e., they consist of a single uniform phase). Consequently, their mechanical properties can be described by a small number of material constants obtained from a simple tensile test. In contrast, describing the properties of anisotropic and inhomogeneous composite materials requires many more material constants obtained from a range of mechanical tests. For example, determining the static bulk properties of composite materials requires tension, compression, and shear tests. Other tests are used to characterize properties related to inhomogeneity, such as interlaminar fracture toughness, which measures resistance to delamination. Creep and fatigue testing is needed to predict the long-term durability of a material in service. It is often necessary to understand how the material behaves under high rates of strain—conditions that would be encountered in a crash. Further, tests generally need to be conducted over a range of temperatures and other environmental conditions.

## TEST TYPES

Determining the static bulk properties of a composite laminate requires tension, compression, shear, and flex tests. In most cases, the properties of interest are *in-plane* properties (in the direction of the plane), but in some cases the *through-thickness* properties (in a direction normal to the plane of the laminate) are also required.

In-plane tension testing of composite laminates is similar, in principle, to a traditional metals or plastics tension test. The test specimen is usually a rectangular coupon cut from a laminate panel in a specific direction relative to the fiber direction, such as specimens cut from a unidirectional laminate panel at 0° and 90° orientations to the fiber direction. Specimens are usually provided with bonded tabs to prevent the grip jaws from damaging the composite and causing premature failures. Through-thickness tension testing on thin laminates can be performed, indirectly, by subjecting a curved laminate beam to a four-point bending test. This



Typical composite test specimens.

results in a through-thickness tensile stress in the curved section. On thicker laminates it may be possible to perform direct tension tests on cylindrical specimens cut from the laminate.

In-plane composite compression test methods provide a means of introducing a compressive load into the specimen and preventing buckling of the specimen under the compressive load. Three methods of introducing a compressive load into a test specimen include:

1. End loading: The load is introduced by pushing on the flat end of the specimen.
2. Shear loading: The load is introduced into the wide faces of the specimen.
3. Combined loading: A mix of shear and end loading.

Two approaches are applied to prevent buckling of test specimens, using a test specimen with a short unsupported gauge length and using a lateral support along the specimen length. There are several different compression test methods and associated fixtures in widespread use that employ different methods of load introduction and anti-buckling. All composite compression fixtures are required to have excellent axial alignment and high lateral stiffness in order to prevent the large lateral loads that can be generated during the test and cause specimen bending. Most compression test methods require specimen bending to be monitored and set a limit for maximum allowable bending during a test.

Shear properties for design databases are generally determined using a V-notch specimen subjected to shear loading across the V-notch using either ASTM D5379 (Iosipescu) or ASTM D7078 test fixtures. Specimen preparation and testing for V-notch shear tests is complex and there are simpler shear tests that are suitable for comparative testing, screening, and quality control (QC).


Instron's electromechanical machine is capable of performing a variety of composite tests over a range of temperatures.

ASTM D7078 V-notched shear specimen and test fixture.

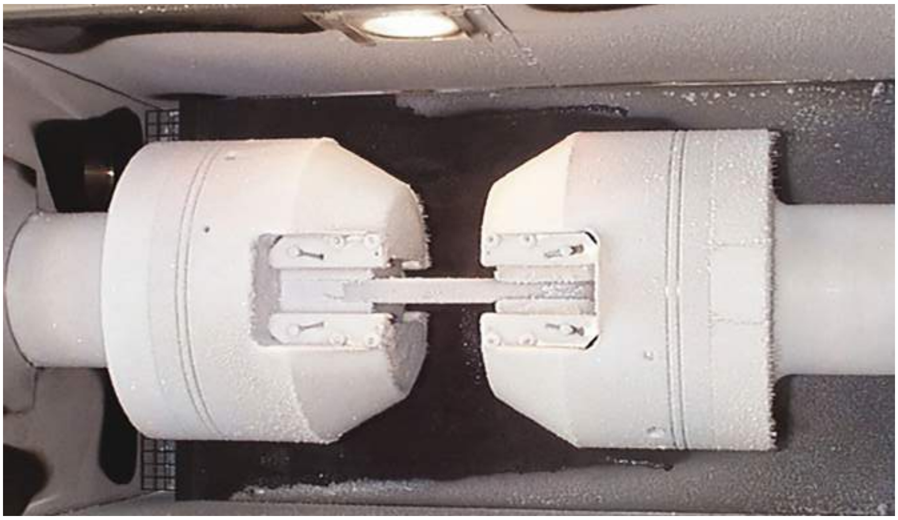
The in-plane shear (IPS) test is a tension test on a specimen cut from a laminate panel containing only 0° and 90° fiber directions so that the fiber directions are ±45° to the specimen axis. This test enables shear modulus and shear strength to be determined. The interlaminar shear strength (ILSS) test is a widely used QC test. This method subjects a small, simple, rectangular specimen to three-point bending. This configuration results in large shear stresses along the mid-plane of the specimen, resulting in shear failure.

Flexure testing is also used to determine a number of composite material properties. Compared to other test methods, flex testing has the advantage of requiring simple rectangular specimens without tabs or complex machining.

In addition to tests designed to determine the bulk properties of composites, a number of tests have been developed to determine the interlaminar properties (e.g., delamination) of composite laminates. Examples of such tests include *double cantilever beam (DCB) - Mode I fracture testing* and *end notched flexure (ENF) - Mode II fracture testing,* which enable determination of fracture toughness parameters.

Fatigue testing of composite materials is generally performed using tension-tension cyclic loading of rectangular specimens. Typically, a number of cyclic tests are performed at various stress amplitudes in order to produce an S-N curve that plots the stress amplitude against the number of cycles to failure. Fatigue testing of composites is time consuming because the test frequency must be limited to prevent the specimen from overheating. Fatigue loading cycles, which include compression loading, are not common due to the difficulty of preventing specimen buckling.

High-rate testing of composite materials is required to predict their behavior in the event of a crash. Common examples of high-rate testing of composite materials include impact testing and high-rate tension/compression testing. In a high-rate impact test, a composite panel or part is subject to an impact from a drop weight



Low-temperature testing in an environmental chamber.

or hydraulically driven indenter. After impact, damage is evaluated by either visual or ultrasonic inspection and/or determination of residual strength in a compression after impact (CAI) test. In a CAI test, an impact-damaged composite panel is mounted in a support to prevent buckling and loaded in compression until it fails. High-rate tension or compression testing can be performed either using a drop tower with a high-speed force sensor or with a high-rate servohydraulic testing machine. The servohydraulic machine provides a more flexible platform for this type of work. For example, it can test over a wider speed range and can maintain a constant speed during the test.

## CONDITIONING AND TEST ENVIRONMENTS

The properties of polymer matrix composites are influenced by environmental conditions. The most common environmental factors include temperature and humidity. Testing over a range of temperatures is normally conducted inside a temperature chamber with heating and cooling capability. Evaluating the effects of humidity requires long-term exposure of test specimens to a humid atmosphere in a humidity chamber (a process known as conditioning), followed by testing. The process of absorbing and desorbing moisture is slow, so there is no need to conduct the final testing in a humid atmosphere.

## TEST STANDARDS

The main international composite testing standards are those maintained by ASTM, ISO, and CEN (European Committee for Standardization). In addition to international standards, a number of manufacturers' proprietary standards are in widespread use including the BSS series from Boeing and the AITM series from Airbus. Finally, some obsolete standards are still in use, such as those published by the Suppliers of Advanced Composite Materials Association (SACMA) and the Composites Research Advisory Group (CRAG).

## CONCLUSION

Composite materials offer great potential for future generations of lightweight, environmentally friendly vehicles. These materials are complex and comprehensive data is needed for design and modeling. Although a range of mechanical tests is required to obtain data, the aerospace industry has already developed, validated, and standardized these test methods—and the automotive industry can benefit from this effort. **~AM&P**

**For more information:** Ian McEnteggart is composites marketing manager, Instron, 825 University Ave., Norwood, MA 02062, ian_mcenteggart@instron.com, www.instron.com.

# DISCOVERY OF Q-PHASES AND DIRECT CONVERSION OF CARBON INTO DIAMOND AND h-BN INTO c-BN

## The discovery of new phases of carbon and direct conversion of carbon into diamond and diamond-like materials—at ambient conditions and without a catalyst—is a breakthrough with tremendous potential for electronics and hard-materials applications.

*Jagdish Narayan,* FASM, Anagh Bhaumik, and Roger Narayan,* FASM*
*Department of Materials Science and Engineering*
*North Carolina State University, Raleigh*

Because graphite is the stable form of carbon, its conversion to diamond at ambient pressures and temperatures goes against equilibrium thermodynamics and the carbon phase diagram. The phase diagram shows this can be done only at very high pressures and temperatures (>120,000 atm and 5000K), which is expensive and energy intensive with limited throughput. Carbon to diamond conversion at ambient pressures and lower temperatures is scientifically challenging with immense technological significance[1-4]. Conversion of carbon into diamond has been a scientific quest for many years. Diamond is a highly desirable material with applications ranging from abrasives, protective coatings, and biomedical uses to electronics, photonics, and display devices.

Conventional bulk processing involves high pressures and temperatures[1], and chemical vapor deposition (CVD) of thin films requires high temperatures in the presence of hydrogen[5], requirements that lead to low production volumes and high costs. Formation of nanodiamond from silicon carbide (SiC) has been reported at temperatures of ~1000°C under flowing hydrogen and chlorine gases at ambient pressure[6]. According to the equilibrium phase diagram (Fig. 1), graphite, diamond, liquid, and vapor are thermodynamically stable forms of carbon[1]. At low pressures, graphite converts directly into vapor above a temperature of roughly 4000K. Diamond synthesis from liquid carbon requires even higher temperatures and pressures, as the graphite/diamond/liquid carbon triple point occurs at 5000K/12 GPa, where 1 GPa = 9869 atm.

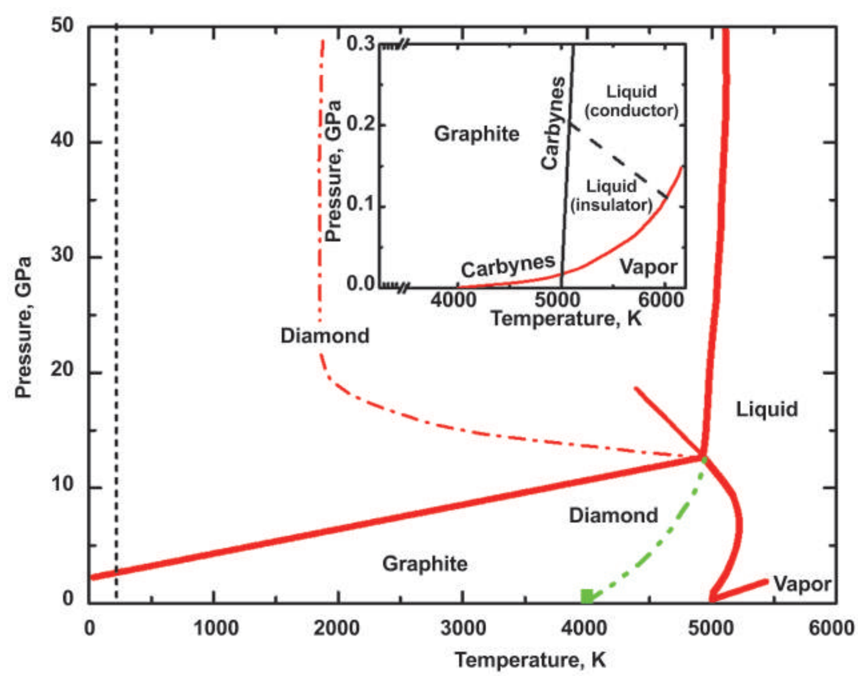



**Fig. 1** — Carbon phase diagram in which amorphous diamond-like carbon melting is introduced at 4000K at ambient pressures (dotted green line)[1].

*Member of ASM International

Diamond can exist in the interiors of the outer planets (Uranus and Neptune) and Earth's mantle, consistent with the phase diagram, where pressure/temperature are 600 GPa/7000K and 135 GPa/3500K, respectively. Currently, diamond powders are synthesized by graphite to diamond conversion at high pressures and temperatures. Graphite is transformed into diamond at temperatures above about 2000K at 6-10 GPa using a liquid metal (iron) catalyst, a process used for commercial synthesis of diamond[1] (Fig. 1). Due to the high binding and activation energies of transformation, carbon polymorphs exist metastably well into a pressure-temperature region where a different phase is thermodynamically stable. For example, diamond survives indefinitely at room temperature, where graphite is the stable form.

This article discusses the discovery of the direct conversion of carbon into diamond at atmospheric pressure and ambient temperature in air[3-4]. The transformative attributes of the discovery enhance diamond yield and reduce manufacturing costs. Thermodynamic limits are bypassed with the help of kinetics to create novel carbon-based structures with exciting new properties. Rapid melting using nanosecond laser pulses enables modification of the equilibrium thermodynamic (P vs. T) phase diagram. Super-undercooled states of molten carbon and BN are created, which are quenched to form novel phases (Q-carbon and Q-boron nitride, or Q-BN) from which different diamond and cubic boron nitride (c-BN) structures are formed. The entire process is completed in less than a millionth of a second, and the process can be repeated 10 to 200 times per second.

