MAY/JUNE 2017 | VOL 175 | NO 4

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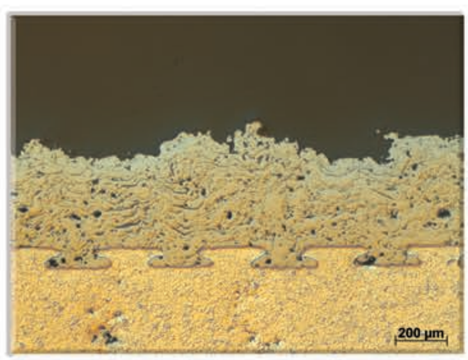

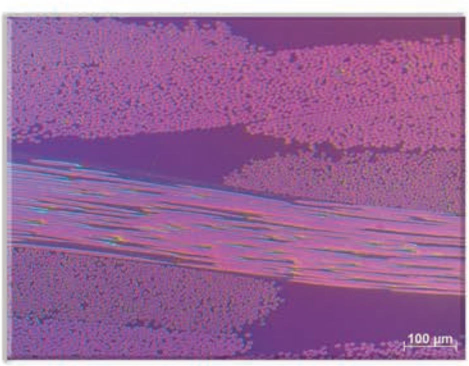

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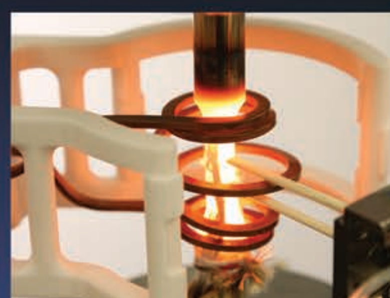

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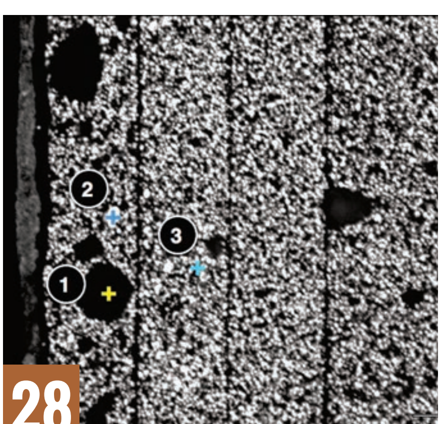
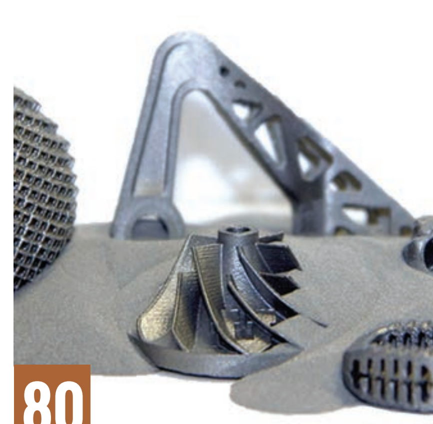
On the Cover:

Midsize Yamaha motorcycle. New designs from Yamaha are incorporating aluminum components produced by high pressure die casting. Courtesy of Yamaha Motor Co. Ltd.





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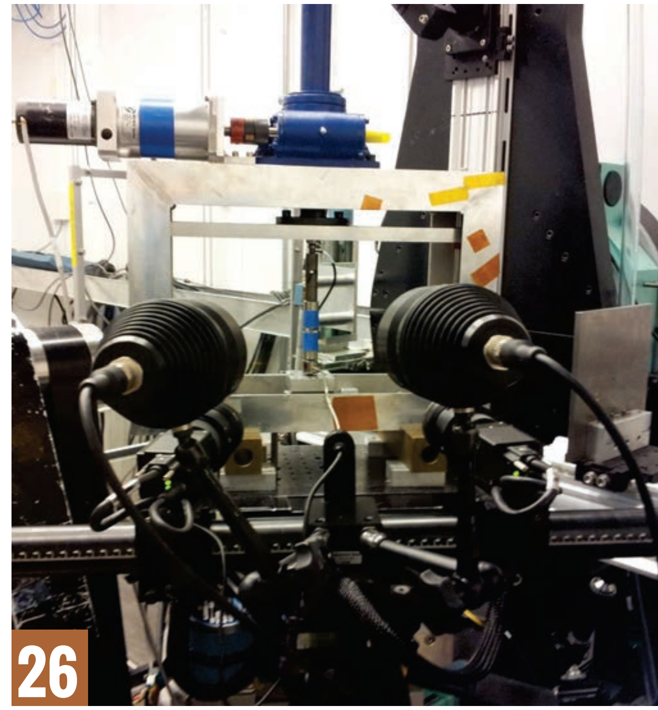
FEATURES



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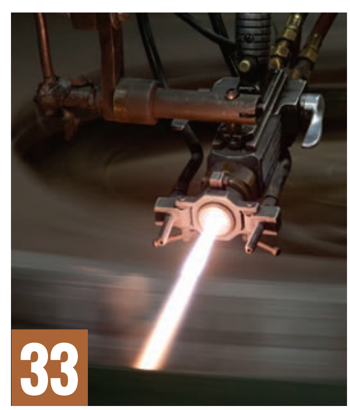

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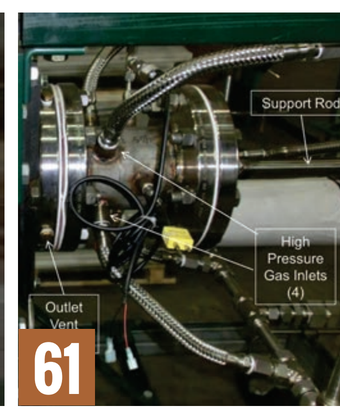

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TRENDS

INDUSTRY NEWS

DEPARTMENTS

Advanced Materials & Processes (ISSN 0882-7958, USPS 762080) publishes eight issues per year: January, February/March, April, May/June, July/August, September, October and November/December, by ASM International, 9639 Kinsman Road, Materials Park, OH 44073-0002; tel: 440.338.5151; fax: 440.338.4634. Periodicals postage paid at Novelty, Ohio, and additional mailing offices. Vol. 175, No.4, MAY/JUNE 2017. Copyright © 2017 by ASM International. All rights reserved. Distributed at no charge to ASM members in the United States, Canada, and Mexico. International members can pay a $30 per year surcharge to receive printed issues. Subscriptions: $475. Single copies: $51. POSTMASTER: Send 3579 forms to ASM International, Materials Park, OH 44073-0002.
Change of address: Request for change should include old address of the subscriber. Missing numbers due to "change of address" cannot be replaced. Claims for nondelivery must be made within 60 days of issue.
Canada Post Publications Mail Agreement No. 40732105. Return undeliverable Canadian addresses to: 700 Dowd Ave., Elizabeth, NJ 07201. Printed by Publishers Press Inc., Shepherdsville, Ky.

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TEAMWORK! TEAMWORK! THAT'S WHAT COUNTS!

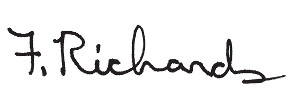
As part of the ongoing ASM Renewal effort, all ASM staff members recently took part in a two-day training program. Along with some teambuilding exercises and conversations, we also learned new listening and storytelling skills. As one of our coaches said, how many of us have had any formal listening training? When this question was posed, nobody raised their hand—yet being a good listener can work wonders in both personal and business settings. During the offsite training retreat, we all practiced gathering stories from each other and repeating them back to make sure we understood the point of the story. These were useful exercises and I can certainly think of a few friends and colleagues who could benefit from upping their listening game. All in all, the session seemed to go well and the teambuilding aspect was a major benefit.

Speaking of teamwork, sometimes the best opportunities seem to arise from challenges of all sizes. Be sure to check out the ad hoc pit crew story on page 65 starring Ravi Ravindran and other members of the ASM Nominating Committee. To peak your interest, let's just say it begs the question, "How many materials engineers does it take to change a tire?"