The critical breakthrough is that synthesis and processing are done in a liquid phase, where diffusivities are on the order of $10^{-4}$ $cm^2/s^{-1}$, some eight orders of magnitude faster than the highest solid state diffusivities. This research focuses on synthesis and scale-up processing of nanodiamonds (1-100 nm of uniform size), microdiamonds (100-500 nm), and microneedles (>2000 nm), as well as large-area single-crystal thin films on practical sapphire and glass substrates, from which diamond and related c-BN are harvested and substrates recycled. The discovery provides an inexpensive way to convert carbon into diamond and hexagonal boron nitride (h-BN) into c-BN and harvest them conveniently for a variety of applications.

## RESULTS AND DISCUSSION

The atomic structure of carbon atoms consists of six electrons ($1s^2 2s^2 2p^2$) whose charge is balanced by six protons in the nucleus, which also has six neutrons. Mixing wave functions of the outer four electrons ($2s^2 2p^2$) determines bonding characteristics in the crystalline phase. The $sp^2$ hybridization leads to formation of graphite bonding within the sheets, and the extra 2s electron provides for the delocalization of electrons and metallic behavior. The $sp^3$ hybridization, by comparison, leads to the formation of diamond semiconductor with a bandgap of 5.52 eV. Thus, transformation of graphite to diamond requires controlled mixing of the outer four electrons, which has been attempted electronically using high-power photon (laser) beams during laser ablation of graphite. Resulting diamond-like carbon films have a very high fraction of local $sp^3$ bonding in the amorphous phase, but diamond phase formation with long-range $sp^3$ bonding occurs only occasionally. However, providing diamond seeds enables growing the diamond phase on the seeds. In this transformative approach, the $2s^2$ and $2p^2$ electrons are mixed thermally. Melting rapidly creates metallic super-undercooled carbon with delocalized electrons, and quenching achieves short-range $sp^3$ bonding in Q-carbon and long-range $sp^3$ bonding in diamond, which can be nucleated from the Q-carbon, or grown on a template directly from the super-undercooled carbon.

Amorphous metastable diamond-like carbon with some $sp^3$ content and super-undercooled liquid carbon are introduced into the thermodynamically stable forms of carbon, graphite, diamond, liquid, and vapor[1] (Fig. 1). This is accomplished by nanosecond laser melting of diamond-like carbon, where the undercooled state is at a temperature around 4000K, about 1000K lower than the melting point of graphite. Quenching the super-undercooled liquid forms Q-carbon, nanodiamond, and microdiamond by controlling nucleation and growth times. Providing a growth template enables growing large-area single-crystal thin films through the paradigm of domain matching epitaxy[7]. The new state of carbon (Q-carbon) has a very high fraction of $sp^3$ bonded carbon and the rest $sp^2$, and is expected to exhibit novel physical, chemical, mechanical, and catalytic properties. There is more than a 10% reduction in volume when as-deposited amorphous carbon is melted in the undercooled state and quenched as Q-carbon. The Q-carbon exhibits unique properties including ferromagnetism at room temperature and above. Formation of the cubic diamond phase can occur if sufficient time is allowed for homogeneous nucleation, or when substrates that are lattice and planar matched with cubic diamond are provided during nucleation[2-4].

The primary focus of this work is on synthesis and processing of nanodiamonds, microdiamonds, and microneedles, as well as large-area single-crystal thin films at ambient pressure and atmospheric pressure in air. This is achieved by nanosecond laser melting of diamond-like amorphous carbon films on practical sapphire and glass substrates. Irradiation with ArF Excimer laser pulses (193 nm wavelength or photon energy of 6 eV and pulse duration of 20 ns) confines laser energy and selectively melts diamond-like carbon films. Undercooling values for amorphous diamond-like carbon are considerably higher than those achieved during melting of crystalline carbon, such as highly oriented pyrolytic graphite (HOPG) samples, which do not yield diamond[8-9]. Nanosecond pulsed laser melting of amorphous carbon leads to a highly undercooled state, which can be

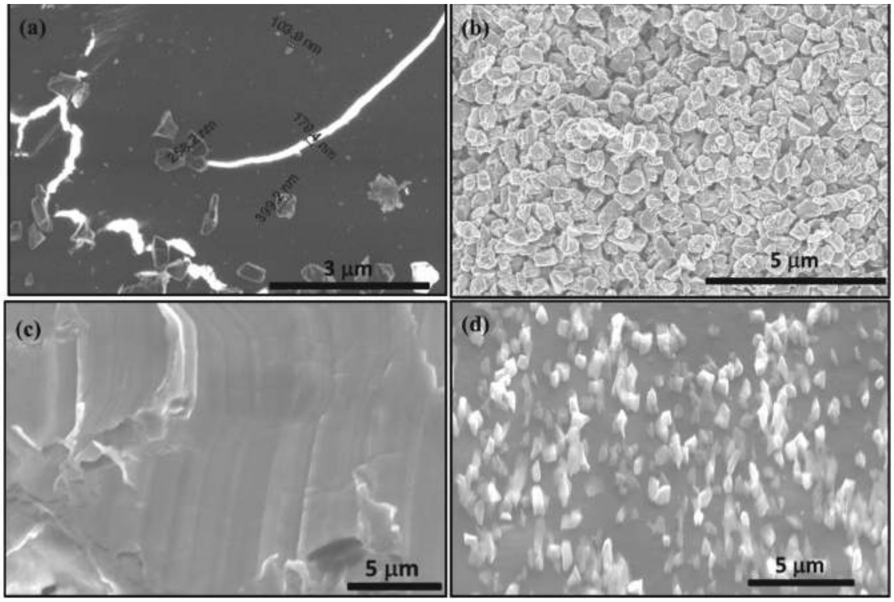



**Fig. 2 —** SEM micrographs: (a) nucleation of microdiamond from the Q-carbon (mechanism of carbon into diamond conversion), (b) mixture of nanodiamond and microdiamond, (c) entire area covered with microdiamond, and (d) diamond nanoneedles and microneedles.

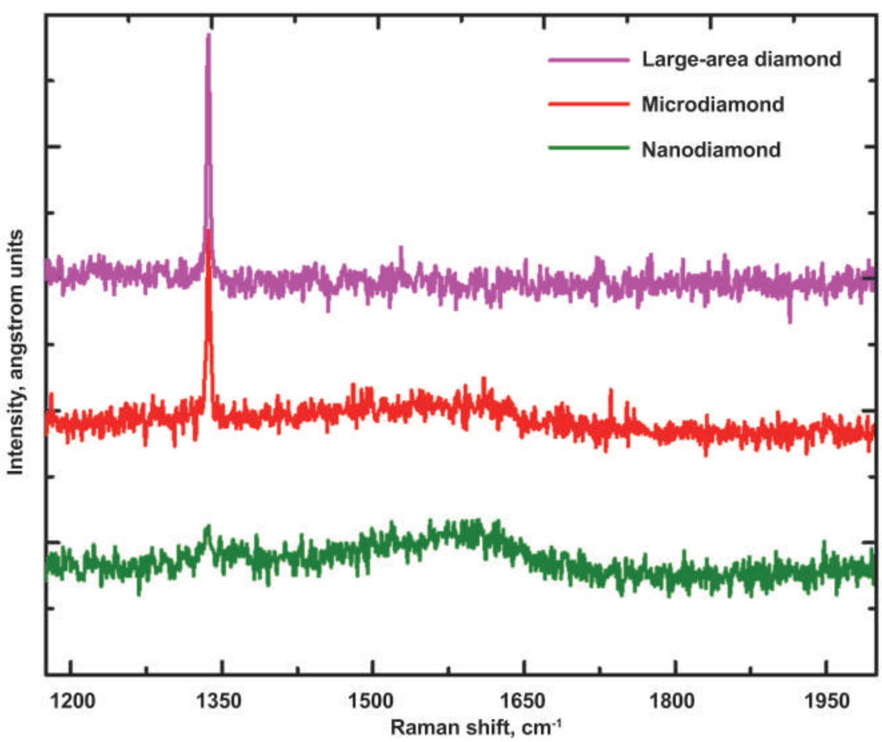



**Fig. 3 —** Raman spectroscopy of nanodiamond, microdiamond, and large-area thin films using 633 nm laser excitation wavelength.

quenched into a new state of Q-carbon from which nanodiamonds, microdiamonds, and microneedles are formed. The structures obtained from practical, inexpensive sapphire and glass substrates are conveniently harvested and substrates recycled, thus reducing the carbon footprint and creating very useful products for mankind.

Q-carbon serves as a mother source for diamond nucleation and growth. Figure 2a shows the formation of Q-carbon and growth of microdiamond from it after irradiation with a single laser pulse. The Q-carbon exhibits a bright contrast under secondary electron imaging in a scanning electron microscope. Kelvin probe force microscopy (KPFM) was used to measure surface potential on the Q-carbon filaments, which were embedded into diamond-like carbon. Results show up to 40 meV lower surface potential than that of diamond-like carbon, indicating a higher field-emission potential compared with the already inherently high field-emission properties of diamond-like carbon. Surface potential decreases at nanodiamonds embedded into the Q-carbon filaments, and is lower than Q-carbon values.

Measurements are consistent with secondary electron-emission contrast in the SEM images, showing significantly enhanced contrast for the Q-carbon. Controlling diamond nucleation and growth enables converting all the carbon into microdiamonds (500 nm average size) as shown in Fig. 2b. Formation of large-area single-crystal diamond films is achieved when sapphire is provided as a template during growth from the super-undercooled state as shown in Fig. 2c. Formation of 200 to 300-nm diameter by up to 3.0 µm long nanoneedles and microneedles is achieved by nucleation and growth of diamond from liquid carbon. The microneedles are single crystals, and grow out of Q-carbon near the film-substrate interface.

Raman spectroscopy is used to characterize diamond and related materials[10]. Its versatility is further improved by using a range of excitation wavelengths, particularly one wavelength in the UV range, as the sensitivity to $sp^3$ bonding is the strongest. Figure 3 shows spectra from nanodiamond, microdiamond, and large-area thin films. The characteristic sharp peak at 1332 $cm^{-1}$ confirms the formation of diamond phase and the potential of the transformative technique. The results in Fig. 3 are from 8-nm nanodiamond, 500-nm microdiamond, and 50+ µm thin film.

## DIRECT CONVERSION OF HEXAGONAL AND CUBIC BN

Direct conversion of h-BN into pure c-BN is accomplished by nanosecond laser melting at ambient temperatures and atmospheric pressure in air.

According to the phase diagram, the transformation from h-BN into c-BN can occur only at high temperatures and pressures, as the hBN-cBN-liquid triple point is at 3500K/9.5 GPa. Nanosecond laser melting creates a super-undercooled state and shifts the triple point to as low as 2800K and atmospheric pressure. Rapid quenching from the super-undercooled state leads to formation of Q-BN. The c-BN phase is nucleated from Q-BN depending on the time allowed for nucleation and growth.

Figure 4 shows the BN phase diagram in the pressure and temperature range of 0-10 GPa and 0-4000K, respectively, containing regions of phase stability for c-BN, h-BN, liquid, and vapor[11]. According to the phase diagram of Corrigan and Bundy (curve 1), the c-BN line intersects the pressure axis at 1.4 GPa at 0K without crossing the temperature axis, making h-BN the stable phase in the entire temperature range of 0 to 3000K, above which BN turns into vapor[11]. Solozhenko, et al., tried to refine the phase diagram based on experimental data on BN melting and extrapolation of specific heats of various BN polymorphs into high-temperature regions. This modification (curve 2) shifts the L-cBN-hBN triple point from 3500K/9.5 GPa (Corrigan-Bundy P-T diagram) to 3700K/7.0 GPa, and shows cBN is the stable phase in the temperature range of 0 to1600K, and h-BN beyond that at atmospheric pressure[12-13].

Figure 5a shows the formation of Q-BN and nano and microcrystallites of c-BN after treatment with a single laser pulse. Figure 5b shows the formation of single-crystal nanoneedles and microneedles of c-BN; some microneedles are over two microns long. The mechanism of nanoneedle and microneedle formation is illustrated in Fig. 5c, where interfacial instability in super-undercooled BN leads to the formation of periodic features on the order of 90 nm, which coalesce to form larger size microneedles.

Large-area single crystal thin films are formed in the middle of the laser beam, where there is 100% conversion of h-BN into phase pure c-BN (Fig. 5d). Thus, c-BN structures in the form of nanodots, nanorods, microcrystalline thin films, and large-area single crystal c-BN thin films are formed by controlling laser parameters. These structures are phase-pure c-BN with 100% conversion from h-BN into c-BN[14]. CVD methods for c-BN processing are not well established, and only 85% phase-pure c-BN

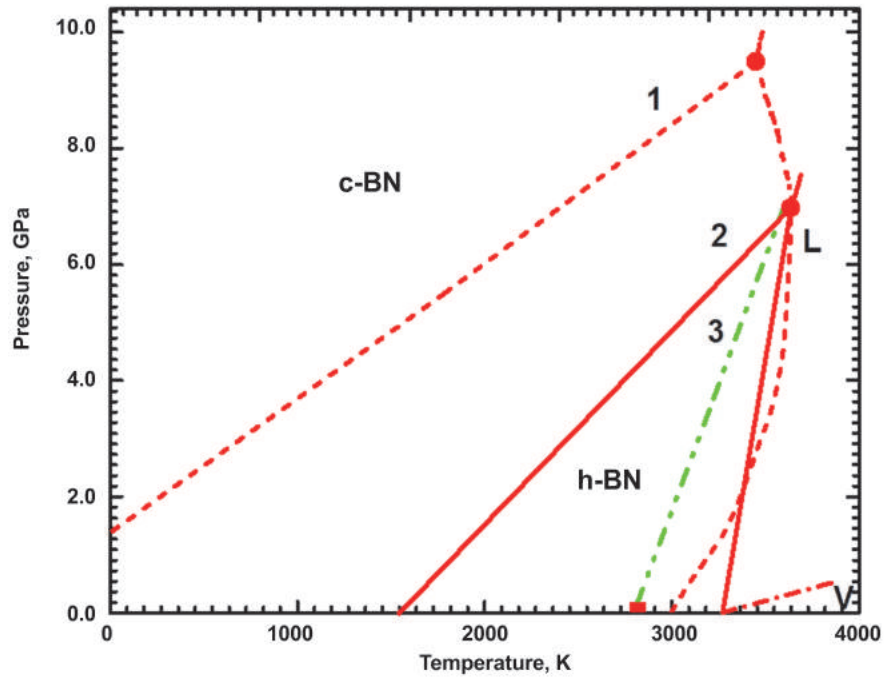



**Fig. 4 —** BN phase diagram showing P-T phase space for stability of h-BN, c-BN, and liquid BN (L): Dotted lines based on Bundy[11], dotted lines are recent modifications[12-13], and dash-dot line extension for super-undercooling[11].