Also in this issue are other prime examples of groups of people working together. For one, consider our quarterly newsletters. Both *HTPro* and *iTSSe* are included in this special double issue of *AM&P*. These newsletters are definitely a team effort and we couldn't produce them without the help of key industry insiders in both the ASM Heat Treating Society (HTS) and ASM Thermal Spray Society (TSS). Within HTS, we have an R&D Committee chaired by Mike Pershing and formerly by Aquil Ahmad. These leaders, along with a very active group of members, provide technical insights, editorial direction, and state-of-the-art manuscripts about today's heat treating environment. The same holds true for TSS. Charlie Kay is instrumental as an editor and advisor for *iTSSe* and encourages others, such as Chris Berndt in this issue, to provide current and insightful articles on the state of thermal spray. These publications simply would not be possible without this kind of collaboration.

As another example of teamwork in this issue, see the advanced high-strength steel update beginning on page 25. This article highlights an industry partnership involving Chrysler, GM, and Ford, and its progress on the collaborative development of lightweight automotive metals. Also involved in the effort are Pacific Northwest National Laboratory, Brown University, The Ohio State University, the University of Illinois, Colorado School of Mines, Clemson University, AK Steel, Argonne National Laboratory, and the Auto/Steel Partnership. In short, the team has developed two new high-performance alloys and scaled up its steelmaking process to produce large heats. Again, this kind of groundbreaking research would not be possible without bright minds from several key industry players working together toward a common goal.

If your organization has been involved in teambuilding or listening training, we'd like to hear your thoughts on the matter and see if you've noticed positive results. In the meantime, we hope you enjoy our double issue!



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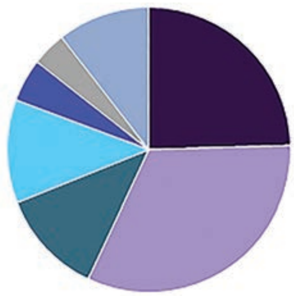
MARKET SPOTLIGHT

CARBON THERMOPLASTIC COMPOSITES MARKET POISED FOR GROWTH

U.S. CFRTP Composite Market Volume Share by Application, 2015 (%)



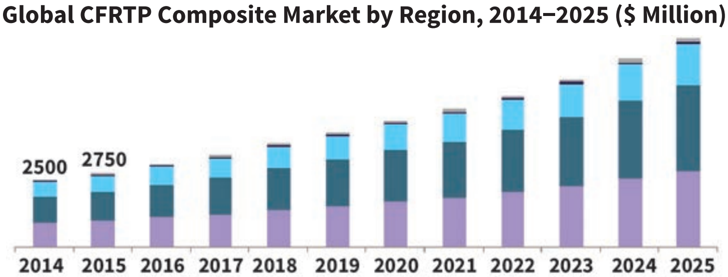
Source: Grand View Research Inc.

A new report from Grand View Research Inc., San Francisco, values the global carbon fiber reinforced thermoplastic (CFRTP) composites market at \$2.75 billion for 2015, with growth projected at a CAGR of 10.8% from 2016 to 2025. "Carbon Thermoplastic (CFRTP) Composites Market Analysis by Raw Material (PAN, Pitch), by Application (Automotive, Aerospace & Defense, Wind Turbines, Sport, Construction, Marine), and Segment Forecasts, 2014–2025" shows increasing use of CFRTPs in industries such as automotive, aerospace, wind energy, construction, and marine due to more stringent requirements for lightweight materials and fuel efficiency. Automotive use is the fastest growing application segment with an estimated CAGR around 14% over the forecast period.

The primary ingredients in CFRTP manufacturing are polyacrylonitrile (PAN) and petroleum pitch. The superior properties of PAN over petroleum pitch are expected to drive the PAN market for the global CFRTP market, say analysts. The PAN-based CFRTP market in North America is projected to grow at a CAGR of over 12%, creating a demand of more than 18,000 tons by 2025. North America is expected to be the largest market for CFRTPs, accounting for over 35% of global market demand due to the concentration of major aircraft and defense manufacturers. Europe is projected to be the fastest-growing market. Strict laws and regulations regarding vehicle emissions and dedicated attempts made by European automakers in this regard are further expected to spur growth in this area.

In terms of competition, key players include Toray Industries Inc., SGL Group, Hexcel Corp., Teijin Ltd., Mitsubishi Rayon Co. Ltd., and BASF SE, among others. Agreements, partnerships, supply contracts, alliances, joint ventures, and collaborations are the main strategies adopted by these companies to achieve growth, especially in the automotive sector. The CFRTP market is defined by the presence of few participants, with the major ones having a high level of value chain integration. *For more information, visit grandviewresearch.com.*

Global CFRTP Composite Market by Region, 2014–2025 (\$ Million)



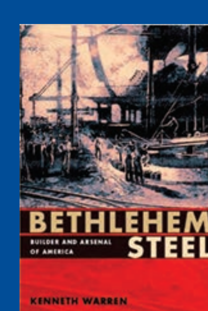
Source: Grand View Research Inc.

FEEDBACK

BOOKS ON BETHLEHEM

I recently read two very interesting articles in *AM&P* on the decline of the American steel industry ("Metallurgy Lane," Nov/Dec 2016 and January 2017). I joined Bethlehem Steel in 1977 just out of graduate school and I was there when the first round of layoffs hit at Homer Research and Martin Tower. I left shortly after that and just retired after more than 35 years in the chemical and oil industries. Do you know of any good books that chronicle the decline of steel? In the last few years, I've read two books on what happened in the auto industry and would like to find a similar book on steel. I read "Crisis in Bethlehem" by John Strohmeyer and enjoyed it. However, because it was published in 1986, it misses the last 30 years.

Lindell (Bob) Hurst



[I would recommend "Bethlehem Steel: Builder and Arsenal of America" by Kenneth Warren, published in 2008 by the University of Pittsburgh Press. —Charles R. Simcoe]

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

OMG!
OUTRAGEOUS MATERIALS GOODNESS

Bionic hand used to demonstrate biomimetic properties. Courtesy of Sam O'Keefe, Missouri S&T.

SUPERELASTIC AEROGELS LEND A HELPING HAND

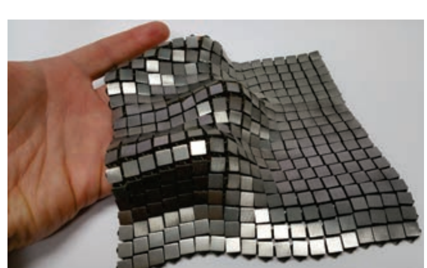
Chemists at Missouri University of Science and Technology, Rolla, are making polymeric aerogels with rubberlike elasticity that can remember their original shapes. "The specific kind of polyurethane aerogels we have created are superelastic, meaning they can be bent in any direction or be smashed flat and still return to their original shape," explains lead researcher Nicholas Leventis. "Our superelastic aerogels are different from rubber in that they can return to a specific form on command. That is, they also show a strong shape memory effect, meaning they can be deformed and cooled and keep the deformed shape forever. However, when the temperature rises to room temperature, they recover their original undeformed shape."

As part of the project, Leventis and his group created a bionic hand capable of mimicking coordinated muscle functions. When stimulated by heat, the aerogel can close from its open-palm state and grab a pen. "We believe this work has produced one of the 'holy grails' in the field of aerogels," says Leventis. "I see a lot of biomimetic applications for these aerogels in the future. Their flexibility, combined with elasticity, greatly enhances the range of possible uses." *news.mst.edu.*

FUNCTIONAL FABRIC BLASTS OFF

Raul Polit Casillas, whose mother is a fashion designer in Spain, grew up around fabrics. Now a systems engineer at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, Calif., he is still immersed in the textiles world, designing advanced woven metal materials for space. These fabrics could be useful for large antennas and other deployable devices because the material is foldable and its shape can change quickly. The fabrics could also be used for spacesuits and to shield spacecraft from meteorites, among other applications. The prototypes that Polit Casillas and his team have created look like chain mail, with small silver squares strung together. But they are not sewn by hand: They are printed using additive manufacturing.

"We call it '4D printing' because we can print both the geometry and function of these materials," says Polit Casillas. "If 20th century manufacturing was driven by mass production, then this is the mass production of functions." The space fabrics provide four essential functions: reflectivity, passive heat management, foldability, and tensile strength. One side reflects light while the other absorbs it, acting as a means of thermal control. They can also fold in many different ways and adapt to various shapes, but are sturdy enough to handle pulling forces. *www.jpl.nasa.gov.*



Metallic space fabric created using 3D printing techniques that add different functionality to each side of the material. Courtesy of NASA/JPL-Caltech.

CONDUCTIVE INK WINS PHOTO CONTEST

An image of spectacular swirling graphene ink in alcohol, which can be used to print electrical circuits onto paper, won the overall prize in a renowned science photography competition, organized by the UK's Engineering and Physical Sciences Research Council (EPSRC). "Graphene—IPA Ink," by James Macleod of the University of Cambridge, shows powdered graphite in alcohol, which produces a conductive ink. The ink is forced at high pressure through micrometer-scale capillaries made of diamond. This rips the layers apart and results in a very smooth and conductive material in solution. *www.epsrc.ac.uk.*

"Graphene—IPA Ink" by James Macleod, University of Cambridge.

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

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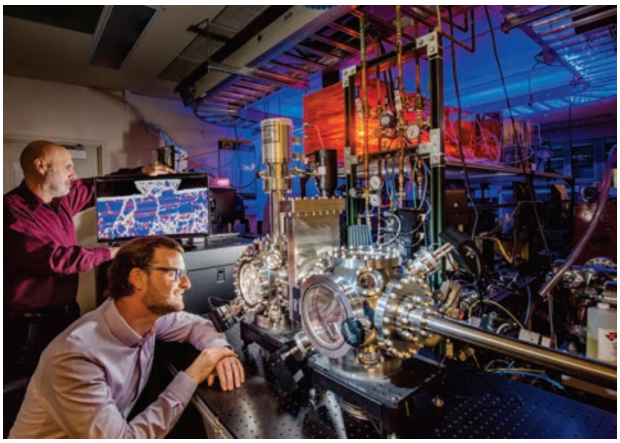

Michael Chandross, left, and Nicolas Argibay use computer simulation and an ultrahigh vacuum tribometer for friction and wear testing. Courtesy of Randy Montoya.

MAKING CONTACT WITH A NEW PREDICTIVE MODEL

Scientists at Sandia National Laboratories, Albuquerque, N.M., developed a new predictive model for metal friction behavior based on materials properties. Their research demonstrates that microstructural stability governs friction behavior, giving engineers a much more precise approach to material characterization, selection, and design. "You go from just having to say, 'The material's behavior will be this because we measured it in those conditions' to saying, 'I can tell you what conditions you can run in and get the behavior you want,'" explains materials scientist Nicolas Argibay. Until now, engineers applied rules of thumb for different conditions along with the conventional wisdom that harder materials create less friction.

The new model could revolutionize design of electrical contacts, including those used in electric cars and wind turbines. Researchers are developing a prototype for a copper-against-copper alloy rotary electrical contact for wind turbines, revisiting an approach that was not workable before the new predictive model was discovered. Ultimately, the model may allow the electrical contacts industry to turn to higher-performance direct current devices instead of the alternating current devices now in use. *sandia.gov.*

IT'S JUST A PHASE

An international team of researchers discovered a hidden amorphous phase in a class of metallic glass. Led by researchers from City University of Hong Kong, the team examined palladium-nickel-phosphorus metallic glass during heating. Reportedly for the first time ever, the scientists simultaneously assessed changes in structure—by measuring small-angle neutron scattering and heat absorption—using differential scanning calorimetry.

"We were able to directly correlate changes in the structure of the material with the energy required for that structure to change," explains Elliot Gilbert, instrument scientist at the Australian Center for Neutron Scattering, where the experiment took place. Other labs provided high-resolution microscopy images, electron diffraction patterns, and synchrotron x-ray measurements, which showed a rearrangement of atomic clusters with temperature.

Unlike most metals, which have atoms packed into regular arrays, metallic glass is composed of atoms in a disordered arrangement that has long interested scientists because it imparts valuable properties, such as hardness, corrosion resistance, and formability.

The discovery could allow researchers to induce this amorphous phase in metallic glass, tuning the properties of the material to better suit different purposes. Metallic glass is

BRIEFS

A new standard is forthcoming from **ASTM International,** West Conshohocken, Pa.—E3061, Test Method for Analysis of Aluminum and Aluminum Alloys by Inductively Coupled Plasma Atomic Emission Spectrometry (Performance Based Method). Developed by ASTM's committee on analytical chemistry for metals, ores, and related materials (E01), E3061 offers a performance-based method that also provides established preparation and analysis techniques. *astm.org.*

Nucor Corp., Charlotte, N.C., will invest $85 million to upgrade the rolling mill at its steel bar mill in Marion, Ohio. **Nucor Steel Marion Inc.** is Ohio's largest manufacturer of rebar and signpost, capable of producing over 400,000 tons annually. *nucor.com.*

In a multiyear agreement, **Toyota North America** named **Arconic,** New York, as the sole aluminum sheet supplier for the Lexus RX, a luxury SUV that debuted last year featuring aluminum exterior panels. Arconic will supply the sheet from its plants in Davenport, Iowa, and Danville, Ill., and estimates that its automotive sheet revenue could grow to $1.3 billion in 2018. *toyota.com, arconic.com.*

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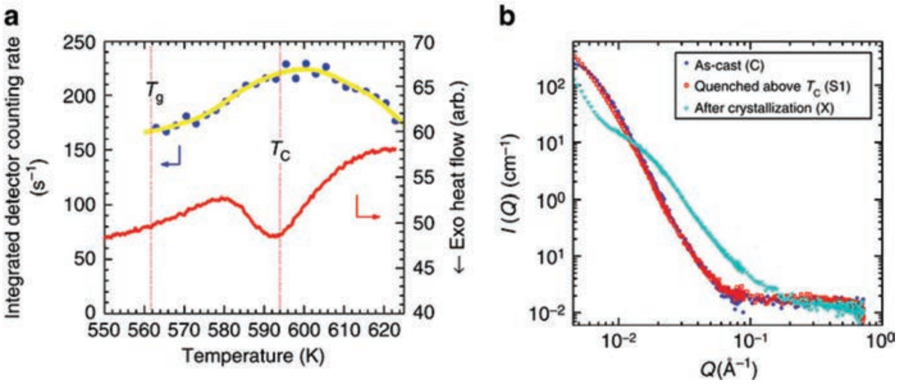
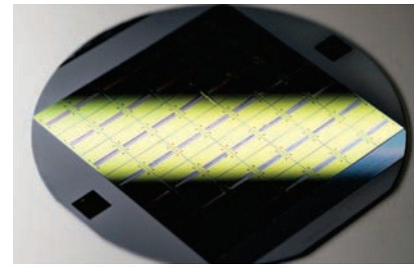


Results of simultaneous DSC-SANS measurements for the Pd41.25Ni41.25P17.5 alloy. (a) The integrated detector counting rates as a function of temperature. The simultaneous DSC scan is superimposed, showing a TC ~ 594 K at a heating rate of 2.5 K/min. The coexistence of two phases can be clearly seen in the vicinity of Tc. (b) Full-Q range SANS data for three samples: as-cast condition (C), quenched from 623 K after the transformation had ended (S1), and quenched after crystallization at 673 K (X).