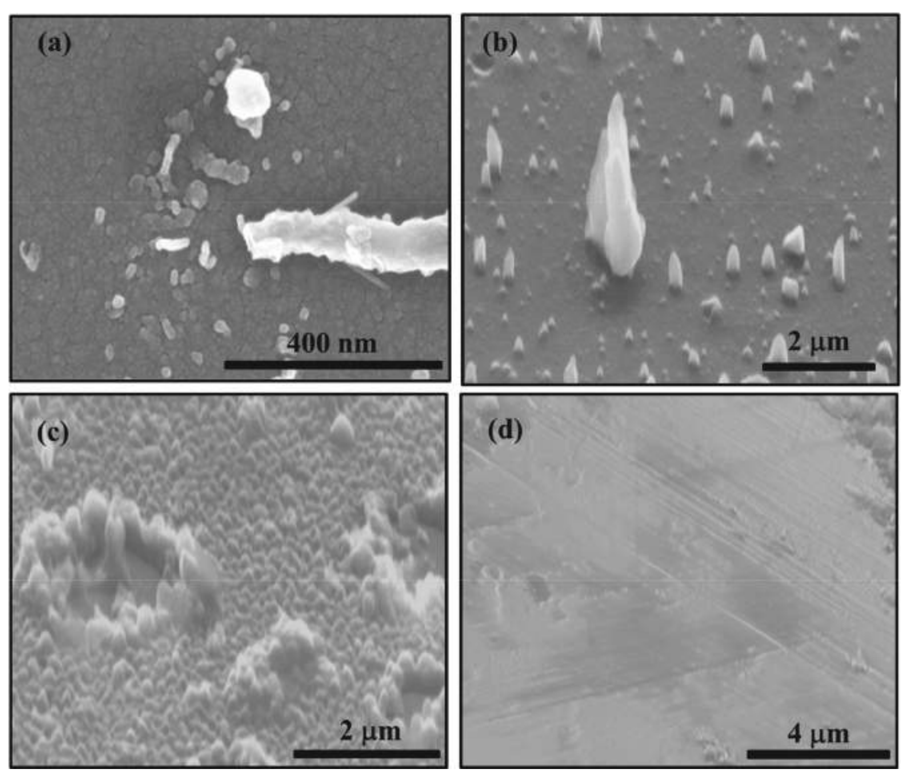



**Fig. 5 —** SEM micrographs: (a) nucleation of c-BN from Q-BN (mechanism of h-BN to c-BN conversion), (b) formation of c-BN nanoneedles and microneedles up to three microns long, (c) mechanism of initial stages of formation of nanostructures consisting of their coalescence and nanoneedle evolution, and (d) formation of large area flat c-BN films.

has been obtained by energetic physical vapor deposition (PVD) methods. Problems associated with the formation of phase-pure c-BN are discussed in the literature[15-16].

## SUMMARY

Q-carbon is a metal or semiconductor, and has robust ferromagnetism at room temperature with a Curie temperature above 500K, suitable for use in biocompatible implants and magnetic sensors. Q-carbon is harder than diamond because the C-C bond length is smaller than that in diamond, making it well suited to applications in high speed machining and deep sea drilling. Further, its low work function and negative electron affinity have applications in efficient display devices.

The diamond phase nucleates in the Q-carbon and grows in the form of nanodots, microdots (microcrystals), nanoneedles, and microneedles. Growth depends on the time allowed during the quenching cycle via homogeneous nucleation and growth. Large-area single crystal films form if an appropriate epitaxial template is provided for domain matching epitaxy. Diamond can be doped with both n- and p-type dopants, which is critical for solid-state devices. So far, only p-doped diamond was created by CVD. This opens up the field of diamond transistors and high-power devices needed for advanced power grids and high-speed digital communication. Diamond can also be deposited on heat-sensitive substrates at low temperatures, as pulse laser heating is confined primarily into the carbon layer.

This discovery is of interest in other fields as well, because the ferromagnetism in carbon (liquid carbon and Q-carbon in the Earth's mantle) can explain the protection of Earth from solar plasma and flares. A similar breakthrough has been discovered in BN, creating Q-BN and its direct conversion to c-BN (cousin to diamond) and diamond/c-BN epitaxial composites. These materials are critical for creating the next-generation power grid and information superhighway, replacing today's bulky transformers and other components. **~AM&P**



**For more information:** Jagdish (Jay) Narayan is the John C.C. Fan Family Distinguished Chair in Materials Science, North Carolina State University, EB I, Suite 3030, Centennial Campus, Raleigh, NC 27695-7907, 919.515.7874, j_narayan@ncsu.edu, www.mse.ncsu.edu.

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# METALLURGY LANE

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

## PIONEERS IN METALS RESEARCH—PART VI

### THE INVENTION OF THE SINGLE CRYSTAL JET ENGINE BLADE UNDER FRANK VERSNYDER AND A TEAM OF SCIENTISTS AT THE PRATT & WHITNEY DIVISION OF UNITED TECHNOLOGIES IS CONSIDERED ONE OF THE 50 GREATEST ADVANCES IN METALLURGICAL HISTORY.

The research program involving single crystal jet engine blades began in the early 1960s at the Pratt & Whitney Division of United Technologies Corp. It was spearheaded by Francis Louis VerSnyder who had just joined the company. During this era, Pratt & Whitney was expanding its research efforts into making major improvements in the metal alloys used in the hottest part of the jet engine. This initiative was a long-range project with a goal of eliminating failures that sometimes occurred at the grain boundaries of cast turbine blades. These blades were made of nickel base alloys that could withstand the extreme operating temperatures.

VerSnyder grew up in Watertown, N.Y., as an only child in a single parent household. His mother died at his birth, and his father was old enough to be his grandfather. In the 1940 census, VerSnyder was listed as 14 years old and his father as 56. He attended local parochial schools through high school and joined the army in 1943 at age 18. He served in the 54th Armored Infantry Division in Italy, France, and Germany. He was wounded several times and received the Purple Heart with Oak Leaf Cluster and campaign ribbons with four battle stars. He was discharged in fall 1945, still just 20 years old.

VerSnyder attended Notre Dame University on the GI Bill, earning a B.S. in Metallurgical Engineering in 1950. He then joined the Small Aircraft Engine Division of General Electric Co. in Lynn, Mass. By 1955, he had transferred to the Central Research Laboratories of GE in Schenectady, N.Y., where he remained until 1961 when he was recruited by Maurice Shank from the Pratt & Whitney Engine Division of United Technologies Corp. At P&W, he supervised a new group that had a 10-year goal of improving the reliability of engine blades operating in the hottest part of the engine.

Francis Louis VerSnyder.

Maurice “Bud” Shank.


VerSnyder received the National Medal of Technology and Innovation in 1986.

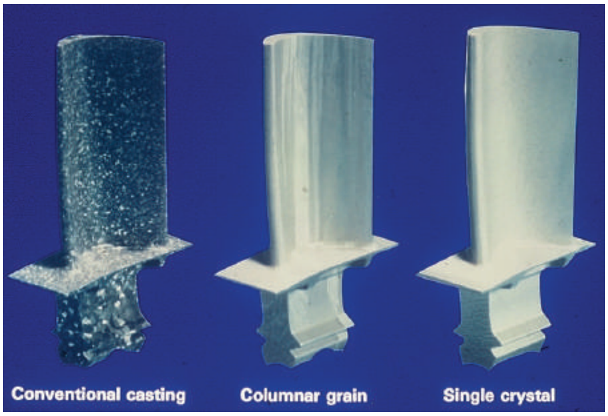
### GRAIN BOUNDARIES IN CASTINGS

When molten metal is cast into a ceramic mold, solidification begins at the cold wall of the mold. The solid metal grows as crystals into the remaining liquid until it fills the complete space of the mold. Each of these growing crystals—or grains—contacts other grains that are growing at different orientations in space. Where they meet, they form boundaries that must adjust to these different orientations. These boundaries are weak regions in the alloy.

Cast turbine blades have many grains that can be seen by chemically etching the surface. Some areas of the boundaries lay along the length of the blade while others lay across it, called transverse boundaries. In operation, blades spin at very high revolutions per minute so the major stress is along the blade’s length. The boundaries that cross the blades are the ones that are weak during operation, and failure can occur by separation at these boundaries.

### DIRECTIONALLY SOLIDIFIED ENGINE BLADES

The original goal of the program was to grow grains in only one



Three grain configurations for the same component.


The F-111 fighter jet engine was the first aircraft to employ directionally solidified blades.

direction—the length of the engine blade—thus eliminating grain boundaries across the blade. To accomplish this, the beginning of solidification would need to occur from only the bottom of the mold. This required heating the mold to high temperature to prevent solidification on the mold walls. Solidification was then limited to a water-cooled plate at the bottom of the mold. Although many grains would form, they would only grow in one direction as heat was withdrawn through the casting mold. The process required precise control of molten metal temperature, mold shape and wall thickness, mold temperature, and withdrawing the mold as the liquid/solid interface moved up the mold so that the newly formed solid grains did not remelt.

After this process was perfected in the laboratory, it had to be translated into production by the jet engine blade manufacturers. The first engine to use directionally solidified (DS) blades was in the F-111 fighter plane. During the 1970s, DS blades were used in Pratt & Whitney engines for the Boeing 747 and McDonnell Douglas DC-10, as well as the new F-15 and F-16 fighter planes. Engines built by General Electric and Rolls-Royce used DS blades as well.

## SINGLE CRYSTAL ENGINE BLADES

With the success of laboratory work on DS blades, attention turned to making a single crystal version. This would be the ultimate accomplishment in the science of metallurgy. Single crystals had been made and studied in the past, but they were small samples from pure metals—copper and zinc. No attempt had ever been made to make a single crystal in a metal as complicated as the nickel base alloys used at the extreme temperatures of the jet engine, and no one had ever contemplated making a useful part. This was virgin territory for metals technology.

The first breakthrough came when a member of the team, Steven Copley, was making a coiled spring to study the properties of DS crystals. He used a mold in the shape of a coiled spring suspended in liquid metal with DS crystals growing from the bottom of the regular water-cooled plate. As the growing crystals entered the opening of the coiled mold and grew up the spiral shape, they had various orientations in space. Crystal orientations grow at different rates into the liquid metal with one orientation growing the fastest. As they grew up the spring mold, the favored orientation grew ahead of the others until only a single orientation was present, a single crystal. This spiral mold, called the "pig tail," became the process for producing single crystal jet engine blades.

## ALLOY DEVELOPMENT

The single crystal blade revolutionized the operation of jet engines and aircraft travel. The engine could operate at temperatures roughly 100°-150°F higher than before. The new blades improved operating efficiency, fuel economy, and time between engine overhauls. These higher temperatures required new alloys and a new ceramic coating to protect the blades. Throughout the program, alloy composition had to be adjusted to account for different grain formations and solid solution strengthening. The final alloy had the following composition—10% chromium, 5% cobalt, 4% tungsten, 1.5% titanium, 5% aluminum, and 12% tantalum. By the end of the 1970s, single crystal blades replaced the DS blades in the Boeing 747 and were used in the new Boeing 757and 767, as well as the Airbus A310. Single crystal blades are now standard in all large engines for commercial and military aircraft.

## AWARDS AND HONORS

VerSynder earned his first award in 1954, the Henry Marion Howe Medal from ASM International, for his work on the microstructure of jet engine alloys. He had only been in research for four years at this time. For his inventions in DS and single crystal engine blades, he received the George J. Mead Medal for Engineering Achievement from United Aircraft in 1965, the Clamer Award from The Franklin Institute in 1973, and the ASM Engineering Materials Achievement Award in 1975. He was selected for the National Academies of Sciences, Engineering Division, in 1981. VerSnyder also received the highest award given to a civilian, the National Medal of Technology and Innovation, presented in the Oval Office by President Ronald Reagan in 1986. His research and development of directional solidification and single crystal casting for jet engines is listed by AIME as one of the 50 greatest advances in the history of metals. VerSnyder continued his research at the Pratt & Whitney Engine Laboratories for the rest of his career. He died in 1989 at the age of 64.