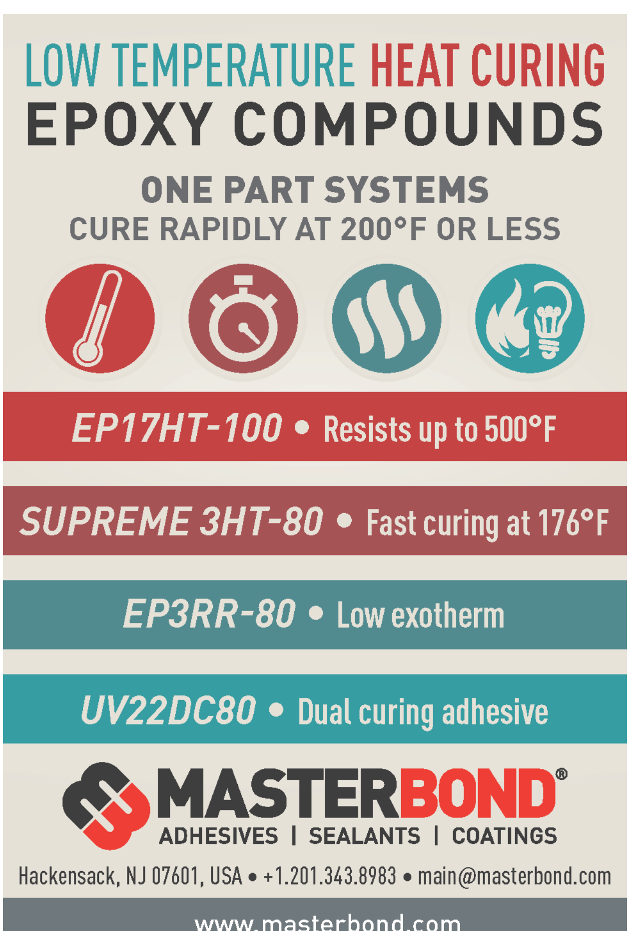
used in a range of applications including medical devices, transformers, and sports equipment. *www.ansto.gov.au.*

FLEXIGLASS MINIATURIZES MEDICAL TESTING

Researchers at Brigham Young University, Provo, Utah, developed a flexible glass membrane that could lead to a new family of onsite, rapid analysis medical devices. Glass has long been a go-to material for medical testing but its brittleness is a barrier in certain applications. Currently, lab-on-a-chip technology exists on the microscale, but the new material, which bends on the nanoscale and snaps back into shape, could take testing to the next level of detail. "We've created glass membranes that can move up and down and bend," explains electrical engineering professor Aaron Hawkins. "They are the first building blocks of a whole new plumbing system that could move very small volumes of liquid around." The glass membrane device would only require a drop or two of blood to run a test, trapping and analyzing tiny biological particles like proteins, viruses, and DNA. Analysis time could be slashed: Instead of shipping blood to a lab, the new device could provide test results on the spot. *byu.edu.*



Flexible glass membrane for medical devices. Courtesy of Jaren Wilkey/BYU.



LLNL researchers are joining forces with the U.S. Navy Metalworking Center to study ways to reduce the high cost of inspecting welds on nuclear-powered submarines.

CHEERS TO NEW WELD INSPECTION METHOD

Lawrence Livermore National Laboratory (LLNL), Calif., and the U.S. Navy Metalworking Center, Johnstown, Pa., are investigating a nondestructive method to inspect welds on nuclear-powered submarines. The technology uses acoustical structural excitation along with ultra-wide-band radar technology to "hear" defects through the submarine's coating. LLNL materials and engineering section leader Karl Fisher equates the method to tapping wine glasses—an intact glass will "ding" while a cracked glass only plunks. "In theory, the defect will radiate differently and have a different mechanical response, and we could scan it and find out where," he explains. The technology has been used to locate improvised explosive devices underground, and while it isn't guaranteed to work on submarines, it could help narrow down the search area for weld defects. Currently, hull inspections require removal and reinstallation of the submarine coating. Reducing the need for this process could shrink costs by as much as $1.2 million per hull per inspection cycle, or $6 million over a five-year period. *llnl.gov.*

SHEDDING LIGHT ON COMPOSITE INTERFACES

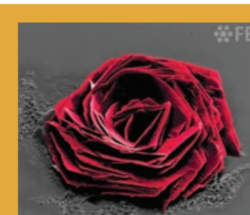
Researchers at the National Institute of Standards and Technology (NIST), Gaithersburg, Md., embedded a nanoscale probe into lightweight fiber-reinforced polymer composite, exposing damage at the interfaces between the fiber and polymer—reportedly for the first time. The probe, known as a mechanophore, was created from rhodamine spirolactam (RS), a dye that fluoresces under applied force. The RS molecule was attached to silk fibers contained in an epoxy-based composite. When force was applied to the composite, the RS was activated, and a red laser and microscope were used to take images of the miniscule fissures revealed in the glowing fibers. Conventional optical imaging techniques, which cannot record images smaller than 200-400 nm, are incapable of capturing fiber-polymer interfaces, some of which are only 10-100 nm thick.

The sensors could be used to speed up product testing and optimize composites for different applications, according to researcher Jeffrey Gilman. "If you attempt a design change, you can figure out if the change you made

Examples of the silk used in experiments to detect damage in composites, shown under black light. Left, ordinary fibroin of the *Bombyx mori* silk worm. Observed fluorescence is the result of molecules already present in the fiber's protein structure. Middle, mechanophore-labeled silk fiber fluoresces in response to damage or stress. Right, control sample without the mechanophore. Courtesy of C. Davis and J. Woodcock/NIST.

BRIEF

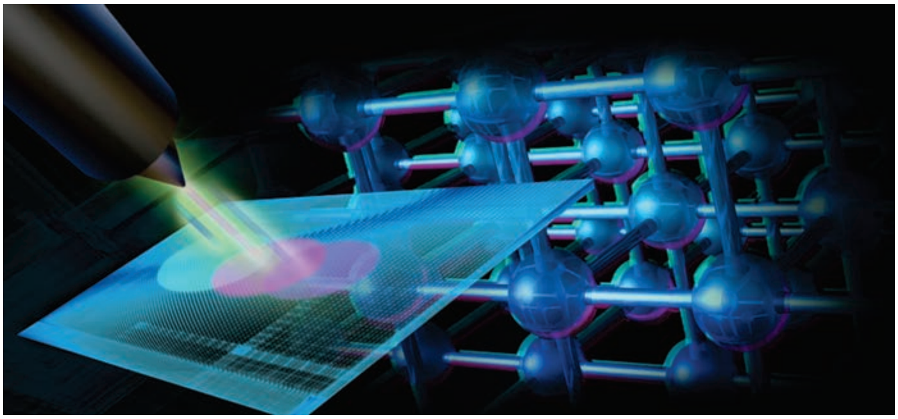
The grand prize winner of the 2016 **Thermo Fisher Scientific** Electron Microscopy image contest is Andrea Jacassi from the **Italian Institute of Technology** for "Cysteine Rose." The image was captured using the Helios NanoLab 650 DualBeam focused ion beam/scanning electron microscope, produced by **FEI,** Hillsboro, Ore., a recent acquisition of Thermo Fisher, Waltham, Mass. *thermofisher.com.*



A crystal of cysteine produced by drying a highly concentrated solution of cysteine on a silicon nitrite substrate. Courtesy of FEI.

improved the interface of a composite or weakened it," he says. Improving the ability of composites to withstand extreme cold and heat, as well as exposure to water, could be a boon to efforts to build more resilient infrastructure components such as bridges and wind turbine blades. *nist.gov.*