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

# 2016 HEAT TREAT MEXICO

September 20-23, 2016

## ADVANCED THERMAL PROCESSING TECHNOLOGY CONFERENCE AND EXPO
## FIESTA AMERICANA | QUERETARO, MEXICO

# REGISTRATION OPEN SOON!

The ASM Heat Treating Society will present a new and exciting global event, Heat Treat Mexico, which will showcase the heating/heat treating resources and technology available to the important automotive manufacturing market in Mexico. When registration opens, attendees will get the following for the low price of $250 USD (member)/$265 USD (non-member):

- Education Short Course, "Metallurgy for the Non-Metallurgist", including class materials
- 3-Day Heat Treating Symposium
- Daily Lunch (4 total) and Refreshments Breaks
- Welcome Reception with exhibitors
- Special Networking Event, with open bar
- Dedicated networking times with exhibitors
- Courses/Symposium + written materials. Offered in English and Spanish
- Free membership in ASM/HTS for non-members
- Free parking
- Single day rates available

## ONLINE REGISTRATION WILL OPEN IN THE SPRING.

Visit asminternational.org/htmexico to view the entire agenda

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MARCH 2016 | VOLUME 4 | ISSUE 1

# HTPRO

BUSINESS AND TECHNOLOGY FOR THE HEAT TREATING PROFESSIONAL

HTS Heat Treating Society
ASM INTERNATIONAL

# HTPRO

BUSINESS AND TECHNOLOGY FOR THE HEAT TREATING PROFESSIONAL



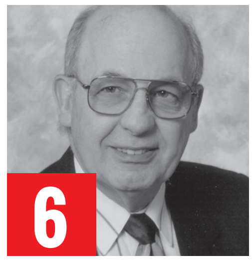
## EDITORIAL OPPORTUNITIES FOR *HTPro* IN 2016

The editorial focus for *HTPro* in 2016 reflects some key technology areas wherein opportunities exist to lower manufacturing and processing costs, reduce energy consumption, and improve performance of heat treated components through continual research and development.

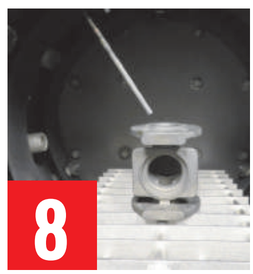
**June** Testing and Process Control
**October** Thermal Processing in Automotive Applications
**November** Atmosphere/Vacuum Heat Treating

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

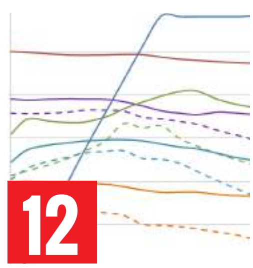
To advertise, contact Erik Klingerman at erik.klingerman@asminternational.org.













## DEPARTMENTS



## ABOUT THE COVER

Decorative parts for the yacht “Hollow Ribbons” made using direct metal laser sintering. Courtesy of Solar Atmospheres of Western PA, solaratm.com

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At the time I wrote my previous column last October, Heat Treat 2015 was right around the corner. It's almost impossible to believe that was nearly six months ago. The show was a huge success with more than 7000 attendees from all around the world, over 140 presentations, and numerous networking opportunities. ASM's Heat Treating Society (HTS) is now building on the momentum created at Heat Treat 2015 with two internationally flavored events in 2016.

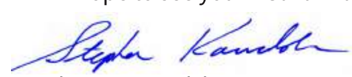
In April, the 23rd IFHTSE Congress will be held in beautiful Savannah, Georgia, sponsored by HTS and the International Federation of Heat Treatment and Surface Engineering (IFHTSE). The meeting will bring together international experts to share some of the latest developments in thermal processing, heat treating, and surface engineering. These are critical topics because technological advancements in these areas are crucial to cost-effective manufacturing of products in almost every industry. Visit asminternational.org/web/ifhtse for more information.

Coming up in October is Heat Treat Mexico, a new international show taking place in Queretaro, an automotive and aerospace hub. More than 35 technical sessions will focus on topics such as induction heat treating, carburizing, nitriding, and more. Registration includes three full days of technical programming as well as a free "Metallurgy for the Non-Metallurgist" short course. Visit asminternational.org/web/htmexico to learn more.

Beyond events, HTS is busy aggressively updating our education courses to be able to meet the needs of our U.S. members as well as our international membership. We are also working more closely with other ASM affiliate societies to ensure that best practices are being implemented across the board. In addition, we are focusing on attracting younger members—both college age and young professionals—to the heat treating industry. Our goal is to capture, nurture, embrace, and encourage the excitement and passion of our younger cohort. They make HTS stronger and are our future leaders.

Finally, as I've mentioned before, we must have fun. We all spend many of our waking hours at work and work-related events. The more you put in, the more you get out. Being an active member of HTS provides a built-in network of industry peers and helps create the vibrant heat treating community we all benefit from.

I hope to see you in Savannah next month!



Stephen G. Kowalski
President, ASM Heat Treating Society

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## HEAT TREATING SOCIETY SEEKS BOARD NOMINATIONS

The ASM Heat Treating Society (HTS) Awards and Nominations Committee is seeking nominations for three directors, a student board member, and a young 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 Nominating Committee may consider any HTS member, even those who have previously served on the HTS Board. **Nominations for board members are due March 21.**

For more information and the nomination form, visit hts.asminternational.org and click on Membership and Networking, then Board Nominations; or contact Joanne Miller at 440.338.5151 ext. 5513, joanne.miller@asminternational.org.

## HTS SEEKS STUDENT BOARD MEMBER APPLICATIONS

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

**Opportunities include:**

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

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

## KEOUGH TO PRESENT AFS HONORARY LECTURE

**John R. (Chip) Keough, FASM,** of Applied Process Inc., Ann Arbor, Mich., was selected by the American Foundry Society (AFS) to present the Cast Iron Division Honorary Lecture at its upcoming Metalcasting Congress in April. The lecture was established in 1993 to honor distinguished members of AFS who have contributed to the knowledge base of cast iron. Keough was selected by the leadership of the Cast Iron Division Programs and Papers Committee to present the invited lecture. Past talks have been delivered by both metal casting professors and industry leaders. Keough's lecture, entitled "The Stuff Matters," will be held on April 17 at the AFS Metalcasting Congress in Minneapolis. Keough is director of the technologies division at Applied Process Inc. and also serves as ASM board liaison on the ASM Heat Treating Society Board. For more information, visit afsinc.org.

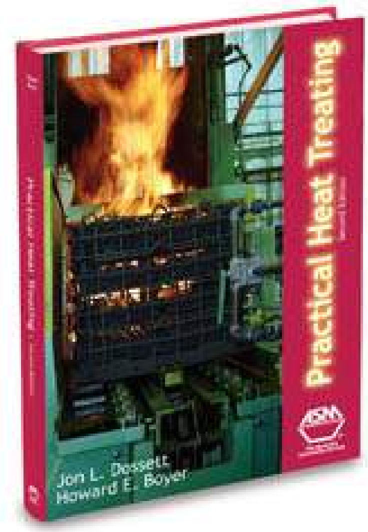
## WPI RECEIVES BERNARD M. GORDON PRIZE

The 2016 Bernard M. Gordon Prize for Innovation in Engineering and Technology Education was awarded to Worcester Polytechnic Institute (WPI) educators **Diran Apelian, FASM** (pictured), Arthur Heinricher, Richard Vaz, and Kristin Wobbe "for a project-based engineering curriculum developing leadership, innovative problem-solving, interdisciplinary collaboration, and global competencies."

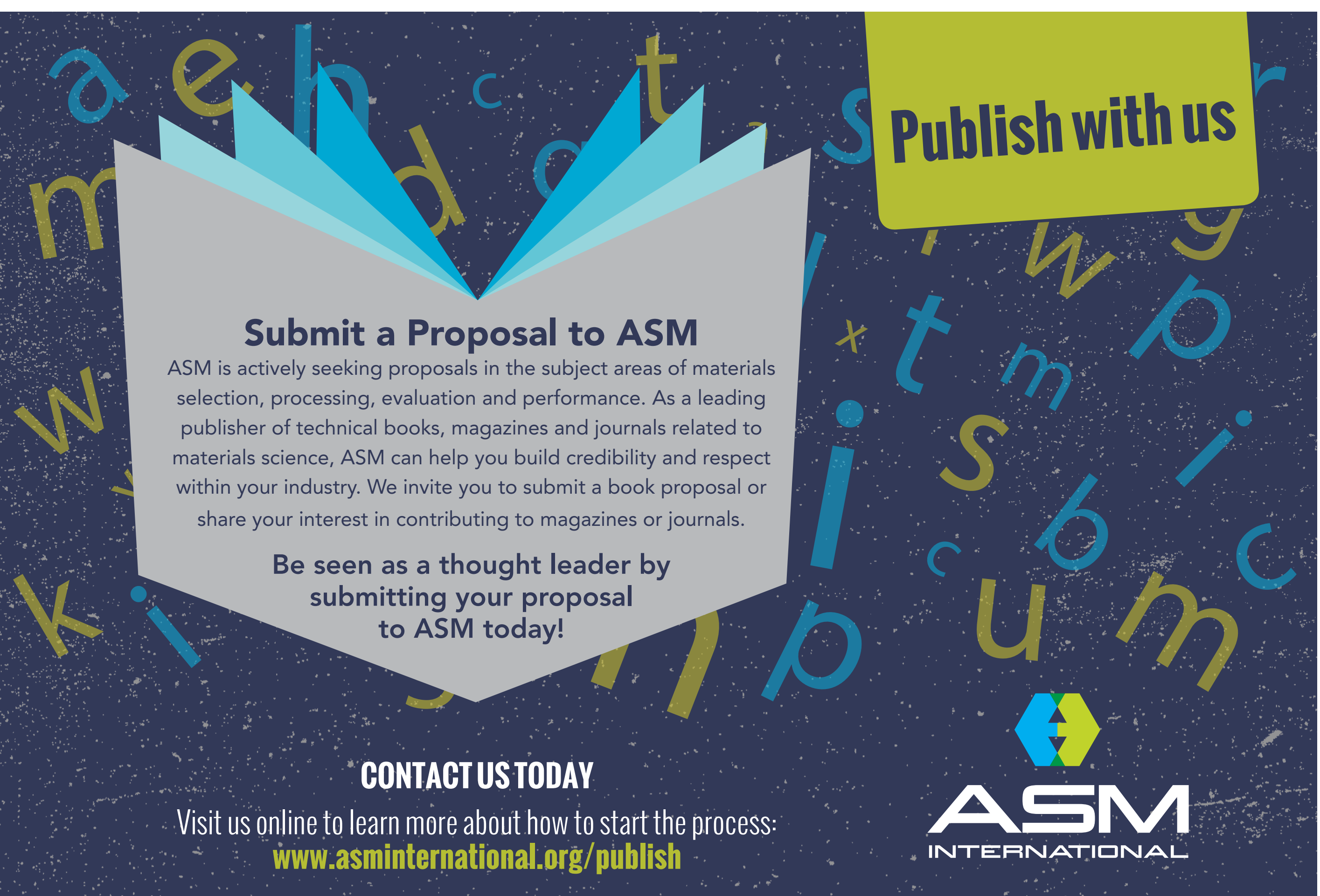
The project-based engineering curriculum at WPI prepares 21st century leaders to tackle global issues through interdisciplinary collaboration, communication, and critical thinking. The Institute's engineering program engages students with a specially designed sequence in which first-year students complete projects on topics such as energy and water; second-year capstones focus on the humanities and arts; junior-year interdisciplinary projects relate technology to society; and senior design projects are done in conjunction with external sponsors, providing relevant experience upon graduation.

Last year, WPI launched its Institute on Project-Based Learning, an initiative to help other colleges and universities make progress toward implementing project-based learning on their campuses. The Bernard M. Gordon Prize for Innovation in Engineering and Technology Education is one of the most prestigious awards in engineering education. For more information, visit wpi.edu.

## PRACTICAL HEAT TREATING TO BE HELD APRIL 4-7




*Practical Heat Treating,* taught by **William Mankins, FASM,** will take place April 4-7 at ASM Headquarters in Materials Park, Ohio. This course focuses on the "how" of heat treating and includes a textbook, *Practical Heat Treating Second Edition*. Students will learn the heat treatment process of steel as well as what type of atmosphere is best for furnace operations for the safety of personnel and equipment. In addition, attendees will learn to recognize heat treating problems and establish quality control procedures. Plant managers, quality control specialists, and engineers alike will benefit from attending this four-day event. Upon completing the course, participants should be able to define and discuss the heat treatment process of steel and other materials; describe heat treat furnace operations and atmospheres for the safety of personnel and equipment as well as maintenance and control; and recognize heat treating problems and establish quality control procedures to produce satisfactory products.



# TRIBUTE TO A HEAT TREATING PIONEER: GEORGE D. PFAFFMANN, FASM FEBRUARY 13, 1928–NOVEMBER 22, 2015

George Pfaffmann was highly regarded as a true leader and innovator in induction heating technology.

**Aquil Ahmad,** Retired Chief Metallurgist, Eaton Corp.

George Pfaffmann was well known throughout the heat treating industry and was an active member of ASM International. He served on ASM's Technology and Programming Committee and the ASM Materials Education Foundation, as well as the Heat Treating Society Board of Trustees and R&D Committee. In September 2013, he presented a talk during the "Masters of Heat Treating Series" at the 27th ASM Heat Treating Society Conference and Exposition in Indianapolis. He spoke about Edwin F. Northrup (1866-1940), widely considered the "father of induction heating." Some of George's other accomplishments include:

Aquil Ahmad and George Pfaffmann at Heat Treat 2013.