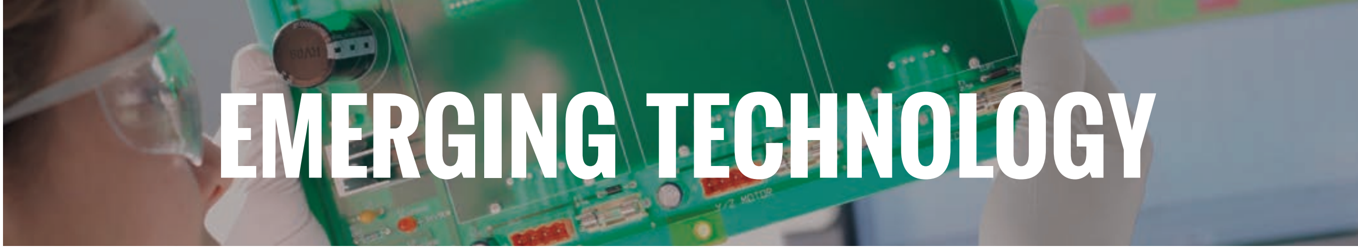
A FRESH ANGLE ON 3D STRESS DATA



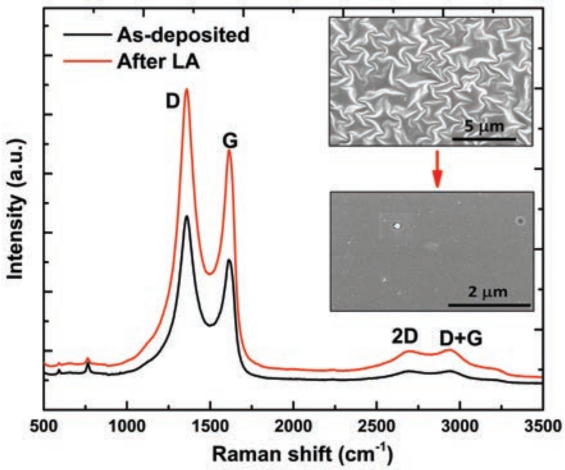
Scientists are using Bragg single-angle ptychography to get a clear picture of how planes of atoms shift and squeeze under stress. Courtesy of Robert Horn/ANL.

A team of researchers from the DOE's Argonne National Laboratory (ANL), IBM, and Institut Fresnel, France, developed a new form of imaging to investigate how planes of atoms in a material behave under stress. The method, called single-angle Bragg ptychography, marries x-ray diffraction and Bragg ptychography to reconstruct 3D data in a way that makes fewer demands on instrument technology than comparable techniques. In x-ray diffraction, atoms in a material scatter x-rays into a pattern, producing a signal that is converted to a series of waves. While the intensity of the waves is recorded, their phases are not. However, both are required to construct 3D data.

To retrieve the missing phases, researchers turned to ptychography, which uses redundant sampling from the same region of the crystal, shifting the x-ray beam only slightly between readings to overlap as much as 60% of the same real space. "By having a lot of the same information encoded in neighboring samples, it constrains the possible configurations of the crystal in real space," explains ANL materials scientist Stephan Hruszkewycz. Knowing the exact position of the beam and the angle at which the crystal's atomic planes would scatter the x-rays allows the scientists to reconstruct the 3D stress data. *anl.gov.*



EMERGING TECHNOLOGY



Raman spectroscopy of the rGO thin films. LA is pulsed laser annealing.

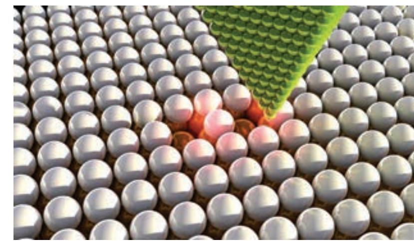
GRAPHENE OXIDE CHANGES CHARGE

Scientists at North Carolina State University, Raleigh, developed a method for changing positively charged (p-type) reduced graphene oxide (rGO) into negatively charged (n-type) rGO, producing a layered material that could be used in transistors for next-generation electronic devices. "Graphene is extremely conductive, but is not a semiconductor. Graphene oxide has a bandgap like a semiconductor, but does not conduct well," explains Jay Narayan, professor of materials science and engineering. To harness both of these desired qualities, the researchers created rGO. However, rGO is p-type. They needed to find a way to create n-type rGO as well, in order to use the material for p-n junction-based 2D electronic devices.

To make n-type rGO, Narayan and his team first integrated p-type rGO across a sapphire and silicon wafer. Then they used high-powered nanosecond laser pulses to disrupt chemical groups at regular intervals across the wafer, moving electrons from one group to another—effectively converting some of the p-type rGO to n-type rGO. The laser radiation annealing provided a high degree of spatial and depth control for creating the necessary n-type regions and the entire process took place at room temperature in less than one-fifth of a microsecond. The end result was a wafer with a layer of n-type rGO on the surface and a layer of p-type rGO underneath. This is critical because the p-n junction—where the two types meet—is what makes the material useful for transistor applications in electronic devices. *ncsu.edu.*

CUSTOMIZING ELECTRONIC PROPERTIES, ATOM BY ATOM

By arranging individual atoms in a lattice, scientists at Aalto University, Finland, created artificial materials that deliver predetermined electrical responses. Working at a temperature of 4 K, the researchers used a scanning tunneling microscope to specifically place vacancies in a single layer of chlorine atoms supported on a copper crystal. They created two structures inspired by fundamental model systems with exotic electronic properties.



Tip of a scanning tunneling microscope above chlorine atoms. By moving individual atoms under the microscope, scientists were able to arrange vacancies in a single layer of chlorine atoms and create atomic lattices with a predetermined electrical response. Courtesy of Aalto University.

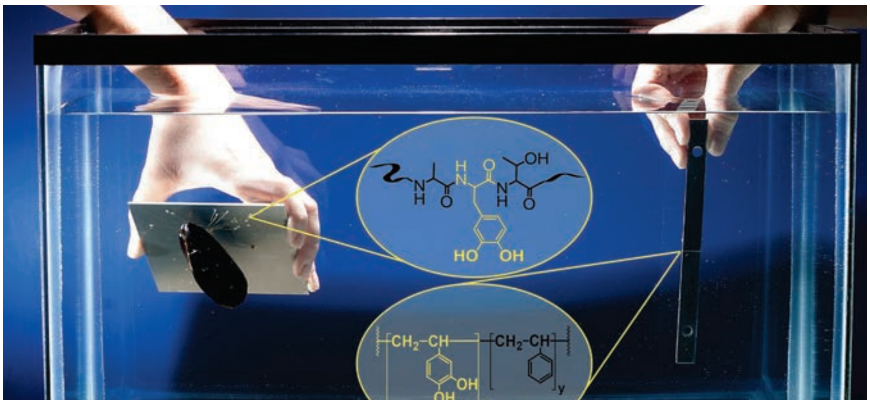
"The correspondence between atomic structure and electronic properties is of course what happens in real materials as well," notes Robert Drost, "but here we have complete control over the structure. In principle, we could target any electronic property and implement it experimentally." The method is not limited to chlorine—the same procedure could be applied in many well-understood surface and nanoscience systems. It could even be adapted to mesoscopic systems, such as quantum dots, which are controlled through lithographic processes, paving the way toward development of designer quantum materials. *www.aalto.fi/en.*

BRIEF

Gurpreet Singh, associate professor at **Kansas State University,** Manhattan, created a clear liquid polymer with the viscosity and density of water that changes into a black glasslike ceramic when heated. Composed of just five ingredients—silicon, boron, carbon, nitrogen, and hydrogen—the material possesses valuable thermal, optical, and electronic properties, and can be mass-produced. *k-state.edu.*

Jars show variations of a patented liquid polymer that looks like water but turns into a ceramic when heated. Courtesy of Kansas State.

PROCESS TECHNOLOGY



Left, a mussel uses its natural adhesive to stick to aluminum. Right, two pieces of aluminum are bonded using the polymer modeled after the animal's adhesive. Chemical structures of the mussel protein and synthetic polymer are shown.

UNDERWATER ADHESIVE FLEXES ITS MUSSELS

Researchers at Purdue University, West Lafayette, Ind., developed a polymer adhesive for wet bonding that could be one of the strongest of its kind to date. The biomimetic glue, called poly(catechol-styrene), borrows the chemistry of the adhesive mussels use to cling to objects underwater. After investigating which aspects of mussel adhesion are most important in a wet and salty environment, researchers determined that the only critical element is a catechol-containing polymer. Catechols are a component of the amino acid DOPA, which is contained in mussel adhesive proteins. According to the team, catechols appear to "drill down" through water to bind onto surfaces themselves, instead of interacting with water as most adhesives do.