- George H. Bodeen Heat Treating Achievement Award, 2003
- ASM Heat Treating Honorary International Symposium Award on Induction Hardening, 2003
- Served on the National Research Council committee to draft the DOE-ITP report, "Decreasing Energy Intensity in Manufacturing"
- Co-recipient of *R&D Magazine's* R&D 100 Award for 2009
- Enlisted in the U.S. Army during WWII and served during the Korean war
- 38 U.S. patents and many more international patents
- Over 50 years of service to ASM

I worked with George for almost a decade. He loved technical research and would long to get to the office at six in the morning and work until late in the evening. Even during the last few weeks before he passed, George would follow the technical developments and contribute his thoughts and opinions. The last technical paper he co-authored, Induction Coupled Thermo-Magnetic Processing, was presented in October 2015 at the 28th ASM Heat Treating Society Conference and Exposition in Detroit.

The work cited below is from discussions with George's colleague, Ron R. Akers, VP of R&D at Ajax Tocco Magnethermic Corp. In 2002, George retired as Ajax Tocco's VP of Technology, after working for 50 years. He then rejoined the company as a consultant VP of Technology until November 22, 2015. George was part of widespread changes the U.S. automotive industry experienced over the past 50 years. The industry went from 100,000-mile automobile *lifetimes* to today where 100,000-mile *warranties* are common. Average mileage has doubled and performance has been enhanced to where most cars are at performance levels approaching previous muscle cars. George was in Detroit during this period and led much of the induction industry's contributions to these changes. His legacy includes the following:

*Camshaft hardening:* George was involved in the conversion from flame hardening to induction hardening of camshafts in the early 1950s and later added high power density hardening to that technology.

*Axle shaft hardening:* George was a leading contributor to the development of full length scan hardening of axle shafts, improving resistance to torsional fatigue by 200%.

*Single shot axle hardening and tempering:* George was involved with introducing the single shot process, increasing the induction hardening production rate to allow the process to be put in line with other processes and improving the metallurgical pattern for many parts that were previously scanned.

*Restraint axle hardening:* George was a leading member of the team that introduced restraint axle hardening to the automotive industry.

*Valve seat hardening:* George invented the induction valve seat hardening process, which was the major breakthrough that paved the way for conversion from leaded to unleaded gasoline.

*Gears:* George has many patents and achievements regarding gears, such as profile gear hardening and front wheel sprocket hardening.

*Powdered metal atomization:* George was part of the early gas atomization process for the production of fine, pure, and high temperature metal powders.

*Hot metal gas forming:* George was an integral part of the Auto Body Consortium in developing a process to replace hydroforming of auto body structural parts.



# USING VACUUM FURNACES TO PROCESS 3D-PRINTED PARTS

Vacuum heat treating is a crucial step in the additive manufacturing process cycle to meet required part quality specifications.

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

Additive manufacturing (AM), or 3D printing, is a revolutionary technology that involves converting a digital model into a net- or near-net shape metallic part by building up layers of powder or wrought feedstock. Many believe AM will change the world of manufacturing, while others believe it will never replace machining, otherwise known as subtractive manufacturing. The reality probably lies somewhere between the skepticism and hype.

## OPPORTUNITIES AND CHALLENGES

The possibilities and benefits of AM are exciting. A huge advantage of the process is that it uses only the material needed to make the part. In addition, unlike subtractive manufacturing, AM has no design constraints, enabling freedom of design for functionality. AM also significantly reduces the time from part design to market: Part manufacturing often begins within one hour of final design.

The various methods of additive manufacturing are truly revolutionary technologies, which present many challenges. One of the main hurdles is the high cost of equipment, where a single printer with ancillary equipment can cost roughly $1 million. Printer feedstock materials are also expensive. For example, the price of metallic powders ranges from $300/lb for alloy steel to $1200/lb for titanium alloys.

The AM field also lacks industry-wide standards. AM metallurgy consists of multiple recast layers (versus traditional metallurgy of one homogenous melt of material), which can result in many inconsistencies. Issues that need to be resolved include how individual layers of deposited material are qualified, quantified, and inspected. Acceptable levels of porosity and density must also be defined. In addition, certain processes produce parts that exhibit different mechanical properties longitudinally with the deposit and transversely across the deposit.

Therefore, the big challenge facing the AM industry is to identify new, effective quality assurance techniques. In most cases, certification and validation initiatives for AM products are being driven by primary contractors such as General Electric Aviation and Lockheed Martin. Many aerospace OEMs have spent millions of dollars on the research and development of new opportunities, especially for the jet engine. With the design freedom that AM provides, aeronautical engineers can now model to the fit, form, and function of a particular part with minimal constraints. As more AM components continue to evolve from the lab into production, the benefits of greater strength, less weight, and significant fuel savings often outweigh the cost. (Fig. 1).

**Fig. 1** — Test turbine engine blades produced by the EBAM process.

## ADDITIVE PROCESSES

*Direct metal laser sintering (DMLS)* is a process in which metal powder is injected into a high-power (400-1000 W) focused laser beam operating under tightly controlled at-mospheric conditions. The laser beam melts the surface of the target material, generating a small molten pool of base material. Powder is delivered and absorbed into the pool, forming a deposit. Typically, the DMLS process is carried out in an inert chamber to control oxidation of the metallic pool. Materials processed via this method include titanium, Inco-nel, and cobalt-chromium alloys. The low deposition rate of DMLS enables production of fine details (Fig. 2).

*Electron beam additive manufacturing (EBAM)* directs a high-power electron beam to selectively fuse wire on a plate

*Member of ASM International

**Fig. 2 —** Decorative part for the yacht "Hollow Ribbons" made using DMLS.

**Fig. 3 —** EBAM is used to deposit titanium wire on a titanium base.

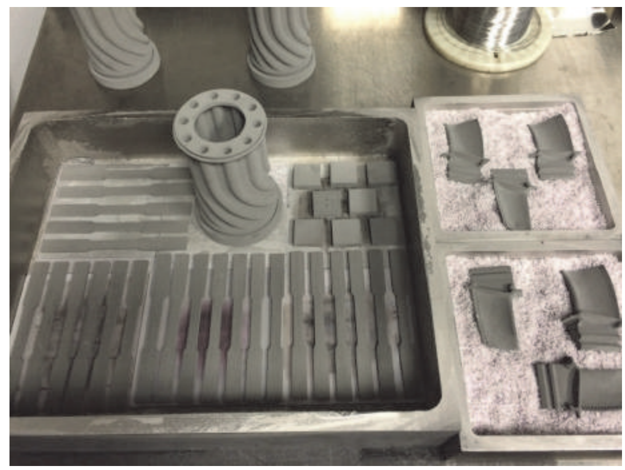


**Fig. 4 —** BJP-printed engine blades and other titanium alloy test pieces.

of similar material within a vacuum chamber. The process deposits material at a higher rate than DMLS, but the finished shape is not as fine. Material for EBAM parts that are vacuum heat treated is predominantly Ti-6Al-4V (Fig. 3).

*Binder jet process (BJP)* involves spraying a liquid binder onto a bed of powder at ambient temperature. The conglomeration of the binder and powder is solidified using a very low heat source equivalent to a heat lamp. Each layer is printed in a manner similar to a printer depositing ink on paper. The printed part is lowered after each layer solidifies until the component is complete (Fig. 4). This method has the lowest manufacturing cost of all additive processes—as much as 10 times less expensive. However, vacuum heat treating of BJP parts is more complicated.

## VACUUM HEAT TREATING AM PARTS

AM is rapidly developing due to the demand for near-net shape parts with geometries that are impossible to machine. Because AM parts require very little material removal during downstream processing, it is imperative that finished parts do not have any decarburization or contaminated surfaces from subsequent thermal processing. Therefore, a crucial piece of equipment in the additive manufacturing industry is a well-maintained vacuum furnace, which operates totally devoid of oxygen, is equipped with diffusion pumps to achieve deep vacuum levels, and has very precise temperature control (Fig. 5).

One of the most important factors for successful inert vacuum heat treatment of AM parts is a leak-free furnace. Therefore, a leak rate of less than five microns per hour is imperative regardless of the chamber size. The furnace must also be thoroughly baked out at a minimum temperature of 2400°F prior to an AM furnace cycle. Overall temperature uniformity is critical for successful thermal processing of any parts, especially printed parts. For example, BJP components function as a type of thermocouple sensor. A BJP workpiece that does not reach or exceed a ±2°F temperature range exhibits a lack of temperature control in the form of excessive shrinkage or growth. Therefore, when sintering temperatures (around 2500°F) preclude attaching thermocouples to the workpiece, a Type S sensor must be strategically located within inches of the workpiece (Fig. 6). There is tremendous potential for scrap without precise temperature control.

Solar Atmospheres has processed AM parts of many shapes and sizes. The DMLS method generally requires

**Fig. 5 —** AM-capable vacuum furnaces range from lab size to 48 ft long.

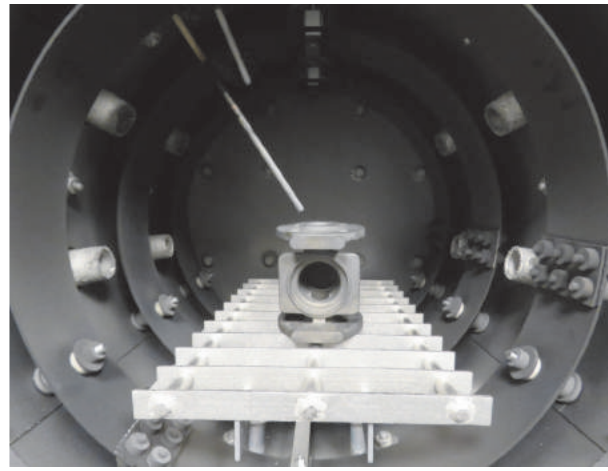


**Fig. 6 —** Heat treating a BJP-printed part requires precise temperature measurement.


**Fig. 7 —** Creep-forming is used to flatten a warped EBAM titanium baseplate by placing weights on the part during heat treatment.

three vacuum heat treating processes per various aerospace standards—vacuum annealing, vacuum aging, and vacuum stress relieving.

Typically, prior to heat treating, EBAM baseplates are severely warped due to high heat concentration of the electron beam on one side of the base material. To counteract the warping, AM companies are trying to simultaneously print on both sides of the base plate. Until the distortion can be better controlled, vacuum annealing and vacuum stress relieving processes are used to "creep form" the parts back into shape so they can be finish machined. Graphite plates, molds, and stainless steel weights are used to help accomplish this task (Fig. 7).

Because BJP involves very little heat during manufacturing, downstream heat treating is often challenging. As with metal injection molding (MIM) metallurgy, the BJP part must be fully densified by vacuum sintering. Sintering temperatures are often within 10°F of the melting point of the base material, so precise pyrometric control is critical. In addition, slow ramp-up rates and various holding times are crucial to bake off residual binders remaining within the delubed parts.

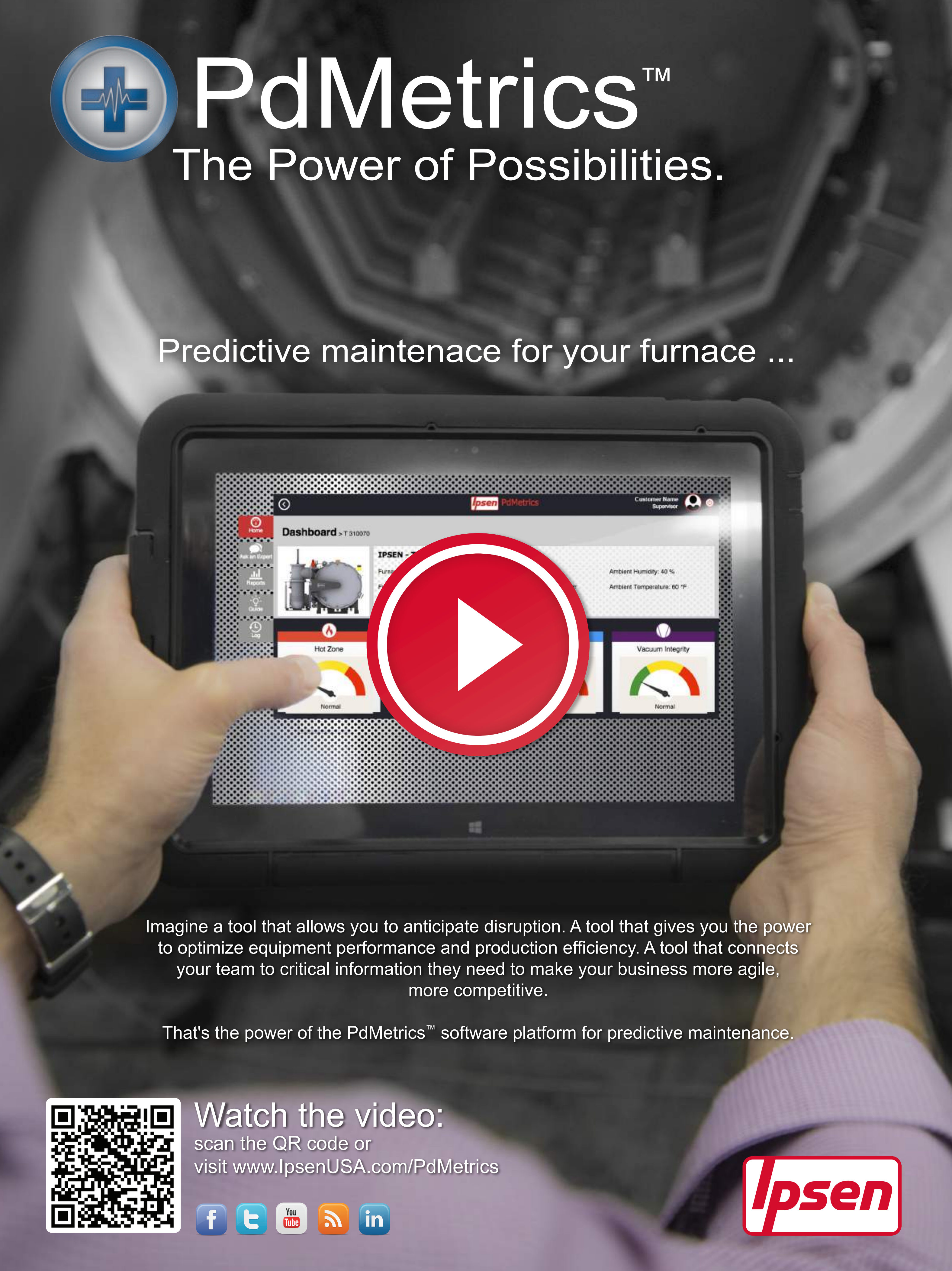
## CONCLUSIONS

Global 3D printing industry revenues from products and services exceeded $2.2 billion in 2014. Revenues for the global market are expected to exceed $21 billion by the year 2020, according to the *Wohlers Report on Additive Manufacturing and 3D Printing.*

The aerospace industry is not the only niche market where AM is making its mark. AM in the medical device market has also grown significantly. The technology's geometric design freedom is particularly useful in orthopedics, enabling the design of more natural anatomical shapes while printing the porous surfaces required for bone grafting purposes.

Additive manufacturing is not yet the manufacturing panacea portrayed by its enthusiasts. Today, 3D printing is not likely to replace traditional machining, because AM only eliminates some—and not all—machining. Even the best finish produced by printing requires final machining and/or grinding, especially for parts that need to be assembled to other components. Additive manufacturing is not about forcing manufacturers and heat treaters to abandon conventional manufacturing processes used for decades. However, it offers an exciting alternative manufacturing method, especially when savings can be realized in design flexibility and fewer manufacturing steps—or even billions of dollars in jet fuel.

**For more information:** Robert Hill is President, Solar Atmospheres of Western PA, 30 Industrial Rd., Hermitage, PA 16148, 724.982.0660, ext. 2224, bobh@solarwpa.com, www.solaratm.com.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# MINIMIZING ALPHA CASE DURING VACUUM FURNACE HEAT TREATING

Understanding detrimental alpha case formation during heat treatment of titanium parts is increasingly important as titanium use in aerospace and medical applications continues to grow.

**Donald Jordan, FASM,* and Virginia Osterman,*** Solar Atmospheres Inc., Souderton, Pa.

Alpha case is a diffusion reaction that occurs at the surface of titanium when processing at elevated temperature in atmospheres containing oxygen, nitrogen, and/or carbon, with oxygen as the prominent element associated with alpha case. Oxygen is solution strengthening at low concentrations, but greatly decreases ductility and forms alpha case at higher concentrations. Thus, alpha case is brittle and has a detrimental effect on part performance and longevity. Higher temperatures increase alpha case. Above 480°C (896°F), air or water vapor begins to produce alpha case. Temperatures less than 550°C (1022°F) limit oxygen mobility and keep the case depth from increasing[1].

To minimize alpha case, high integrity titanium parts are often heat treated in vacuum furnaces to avoid having to remove the case by machining or pickling. The majority of today's production vacuum furnaces are insulated with graphite felt. At lower temperatures in vacuum, water vapor is the principal concern for oxidizing titanium when $H_2O$ dissociates. It is known in industry that water vapor is difficult to "pump out" at low temperature in vacuum. As the temperature increases, water vapor present in the vacuum chamber will be "driven out," oxidizing titanium on the ramp-up to the cycle hold temperature. At higher temperatures, water vapor decreases while $CO_2$ and CO increase, providing additional sources for alpha case formation[2].

In an attempt to minimize oxidation, industry practitioners slow down the ramp rate and incorporate temperature holds if outgassing exceeds a certain pressure[3]. Sound practice requires an initial pumpdown to $1 \times 10^{-4}$ torr or lower (AMS2769 specification) and relatively slow ramp at 600°F/hr; if outgassing occurs, hold until the pressure drops to $2 \times 10^{-4}$ torr. Such procedures negatively affect production time. The current study looks at whether such protocols are reliably effective in reducing alpha case formation.

Color is often used as a post-welding and heat treatment criterion to indicate presence of alpha case. This study examines whether there is any correlation between color and extent of alpha case.

After polishing and etching, alpha case is visible under a microscope as a white-appearing microstructure zone, or alpha phase. The literature lists three principal etchants for revealing titanium alpha case: Kroll's reagent, 2% HF, and Kroll's reagent followed immediately by 2% ammonium bifluoride. Etchant dwell time is an important variable in obtaining reliable results.

## PROCEDURE

Ti-6Al-4V sheet was cut into 13 coupons approximately 1.5 in. square. Twelve samples were divided into six pairs for use in six separate heat treat cycles. The 13th sample was retained as the non-heat-treated baseline (virgin) for metallographic analysis. Additional titanium sheet was used in Test 5 to increase surface area by a factor of nine compared to the other five tests.

The furnace used for all tests was a cylindrical, vertical vacuum furnace—10-in. diameter × 18 in. high—with graphite felt insulation and graphite heating elements. An Ametek residual gas analyzer (RGA) was attached to the furnace. The RGA captures a sample of residual gases in the furnace hot zone to provide a trend analysis of relative gas composition and pressure during the cycle.

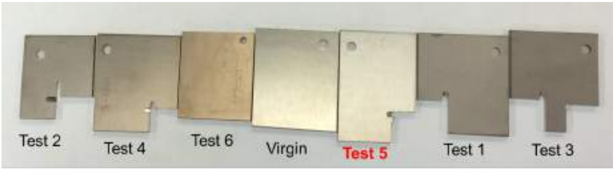
Two ramp rates, one relatively slow and the other fast, and two hold temperatures were used for five test cycles. All cycles began after an initial pumpdown to $1 \times 10^{-4}$ torr. The one-step fast ramp rate was 1200°F/hr to the hold temperature. The two-step slow ramp rate was 300°F/hr to 900°F, then 600°F/hr to the hold temperature. The two hold temperatures were 1450°F and 1750°F with a one-hour hold time. The sixth test cycle used a three-step ramp rate as follows: 300°F/hr to 600°F, one hour hold; 300°F/hr to 900°F, one hour hold; 600°F/hr to 1450°F, one hour hold.

Two coupons were hung on separate molybdenum wires attached to the lid of the furnace for each cycle. One coupon was intended to be color analyzed using a HunterLab spectrophotometer. The second coupon was used for metallographic analysis of alpha case. Specimens were etched using either Kroll's reagent, 2% HF, or Kroll's followed immediately by 2% ammonium bifluoride. Comparisons were made as to which etchant best delineated alpha case along with the effect of dwell time.

## RESULTS AND DISCUSSION

The appearance of coupons from all tests reveals that color is not a distinguishing material attribute (Fig. 1). It is more accurate to say that the samples vary in reflectivity

*Member of ASM International




| Test # | Final T (°F) | Ramp Type | Surface Area | Alpha Case (inches) | Appearance |
|---|---|---|---|---|---|
| 1 | 1750 | Two-step | 1 | 0.004 | Matte gray |
| 2 | 1450 | Two-step | 1 | 0.0008 | Yellow tint |
| 3 | 1750 | One-step | 1 | 0.004 | Matte gray |
| 4 | 1450 | One-step | 1 | 0.0008 | Yellow tint |
| 5 | 1750 | One-step | 9 | 0.002 | Bright |
| 6 | 1450 | Three-step | 1 | 0.0008 | Yellow tint |
| Virgin | NA | NA | NA | 0.000 | Bright |

**Fig. 1 —** Summary of test runs and resulting alpha case and color.

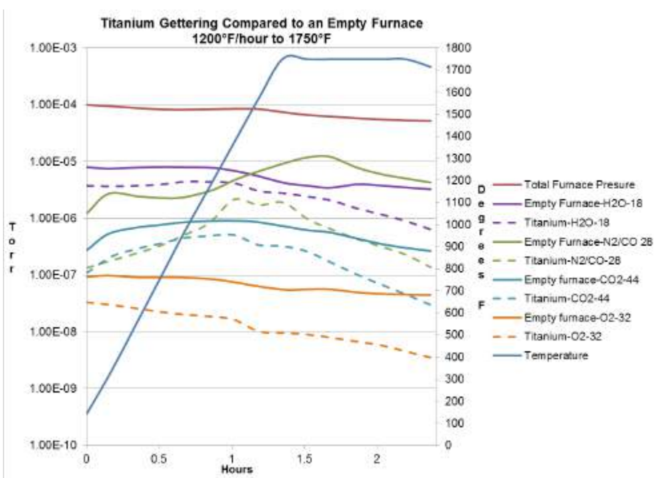



**Fig. 2 —** RGA trends show strong gettering effect of titanium.

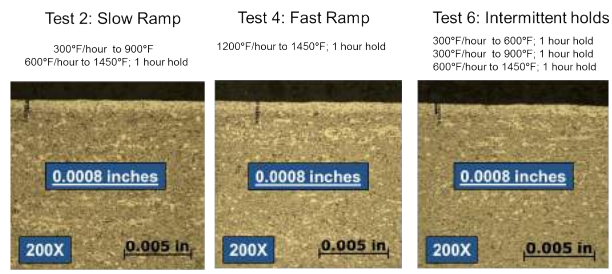



**Fig. 3 —** Metallographic photos of samples heated to 1450°F at different ramp rates.

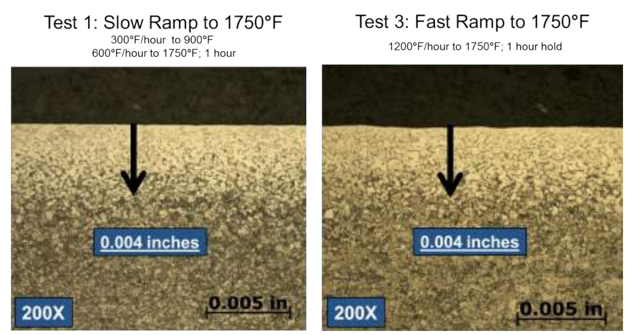



**Fig. 4 —** Metallographic photos of samples heated to 1750°F at different ramp rates.

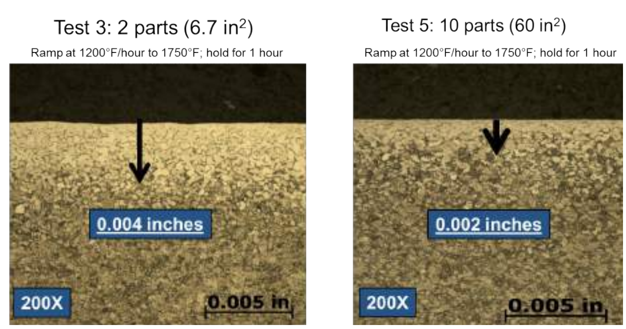



**Fig. 5 —** Metallographic photos show that increased surface area reduces alpha case.

more than color. As a result, the spectrophotometer was not useful for its intended function. However, differences in reflectivity proved meaningful, showing that bright-appearing samples can exhibit more alpha case than non-bright samples. Figure 1 summarizes these results. The two coupons heated to 1450°F show a yellowish tint. The two coupons heated to 1750°F are matte gray. The coupon of Cycle 5 appears as bright as the virgin piece. Based on appearance, the sample from Cycle 5 might suggest that there is no alpha case. However, Test Piece 5 exhibits considerably more alpha case than the yellow tinted samples from Tests 2 and 4.

RGA data reveals that water vapor is the primary oxidizing residual gas resulting in alpha case. As temperature rises, the partial pressure of carbon monoxide and carbon dioxide increase to contribute to alpha case formation. Yet ultimately, the trends show a continuous decrease in partial pressure of furnace gases due to the strong gettering effect of titanium (Fig. 2).

Metallographic results show that visual inspection cannot reliably be used as an indication of alpha case. Varying the ramp rate or incorporating intermittent temperature holds did not affect the amount of alpha case formed in the low temperature cycles (Fig. 3) or high temperature cycles (Fig. 4). Comparison of Cycles 3 and 5, which were one-step fast ramps to 1750°F, shows that increased surface area reduces the amount of alpha case formation (Fig. 5).

Evaluation of three different metallographic etchants indicate that 2% HF best distinguishes the delineation between alpha case and base metal (Fig. 6). However, etching time is all-important in generating an accurate reading

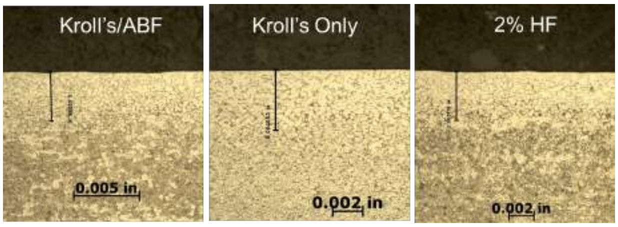



**Fig. 6 —** Etchant effect on delineation of alpha case.

regardless of which etchant is used. Etchant times between six and 10 seconds using 2% HF delineate comparable alpha case when etched immediately after polishing. Etching times longer than 10 seconds cause the case to appear shallower in depth (Fig. 7).