In a series of bond tests conducted in tanks of artificial seawater, the bio-based glue performed better than 10 commercial adhesives when used to bond polished aluminum. Compared to the five strongest commercial glues included in the study, the new adhesive performed better when bonding wood, Teflon, and polished aluminum. In fact, it was the only adhesive tested that worked with wood and it far outperformed the other adhesives when used to join Teflon. Future research will test the adhesive under real-world conditions. *purdue.edu.*

MASS-PRODUCED GRAPHENE STARTS WITH A BANG

Physicists from Kansas State University (K-State), Manhattan, accidentally invented a safe, simple, and affordable method to mass-produce graphene: Fill a chamber with acetylene or ethylene gas and oxygen, create a contained detonation with a vehicle spark plug, and collect the graphene that forms. The serendipitous discovery occurred while the team was developing carbon soot aerosol gels. When they created a detonation in an aluminum chamber filled with acetylene gas and oxygen, the aerosol gels formed by the resulting soot turned out to be graphene. The new process has since been patented.

Other methods of creating graphene are low yield, energy intensive, and even dangerous, involving the lengthy "cooking" of graphite with chemicals—such as sulfuric acid, sodium nitrate, potassium permanganate, or hydrazine—or the heating of hydrocarbons to 1000°C in the presence of catalysts. The new process produces graphene by the gram, rather than milligram, and energy consumption is minimal. One gram of graphene can be produced using only the energy required to ignite a single spark. *k-state.edu.*

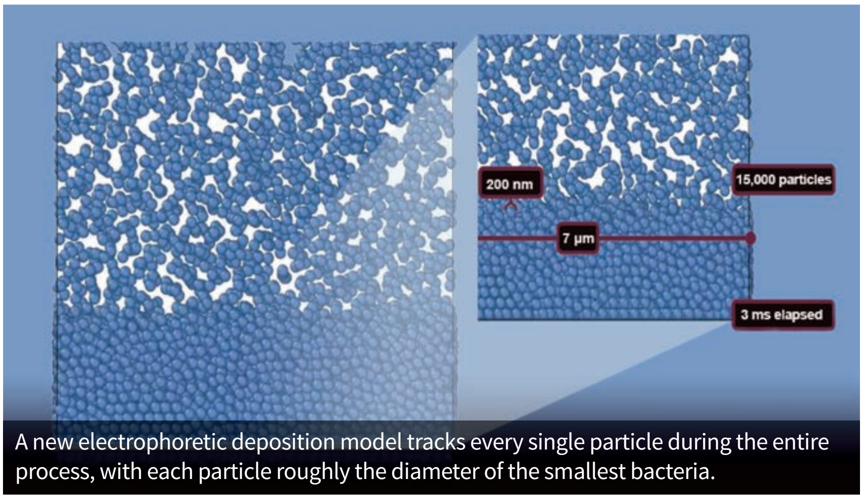
From left, K-State researchers Justin Wright, Chris Sorensen, and Arjun Nepal, with a container of graphene. Sorensen and Nepal patented a method to create graphene through a controlled detonation.

BRIEF

HTS International and the DOE's **Oak Ridge National Laboratory,** both in Tennessee, signed a memorandum of understanding to explore collaborations in advanced manufacturing research. HTS is a supplier to the injection molding and die casting industries, using its metal fusion technology to make steel production components with conformal cooling. *htsintl.com, ornl.gov.*

These coolant lines allow parts to cool faster, boosting productivity for molding and casting manufacturers. Courtesy of ORNL.

SURFACE ENGINEERING



A new electrophoretic deposition model tracks every single particle during the entire process, with each particle roughly the diameter of the smallest bacteria.

DEPOSITION MODEL PARTICULARLY DETAILED

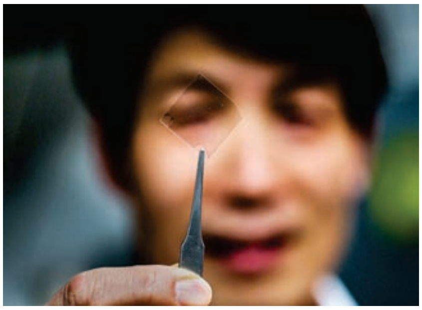
Scientists at Lawrence Livermore National Laboratory (LLNL), Calif., developed a computer model of the process of electrophoretic deposition (EPD) that offers an unprecedented level of detail. EPD employs an electric field to drive colloidal particles suspended in a liquid out of solution onto a conductive substrate, and the new model tracks every single one of these 200-nm-diameter particles during the entire procedure. Based on particle dynamics and running on LLNL's Vulcan supercomputing system, the model was developed through dozens of simulations over a two-year period. The team discovered that not only does electrical field strength affect crystal development, but surprisingly, salt concentration does as well.

The model could be used to better understand deposition kinetics, thus determining how fast to build and anticipate resulting crystallinity, which could impact how armor is produced and how EPD coatings are applied. It could also find application in photonics science, which requires precise control over crystallization. Until now, photonic crystallization has been accomplished through trial and error, but with the new predictive model, virtual experiments could replace months of work in a lab. *llnl.gov.*

ULTRATHIN FILM ON THE SILVER SCREEN

Researchers at the University of Michigan, Ann Arbor, reportedly laid down the thinnest silver film to date, making silver a potential player in the touchscreen market as supplies of current transparent conductors diminish. Thanks to the addition of 6% aluminum, the new film is only 7 nm thick—twice as thin as films made of pure silver—and boasts tarnish resistance as well. The researchers added an antireflective coating that gives the film 92.4% transparency, which was maintained along with the film's conductive properties, even after several months.

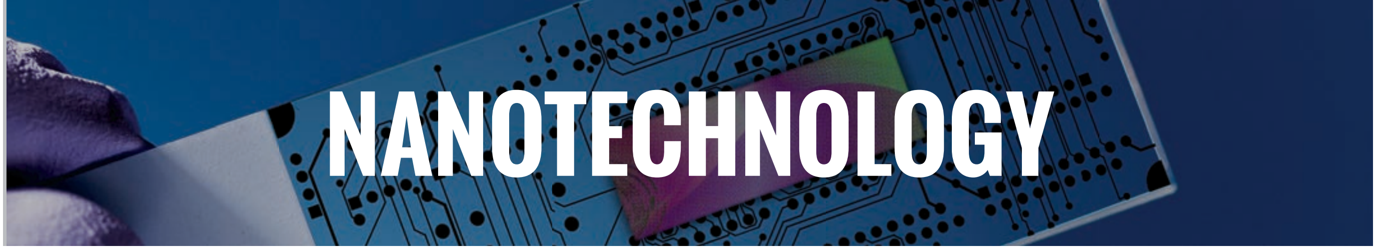
In addition to its touchscreen potential, the smooth silver coating could serve as a formidable plasmodic waveguide—a material that transports information in optical rather than electronic form for faster data transfer. In fact, the film can transmit surface plasmons further than a centimeter, about 10 times longer than other metal waveguides. The silver films can also be layered into a metamaterial hyperlens, which can image objects too small to be seen sharply with optical microscopes and can also enable laser patterning—for instance, etching transistors into silicon chips—with much greater detail than ordinary ultraviolet methods allow. *umich.edu.*


Professor L. Jay Guo holds a piece of transparent silver film. Courtesy of Joseph Xu/Michigan Engineering.

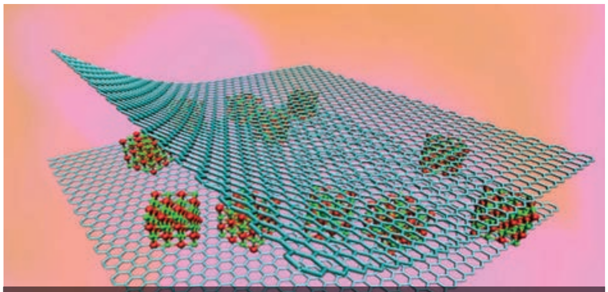
BRIEF

Henkel, Germany, will supply high-impact surfacing film (Loctite EA 9845 LC AERO) to aerospace manufacturer **Textron Aviation Inc.,** Wichita, Kan., for turboprop and business jet composite components. In addition to protecting against lightning strikes, the new epoxy film adhesive is UV resistant and fills voids, producing a smooth, paintable surface. Textron is the first aerospace manufacturer to use the film, which is 30% lighter than alternatives. *henkel.com.*


Courtesy of Textron Aviation.