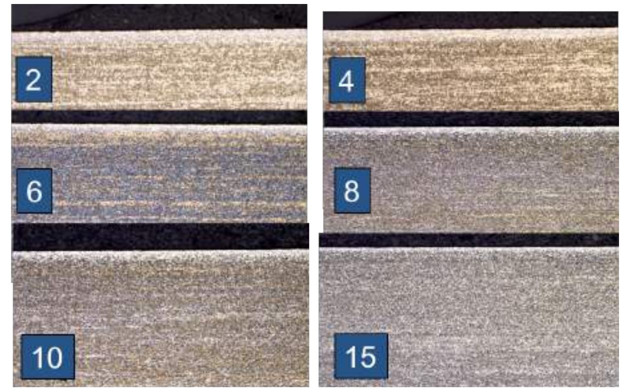



**Fig. 7 —** Etching time in seconds when etched with 2% HF immediately after polishing.

## CONCLUSIONS

The surface color or reflectivity of titanium after heat treatment is independent of the underlying alpha case. Varying ramp rates or instituting intermediate temperature holds during outgassing did not minimize the formation of alpha case, owing to the strong gettering effect of titanium as revealed by the RGA. Temperature, time, surface area, and furnace cleanliness all contribute to the extent of alpha case formation.

RGA data reveals that water vapor is the primary oxidizing residual gas. As temperature increases, carbon monoxide and carbon dioxide contribute to alpha case formation in a graphite-insulated vacuum furnace. Introduction of sacrificial gettering surface area decreased the amount of alpha case on any given test coupon. Thus, it is most beneficial to process as many parts (surface area) as feasible in a heat treatment load. Ramping directly to the hold temperature is beneficial to production efficiency.

Metallographic comparisons of three etchants indicate that etchant type and dwell time can considerably influence the observed depth of alpha case.

**For more information:** Donald Jordan is corporate metallurgist, Solar Atmospheres Inc., 1969 Clearview Rd., Souderton, PA 18964, 800.347.3236, don@solaratm.com, www.solaratm.com.

**References**

1. Matthew J.Donachie, Titanium, A Technical Guide, ASM International, p 61-62, 2000.

2. Trevor Jones, The Use of a Vacuum Residual Gas Analyzer and its Evaluation between a Graphite and Molybdenum Insulated Hot Zone, presented at Furnaces North America, Nashville, TN, October 7, 2014.

3. Don Jordan and Harry Antes, Study of Alpha Case Formation on Heat treated Ti-6-4, *Industrial Heating,* p 45, May/June 2008.

INTERNATIONAL FEDERATION FOR HEAT TREATMENT AND SURFACE ENGINEERING
IFHTSE

# 23rd IFHTSE Congress

April 18-22, 2016 | Savannah, Georgia

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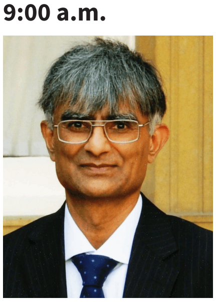
Plan now to attend the 23rd iteration of the IFHTSE Congress, an exciting global event focused on thermal processing, heat treating, and surface engineering organized by the ASM Heat Treating Society and the International Federation of Heat Treatment and Surface Engineering (IFHTSE). The event takes place this April in Savannah, Georgia, and is expected to draw attendees and exhibitors alike for record attendance.

The technical program is now live and registration is open to the public. Registration includes access to the three-day technical program, daily lunch and refreshment breaks, an exhibitors welcome reception on Monday, a reception/dinner on Wednesday, dedicated networking time with exhibitors, and access to online conference proceedings. An optional riverboat cruise takes place Tuesday evening.

## CONFERENCE HIGHLIGHTS

### Keynote Presentations, Tuesday, April 19

**Very Short and Very Long Heat-Treatments in the Processing of Steel**
**9:00 a.m.**



*Presented by Prof. H.K.D.H. Bhadeshia, Dept. of Materials Science and Metallurgy, University of Cambridge*

Harry Bhadeshia is the TATA Steel Professor of Metallurgy at the University of Cambridge. His research is concerned with the theory of solid-state transformations in metals, particularly multicomponent steels, with the goal of creating novel alloys and processes with the minimum use of resources.

**Alloying Element Nitride Development in Ferritic Fe-based Materials upon Nitriding**
**10:00 a.m.**

*Presented by Mr. Tobias Steiner*

Tobias Steiner is a materials expert for stainless steels at Robert Bosch GmbH in the department GS/ECC-FA. His research is mainly focused on the nitriding behavior of ternary Fe-Cr-Mo alloys and the evolution of the XRD peak shape upon nitriding of ferritic alloys.

**Surface Treatment by Electron Beam in Combination with Other Heat Treatment Technologies**
**11:00 a.m.**

*Presented by Prof. Dr.-Ing. habil. Rolf Zenker, Zenker Consult Mittweida*

Rolf Zenker is Honorary Professor at TU Bergakademie Freiberg and Managing Director of Zenker-Consult Mittweida.

### Residual Stress Symposium

This special symposium will provide an overview of the current state of the art for residual stress prediction, measurement, and control in industry. Presentations will be given by major aerospace OEMs and experts in the field of residual stress modeling and measurement.

### Technical Program

Technical program topics include vacuum processes and technology, advanced thermal processing, ferrous and non-ferrous mechanical properties, materials characterization, quenching and quenchants, nitriding, and tribology and wear of engineered surfaces.

## NETWORKING OPPORTUNITIES

### Welcome Reception with Exhibitors

**Monday, April 18, 5:30-7:30 p.m.**
**Hyatt Regency Savannah**

Relax, meet with exhibitors, and enjoy light appetizers and drinks.

### Savannah Riverboat Cruise

**Tuesday, April 19, 6:30-9:00 p.m.**
**Tickets: $85.00 each (pre-registration required)**

Don't miss this exciting night aboard the Savannah Riverboat Cruise with a delicious buffet dinner featuring local cuisine. Venture onto the top deck and capture an amazing evening view of one of the most famous waterfronts in the world.

### Reception and Dinner

**Wednesday, April 20, 6:00-8:00 p.m.**
**Hyatt Regency Savannah**

One ticket is included with registration. Additional tickets are $70.00 each.

Enjoy a night with friends and colleagues at the IFHTSE 2016 Dinner Reception.

### Spouse Program

**Wednesday, April 20, 10:30 a.m.-2:00 p.m**
**Tickets: $75.00 each (pre-registration required)**

View beautiful downtown Savannah on this 90-minute guided history trolley tour and enjoy lunch at The Lady & Sons. Program includes on/off trolley access after the tour for the rest of the day.

## EXHIBITOR LIST

| |
|---|
| Advanced Energy |
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| Wickert Hydraulic Presses USA |
| WPX Faserkeramik GmbH |

To learn more, visit asminternational.org/web/ifhtse/home.

# ASMNEWS

## ROBERT HILL TO CHAIR 2016 NOMINATING COMMITTEE

Members of the 2016 Nominating Committee have been selected and **Mr. Robert Hill, Jr., FASM,** president, Solar Atmospheres of Western PA, Hermitage, Pa., was elected to serve as Chair by the ASM Board of Trustees. Hill has been a member of ASM International since 1980 and has been active in publishing and presenting information on vacuum technologies and vacuum heat treating applications at ASM's Heat Treating Conference and various local chapters throughout the country. In 2000-2001, Hill served as Chair of ASM's Philadelphia Liberty Bell Chapter. In addition, he co-chaired the 2003 and 2005 ASM Heat Treating Society Conference and Exposition and served as ASM Trustee from 2010-2012. He was elected an ASM Fellow in 2013. Hill received a B.S. from Millersville University and a degree in metallurgy from Spring Garden College.


Hill

### ASM Officers Appoint Members

In accordance with the ASM International Constitution, ASM president **Mr. Jon D. Tirpak, FASM,** vice president **Dr. William E. Frazier, FASM,** and immediate past president **Dr. Sunniva R. Collins, FASM,** appointed nine members to the Nominating Committee from among candidates proposed by chapters, committees, councils, and ASM Affiliate Society boards. The committee is responsible for selecting a nominee for vice president-trustee (one-year term) and for nominating three trustees (three-year terms). Members do not select a candidate for president of the Society, because Article IV, Section 3 of the Constitution states that the office of president shall be filled for a period of one year by succession of the vice president. The 2016 Nominating Committee's nominee for vice president will serve as ASM's president in 2018.

### Nominating Committee Members for 2016 Include:

**Erin L. Camponeschi,** materials development engineer, Albany International Corp., Menasha, Wis. (nominated by Emerging Professionals Committee); **Christopher Dambra,** manager, CSC Americas, Oerlikon Metco, Westbury, N.Y. (nominated by Thermal Spray Society); **James G. Hemrick,** senior research engineer, Reno Refractories Inc., Morris, Ala. (nominated by Volunteerism Committee); **Elizabeth R. Huber,** consultant, Houston, (nominated by Houston Chapter); **Stephen G. Kowalski,** president, Kowalski Heat Treating Co., Cleveland (nominated by Heat Treating Society); **Aaron D. LaLonde,** principal materials engineer, Swagelok Co., Solon, Ohio (nominated by Cleveland Chapter); **Dana J. Medlin, FASM,** senior managing consultant, SEAL Laboratories, Omaha, Neb. (nominated by Handbook Committee); **Donald R. Muzyka, FASM,** president & CEO, retired, Special Metals Corp., Reading, Pa. (nominated by Finance Committee); **Tresa M. Pollock, FASM,** professor, University of California, Santa Barbara (nominated by Awards Policy Committee).

The Nominating Committee will meet on April 14-15 and its recommended slate of officers will be published in the June issue of *ASM News*.

### ASM Appoints Interim Managing Director

In early February, ASM International named **Tom Dudley** interim managing director. In this role, he will be responsible for Society operations while the Board of Trustees conducts a national search for a permanent managing director. Dudley was chosen by a selection committee headed by ASM trustee Jackie Earle, a metallurgist at Caterpillar. The search committee recommended Dudley based on his experience, business acumen, leadership, and ability to carry out ASM's vision.


Dudley

## In This Issue



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

A physicist by trade with a major in astrophysics, Dudley has been a private consulting engineer in oil and gas, applications engineer for biopharmaceutical, medical device, and petrochemical markets, and has a background in aerospace, semiconductor, and power industry applications. He has worked extensively with nickel-base alloys and stainless steels, holds a patent for predicting weld corrosion resistance, and pioneered alloy 254SMO as the de facto standard for offshore oil and gas valves. In his most recent position, he worked as group vice president of technology and innovation for Parker Hannifin Corp. In this role, he held global fiscal responsibility for $1.2 billion and had 200 engineers and scientists reporting to him.

Tirumalai Sudarshan, president and CEO of Materials and Modification Inc., will lead the committee conducting a national search to select ASM's next managing director. The committee has a goal date of October 2016.

## Call for Volunteers

ASM International is seeking qualified volunteers for 2016-2017 Committee and Council appointments. For more information, review the Committee Job Descriptions for further details on activities, time commitments, and subcommittees at asminternational.org/membership/committee-involvement. Next, fill out the Volunteer Interest Form found under the Membership tab at asminternational.org. Appointments will be finalized by the end of June with terms beginning **September 1.**

## Emerging Professionals Seek Contributors

The Emerging Professionals Committee (EPC) is always looking for new topic areas to discuss, technical or not. Whether you are looking to write an article for *EPC Corner,* wanting to find out about another industry, or interested in finding out how to handle a certain situation, EPC would love to get some input on what you want to see in the next *EPC Corner!* Articles are due a little over one month prior to the *AM&P* issue, so an article in May would be due at the end of March. For details, contact andrew.devillier@gmail.com.

EPC has also started an ASM Emerging Professionals Facebook page where visitors can learn about what's happening with ASM and the Emerging Professionals in particular. We regularly post links to webinars and EPC events, but we are still looking for new content. Much like the *EPC Corner* articles, we are looking for input on what you'd like to see. Like us on Facebook and send us a message. Find us by searching for "ASM Emerging Professionals" or follow this link: facebook.com/ASM-Emerging-Professionals-1531958930391760.

## ASM International Student Paper Contest Seeks Entries

ASM encourages students to submit papers to the ASM International Student Paper Contest. The contest is designed to increase interest and awareness in materials science and engineering, and to provide recognition for outstanding student efforts in the field. The competition is open to all Material Advantage student members who are enrolled at a college or university offering courses in materials science and engineering. The winner will receive a cash prize of $500, plus up to $500 toward travel expenses to attend MS&T16. In addition, a full set of ASM Handbooks or an online subscription to the Handbooks will be presented to the school or student chapter of the winning entry. For more information, visit asminternational.org/membership/awards/nominate or contact christine.hoover@asminternational.org. **Entry deadline is April 1.**

## ASM Seeks Vice President and Board of Trustees Nominations

ASM is seeking nominations for the position of vice president as well as three trustees. The Society's 2016-2017 vice president and trustee elects will serve as a voice for the membership and will shape ASM's future through implementation of the ASM Strategic Plan.

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

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

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

**Deadline for nominations is March 15.** For more information, visit asminternational.org/vp-board-nominations or contact Leslie Taylor, 440.338.5151 ext. 5500, or leslie.taylor@asminternational.org.

## Canada Council Award Nominations due April 30

ASM's Canada Council seeks nominations for its 2016 awards program. These prestigious awards include:

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

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

**John Convey Innovation Awards**–In 1977, the Canada Council created a new award to recognize contributions of sustaining member companies for further development of the materials engineering industry in Canada. The award considers a new product and/or service directed at the Canadian or international marketplace. Two awards are presented each year, one to a company with annual sales in excess of $5 million, and one to a company with annual sales below $5 million. Recent recipients include CanmetMATERIALS and Nemak, both of Ontario.

Nomination forms and complete rules can be found at asminternational.org/membership/awards/nominate. Contact christine.hoover@asminternational.org for a unique nomination link or more information.