NANOTECHNOLOGY



Nanoclusters of magnesium oxide sandwiched between layers of graphene produce a compound with unique electronic and optical properties, according to researchers who made computer simulations of the material. Courtesy of Lei Tao.

A MODEL COMPOUND

Researchers at Rice University, Houston, built computer simulations of a compound composed of 2D magnesium oxide in bilayer graphene and determined that the material offers a range of unique optoelectronic properties. Unlike graphene on its own, the hybrid has a band gap—the characteristic that makes a material a semiconductor—and its band gap could be tunable depending on the components. The compound's enhanced optical properties are also tunable—and desirable. While a flake of magnesium oxide alone absorbs only one kind of light emission, sandwiching it between layers of graphene allows it to absorb a wide spectrum of light. This could be an important mechanism for delicate molecular sensing. The compound could also find application in catalysis and bio-imaging.

To choose a foundation for their model, the scientists looked to previous experiments where various molecules were encapsulated using van der Waals forces to draw components together. The Rice study is reportedly the first to take a theoretical approach to defining the electronic and optical properties of one of those "made" samples.

"We knew if there was an experiment already performed, we would have a great reference point that would make it easier to verify our computations," explains materials scientist Rouzbeh Shahsavari. He went on to say that his group's theory should be applicable to other 2D materials like hexagonal boron-nitride and molecular fillings. Ultimately, the work could help researchers design a range of customizable hybrids of 2D and 3D structures with encapsulated molecules. *rice.edu.*

UNRAVELING THE MYSTERY OF A BUG'S BODY ARMOR

Scientists at the University of Nebraska-Lincoln discovered a method to analyze the fibrous nanostructure of a beetle's shell, gaining insights that could lead to development of lighter and stronger engineered materials. Composed of chitin fibers just 20 nm in diameter packed and piled into spiraled layers, the exoskeleton is both hardy and lightweight, protecting the beetle's delicate wings without weighing it down in flight. Analyzing the armor's architecture has been difficult in the past due to the fibers' small diameter and helical twisting, known as a Bouligand-type structure. To gain insight into this architecture, the researchers developed a method of slicing down the spiral to reveal a surface of fiber cross-sections at different orientations. Next they investigated the fibers with an atomic force microscope. The process revealed both the nanoscale structure of the exoskeleton and the material properties of the nanofibers. They made their discoveries by analyzing the common figeater beetle, *Cotinis mutabilis,* a metallic green native of the western United States. The technique could be applied to other hard-shelled creatures as well as artificial materials with fibrous structures and could lead to improvements in body armor as well as automotive and aerospace components. *unl.edu.*

Common figeater beetle. Courtesy of bugguide.net.

BRIEF

Rutgers University, New Brunswick, N.J., licensed a technology that enables mass production of graphene at a reduced cost to **Everpower International Holdings Co. Ltd.,** New York. The method uses microwaves to produce high-quality graphene from graphene oxide. *rutgers.edu.*

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OPTIMIZING PROCESS PARAMETERS FOR ALUMINUM-SILICON HIGH PRESSURE DIE CAST POWERTRAINS

Aluminum components with refined microstructures produced by high pressure die casting enable manufacturers to gain energy savings via shorter production cycles—if casting and tempering parameters are optimized.

Wojciech Kasprzak, CanmetMaterials, Ontario, Canada

Hirotaka Kurita, Yamaha Motor Co. Ltd., Shizuoka, Japan

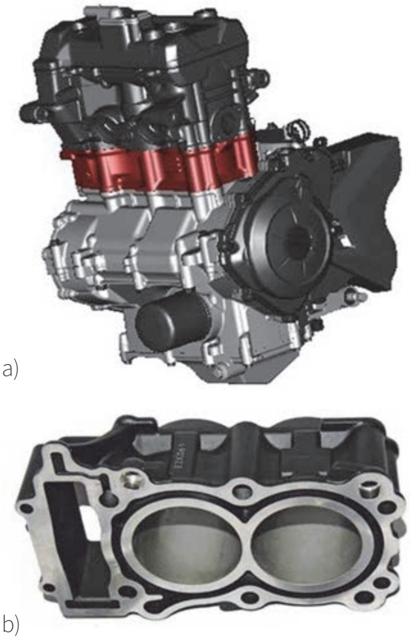
Lightweight Al-Si base alloys are key engineering materials for use in cast automotive powertrain applications due to their combination of structural and service characteristics. Specifically, hypereutectic Al-Si alloys containing >12 wt% Si are materials of choice for use in applications such as engine blocks[1]. A monolithic (linerless) engine block design is cost effective because it eliminates the need to use press-fit or cast-in cylinder sleeves (heterogeneous design), or Cr-Ni base coating (quasimonolithic design) in which thermal spray is deposited on the bore surface[2]. The monolithic design is used in small one-cylinder motorcycles[3], and more recently for manufacturing two-cylinder, water-cooled engine blocks (Fig. 1). Such engines meet size and performance specifications and are used in mid-size motorcycles yielding 36 hp @ 12,000 rpm from 250 cm³ displacement (Fig. 2).

Monolithic engine blocks made of DiASil* (die cast aluminum silicon) hypereutectic Al-Si alloy (Al, 17%Si, 4.5%Cu, and 0.5%Mg) meet modern engine requirements including cooling performance, light weight and compact design, and low manufacturing cost. Alloy wear resistance and thermal conductivity are the main factors affecting oil consumption and engine cooling characteristics. Oil consumption for monolithic blocks measured on a 10,000-km running test at approximately 7000-9000 rpm is improved by up to 50% compared with that for heterogeneous blocks.

Fig. 2 — Mid-size motorcycle powered by a lightweight 250 cm³ water-cooled two-cylinder engine. Courtesy of Yamaha Motor Co.

The alloy's tribological properties are mainly controlled by the primary Si size, distribution, exposure height from the aluminum matrix, and overall alloy hardness[1]. Figure 3 shows the representative microstructure of an etched material sample, which removed a relatively soft α-Al matrix and resulted in exposed primary Si, Al-Si eutectic, and Cu-Mg base phases. The etched surface closely represents an actual cylinder bore following honing. After honing, the primary Si crystals are exposed as high as 0.5 μm. Removal of the metal matrix exposing primary Si crystals promotes elastohydrodynamic lubrication (EHL), which is required to withstand the reciprocal movement of the engine piston[2].

A monolithic block can be produced by various techniques including sand casting, lost foam, and the semipermanent process. High pressure die casting (HPDC) offers high production rates and satisfactory quality at a competitive price. An HPDC system used for R&D studies at CanmetMaterials laboratory is shown in Fig. 4. In the HPDC process, liquid metal is transferred into a shot sleeve from a holding furnace and injected into the water-cooled die where it rapidly solidifies under hydraulic pressure. The actual pressure depends on specific equipment configurations and could be as high as 120 MPa, with a melt flow velocity between 30 and 60 m/s (100 and 200 km/h) at the gates[4]. When the metal temperature drops below the solidus, the casting is ejected from the die



a)

b)

Fig. 1 — Water-cooled 250 cm³ motorcycle cylinder block made of hypereutectic Al-Si alloy (DiASil) using the HPDC process: (a) assembled engine overview; (b) engine block casting. Courtesy of Yamaha Motor Co.