## ASM Materials Camp Canada Announces New Administrator

Carolina Castellanos was recently named as the new administrator for ASM Materials Camp Canada. She is taking over this role from Jan Richmond, who was instrumental in establishing the Canadian camps and served as administrator for the past 16 years. Castellanos has a degree in architecture and has been working at McMaster University as an event planner for the past 10 years.

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

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

- An opportunity like no other!
- All expenses to attend meetings paid for by the respective Society
- Take an active role in shaping the future of your professional Society
- Actively participate in your professional Society's Board meetings
- Gain leadership skills to enhance your career
- Add a unique experience to your resume
- Represent Material Advantage and speak on behalf of students
- Work with leading professionals in the field
- Application deadline is **April 1.** Visit asminternational.org/students/student-board-member-programs for complete form and rules.

Opportunities specific to each Society:

**ASM International**
- Attend four Board meetings (June 20-22, October 23-26 during MS&T16, March and June 2017)
- Term begins June 1

**ASM Heat Treating Society**
- Attend two Board meetings (October 2016 during Furnaces North America and spring 2017)
- Participate in two teleconferences
- Term begins in September

**ASM International Metallographic Society**
- Attend one Board meeting (July 2017)
- Participate in monthly teleconferences
- Term begins in August

**ASM Thermal Spray Society**
- Attend one U.S. Board meeting in the second half of 2016
- Participate in two teleconferences
- Receive a one-year complimentary membership in Material Advantage
- Term begins in October

## FROM THE PRESIDENT'S DESK

Tirpak

### Exploring ASM's Beliefs Statement

For the balance of my term as president of ASM International, I plan to author short briefs that you can read over a cup of coffee. I will expound upon topics such as ASM's beliefs, values, mission, and other subjects. For now, let's explore a proposed beliefs statement:

- We believe materials enable society.
- We believe ASM empowers collective human intellect, which is essential to exploiting these materials.
- We believe that ASM and its members are servant leaders, welcoming all to partner with us in our service to society.

As I write this column, I'm aboard an aircraft comprised of high strength steel in the landing gear, wing and fuselage skins of aluminum, and engine discs, blades, and stators of titanium and superalloys. All of these materials enable a five-hour flight from Charlotte to Los Angeles. Yet this is just one example of how materials enable society through entire industries, from automotive and consumer products to energy and medical equipment.

To create, develop, and deploy these materials for the benefit of humanity, ASM serves as an integrating force. Materials Park, featuring The Dome, is the spiritual focal point of our collective human intellect and serves as the foundation to support our first belief. ASM is ***the place to be*** for world class materials information. Our *Handbooks* (print and digital), databases, courses, conferences, chapters, affiliate societies, partnerships, and awards program all support our members as they support the broader society with information regarding materials science, technology, engineering, and manufacturing.

To quote British metallurgist Cyril Stanley Smith, "The materials engineer is a servant leader." As materials professionals, we are compelled to serve others. We might not make the airplane, but we provide the best of materials science to enable the airplane. We seek to serve and share our expertise, and we welcome ALL in this grand endeavor called materials engineering. We believe in a diverse membership from around the world to serve humanity through materials. I hope you agree with these foundational beliefs!

*Jon D. Tirpak, PE, FASM*
*Chief Volunteer of ASM International*
*jon.tirpak@scra.org*

## CHAPTERS IN THE NEWS

### Detroit Rewards Student Achievements

As part of its student outreach program, the Detroit Chapter judged a "Best Use of Materials Award" at the 2016 Michigan Regional Future Cities Competition. A nationwide competition, Future Cities challenges middle school students to design and create a futuristic city. Entries are judged on the students' vision of advanced materials usage, as well as the variety and use of materials in their model. University High School Preparatory Academy, Southfield, won the award for their city. The challenge was to develop and incorporate new technologies that would allow the needs of future civilizations to be fully met while minimizing waste and maximizing recycling. The team's teacher, Tiffany Hackworth, was honored as Outstanding Teacher for the competition. Chapter members James Boileau, Gerald Cole, Manish Mehta, Eric McCarty, J.P. Singh, Tim Stachowski, and Gary Witt served as judges.

The winning team from University High. Left to right, back row: Andrew Humphries, James Boileau, Robert Magee, and Bob Washer. Left to right, front row: Tiffany Hackworth, Korey Sanders, Robyn Trimble, and Rileigh Foster.


The ASM judging team. Left to right, Tim Stachowski, Gary Witt, James Boileau, Gerald Cole, Eric McCarty, and Manish Mehta.

### India Discusses Materials Camps

Left row, front to back: Pankaj Deval, Rajesh Shah, Ashok Tiwari, Prem Aurora, and Vishwas Altekar. Right row, front to back: Suhas Sabnis, H.M. Mehta, Aziz Asphahani, Sundip Parikh, and Naresh Daftary. The India Chapter, Mumbai, enjoyed a special lunch meeting in February with visiting ASM Materials Education Foundation past chairman Aziz Asphahani, FASM, where topics related to ASM Materials Camp programs and student memberships were discussed.

## MEMBERS IN THE NEWS

### Pollock Named Principal Editor for Metallurgical and Materials Transactions

In January, it was announced that the new principal editor of the *Metallurgical and Materials Transactions (Met Trans)* family of journals will be **Tresa M. Pollock, FASM**. The Alcoa Professor and chair, Department of Materials, University of California, Santa Barbara (UCSB), Pollock will begin her editorship on September 1 and will work alongside current principal editor, **David Laughlin, FASM,** through the end of 2016 when he steps down. Laughlin, the Alcoa Professor of Physical Metallurgy at Carnegie Mellon University, has led *Met Trans* as principal editor since 1987. Pollock likewise has a long association with *Met Trans,* having served as an associate editor since 1997.

Jointly published by ASM International and TMS, *Metallurgical and Materials Transactions* was founded as the *Metallurgical Transactions* journal in 1970, and has since expanded to encompass three peer-reviewed journals for metallurgy and materials science. *Met Trans A* focuses on physical metallurgy and materials science, *Met Trans B* covers the theoretical and engineering aspects of processing metals and other materials, and *Met Trans E* explores materials being investigated or applied to address energy technologies.

Pollock began her career at GE Aircraft Engines, where she developed advanced superalloys for gas turbine engines. In 1991, she joined the materials science and engineering faculty at Carnegie Mellon University, later moving to the University of Michigan in 2000, and then joining the Materials Department at UCSB in 2010. Pollock's current interests span mechanical and environmental performance of materials in extreme environments, unique high-temperature materials processing paths, ultrafast laser-material interactions, alloy design, and 3D materials characterization.

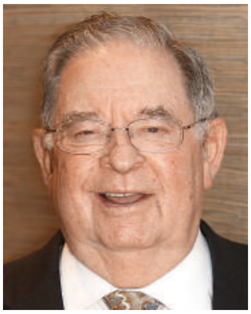
### Abkowitz Honored by Boston Patent Law Association

In October 2015, the Boston Patent Law Association's (BPLA) *Invented Here!* Committee celebrated Massachusetts Inventors Day by holding its fifth annual event honoring New England's innovators and their innovations. This year, the event recognized **Stanley Abkowitz, FASM,** an inventor who is a leader in the titanium industry. Abkowitz has received patents in each of the past seven decades and still has patent applications pending. His innovations have made their way into military, commercial, and consumer products. During his speech, Abkowitz shared how his titanium process and compounds are created and used in the development and production of titanium components.

## Singh Honored as Regents Professor at Oklahoma State

**Raj Singh, FASM,** head of the Oklahoma State University (OSU) School of Materials Science and Engineering, Williams Companies Distinguished Chair Professor, and Director of Energy Technologies programs, was honored as an OSU Regents Professor at the University Awards Convocation on December 1, 2015. The title is bestowed to recognize a scholar or creative artist of exceptional ability who has achieved national and international distinction. Singh's scientific contributions and inventions have been used in the development of products such as ceramic matrix composites for more efficient aircraft engines, more powerful sodium-sulfur batteries utilized for energy storage systems, and novel electrolyte retainers and self-repairing glasses for molten carbonate and solid oxide fuel cells. In 2015, he was also named a fellow of the National Academy of Inventors.

## Gold Receives ASTM International Award



In January, ASTM International Committee B02 on Nonferrous Metals and Alloys presented the Gary M. Kralik Distinguished Service Award to consultant **Michael Gold** of Gold Metallurgical Services LLC, North Benton, Ohio. The committee noted Gold's outstanding service as a member since 1979, and his key contributions to the Subcommittee on Refined Nickel and Cobalt and Their Alloys (B02.07). Gold is also active on Committee A01 on Steel, Stainless Steel and Related Alloys. That committee has honored him with the A01 Award of Excellence and the Award of Merit, ASTM's highest award for individual contributions to standards activities. Gold specializes in materials applications for boilers and pressure vessels, including procurement, production, design limits, fabrication, and failure analysis.

## IN MEMORIAM

**Donald D. Goehler, FASM,** passed away on December 15, 2015. He was born in Portland, Oregon, in 1930 and joined the Puget Sound Chapter in 1957, where he held every office and committee position, serving as chairman, membership chair, and most recently communications chair. He was also the ASM Chapter representative on the Puget Sound Engineering Council (PSEC) and treasurer of PSEC between 1996 and 2010. He was nominated for the Allan Ray Putnam Service Award for his service to the Chapter in 2004, in recognition of his then over 40 years of continuous service. Goehler received his bachelor's degree in metallurgical engineering from the Montana School of Mines in 1952 and joined The Boeing Co. in 1956, where he rapidly progressed to engineering manager, materials technology, a position he held until he retired in 1995. After retiring, he continued as a volunteer engineer at The Museum of Flight in Seattle where he worked on restoration of the Boeing B-29.

**Conrad H. Knerr** passed away on January 21. Knerr was a former owner of one of the Philadelphia Chapter's oldest sustaining member companies, Metlab Co. Knerr's father, Horace, founded Metlab in 1928 and was a University of Pennsylvania graduate in electrical engineering, and before that was one of the Chapter's first chairs in 1924-25. Metlab was originally in the business of fabricating aircraft airframe components and later specialized more in heat treating than fabrication. Conrad earned a bachelor's of science degree in metallurgy from Massachusetts Institute of Technology in 1948 and was a registered professional engineer in Pennsylvania. He served in the U.S. Navy during WWII. Knerr followed in his father's footsteps and joined Metlab in 1948, and was elected to succeed his father as president in 1961. In 1998, he sold the heat treating business. Knerr won his Chapter's Eisenman award in 1994. He served on many committees over the years and was a contributing author to the 10th edition of ASM's *Metals Handbook.*

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# 3D PRINTSHOP

## AMUG ANNOUNCES KEYNOTE SPEAKERS

The Additive Manufacturing Users Group (AMUG) recently announced keynote speakers for its 28th annual conference taking place April 3-7 in St. Louis. Todd Grimm, Jason Lopes, and Paul Litchfield will discuss additive manufacturing applications, trends, and technologies during their lectures. Grimm's presentation, "The Age of Innovation," will examine current and future trends as well as recent product introductions. Spanning film and television, Lopes pushes the limits of AM technology to create amazing physical effects. His lecture will highlight the tools he uses to achieve these results. Among others, his film credits include "Avatar," "Iron Man," "The Avengers," and "RoboCop."

Litchfield's talk, "The Legacy of Reebok Innovation in Partnership with Additive Manufacturing," will share insights into Reebok Advanced Concepts' operations. Litchfield served as vice president of this Reebok division, which develops innovations such as the Reebok Pump, DMX Moving Air, and Checklight. The conference will also feature an innovators showcase, on-stage conversation with Stratasys co-founder Scott Crump, and a panel discussion with 10 leaders of top additive manufacturing companies. The balance of the conference will include more than 200 presentations, workshops, and hands-on training sessions. *am-ug.com.*

From left to right, Jason Lopes, Paul Litchfield, and Todd Grimm.

EOS M 290 DMLS system.

## NEW TOOL ENABLES IN-PROCESS MONITORING

A new add-on to the EOS M 290 DMLS system—called EOSTATE MeltPool Monitoring—may be of particular interest to R&D and manufacturing teams with demanding quality requirements. This online tool offers part traceability as well as automated surveillance and analysis of the material melt pool during the complex direct metal laser sintering (DMLS) build process—per spot, per layer, and per part. According to company sources, the new tool moves part quality assurance from post- to in-process, supporting better risk management, minimizing time and costs for quality assurance, and reducing overall costs per part.

Here's how it works: The tool observes light emitted by the melt pool. Key elements include two photodiodes located on- and off-axis, a camera adapter and specialized signal amplifier, and spectral filters that separate process light from reflected laser light. The software offers automatic data error correction and real-time process visualization and evaluation. For data analysis, the MeltPool Analysis Toolbox visualizes data in 2D or 3D mappings using three advanced algorithms, enabling evaluation of indication clusters. Live monitoring during the build process of actual parts helps to automatically identify error indications based on predefined parameters. *www.eos.info.*

3MF CONSORTIUM

## GE JOINS 3MF CONSORTIUM

The 3MF Consortium, Wakefield, Mass., announces that GE Global Research—the central technology development hub of GE that is pioneering uses for additive manufacturing—has joined at the founding membership level. The consortium is an industry association launched in 2015 to develop and promote a new full-fidelity file format for 3D printing. It was formed to close the gap between the capabilities of modern 3D printers and outdated file formats. The 3MF specification eliminates problems associated with currently available file formats, thereby resolving interoperability and functionality issues. The first version of the 3MF specification is available for download free of charge. *www.3mf.io.*