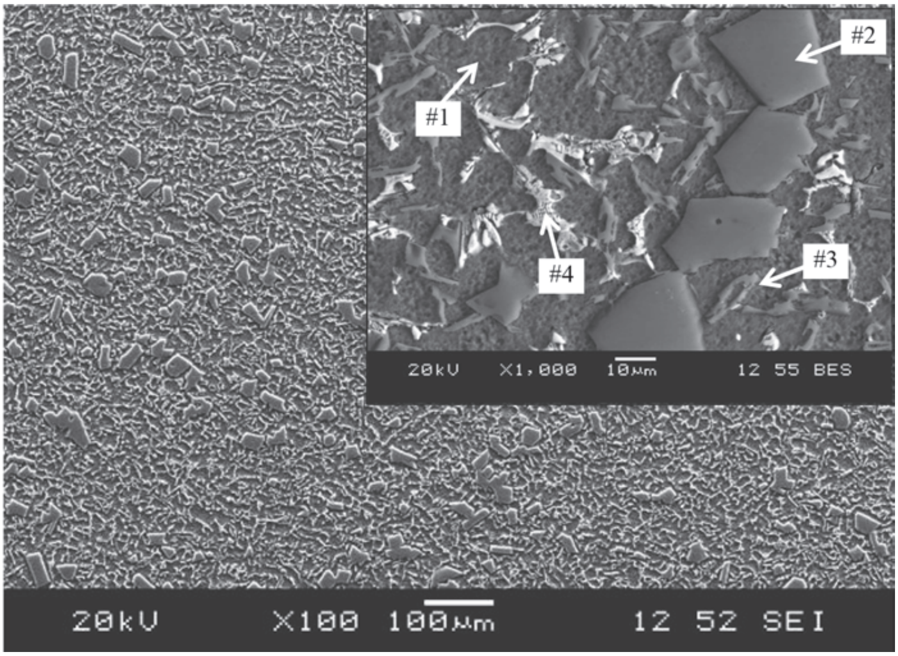


Fig. 3 — Hypereutectic Al-Si alloy (DiASil) microstructure after chemical etching. Inset, because the α-Al matrix (1) was removed, this resulted in exposure of primary Si (2), Al-Si eutectic (3), and Cu/Mg base phases (4).

cavity using a robotic system and followed by an automated water quenching operation. The casting is then ready for post-processing operations including T5 and T6 tempers. Temper selection depends on component requirements and economic considerations. Machining operations for near-net-shape HPDC parts are typically performed after heat treatment and require the casting to be dimensionally stable[2]. Figure 5 shows production process steps.

Hardness is a key quality acceptance criterion for engine blocks because it relates to the cylinder's tribological characteristics. Therefore, in the case of a DiASil cylinder block (Fig. 1b), the targeted hardness of >73 HRB is used as an indicator of heat treatment effectiveness. Heat treament is the most time consuming production step and therefore the most cost-intensive operation (Fig. 5). Thus, there is a need to shorten heat treatment time without compromising hardness, reducing overall manufacturing time and reducing costs. This represents an opportunity for cost savings.

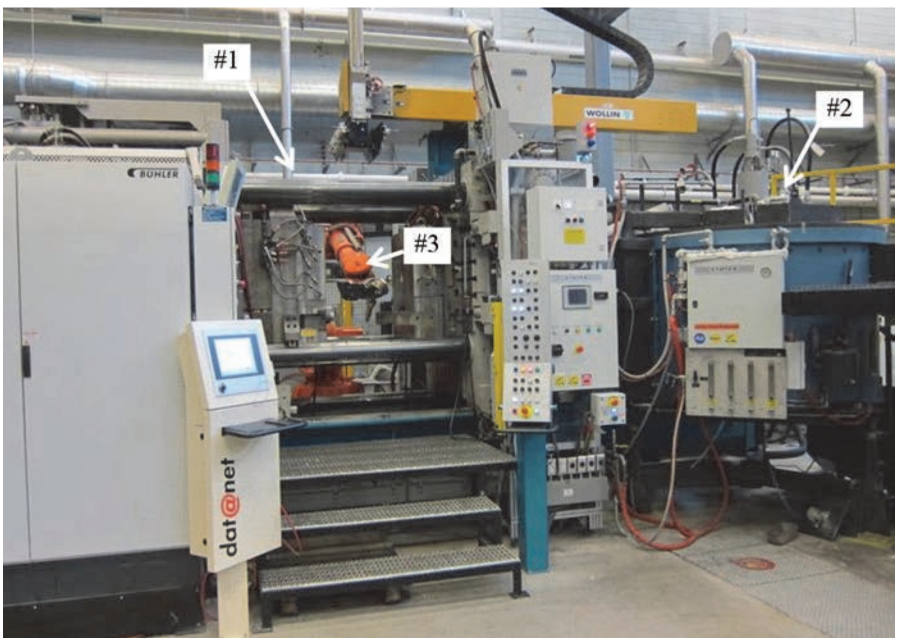
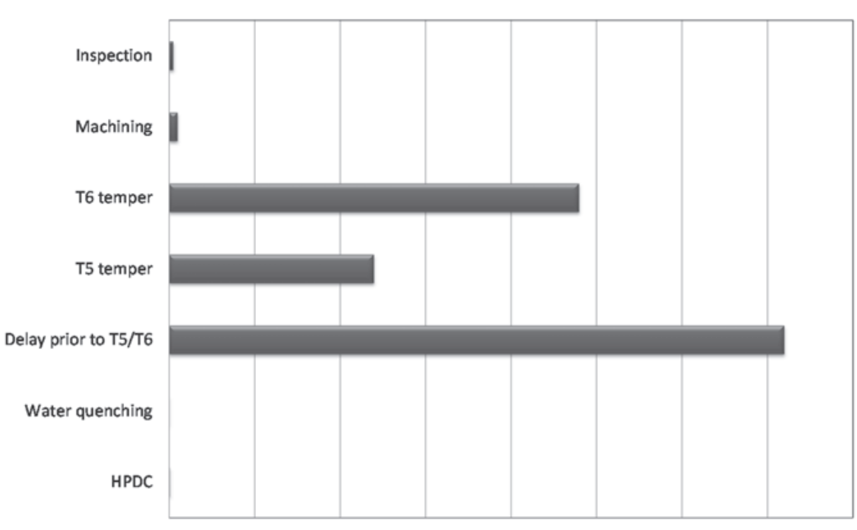


Fig. 4 — CanmetMaterials 1200-ton high pressure die casting system used for R&D studies: (1) clamp area with die; (2) furnace with automated melt transfer system; and (3) robot for parts extraction. Courtesy of CanmetMaterials.



	HPDC	Water quenching	Delay prior to T5/T6	T5 temper	T6 temper	Machining	Inspection
Duration (mins):	1	0.5	720	240	480	10	5

Fig. 5 — Duration (minutes) of manufacturing operations for a motorcycle cylinder block.

OPTIMIZING PROCESS PARAMETERS

The overall production cycle (i.e., from casting through heat treatment) rather than individual operations must be considered to effectively maximize hardness and reduce processing time[1]. Process variables that are not typically optimized or controlled in industrial practice have measurable individual effects, potentially offering additional benefits on their superimposed effect[1].

Using T5 instead of T6 temper. The short T6 temper consisting of solutionizing, quenching, and aging is used for engine block applications to improve mechanical properties and casting homogeneity. The duration of the solution treatment in existing heat treatment standards is often longer than that required to achieve the desired level of microstructure refinement. For the castings in this study, proper optimization of the T6 solution treatment required only 30 minutes at 510°C, which resulted in similar or higher hardness than was achieved by solutionizing at 490°C for 4 hours[3]. Hardness of up to 85 HRB was achieved for T6 tempered conditions (Fig. 6), with an overall process duration of approximately 480 minutes (Fig. 5). A more refined microstructure achieved during HPDC processing yields higher hardness of the α-Al metal matrix.

Castings can experience blistering during the solutionizing treatment. Blistering is a casting defect caused by an increase in gas pressure in subsurface porosity during solutionzing. Increased pressure results in deformation of the thin metal layer surrounding the pore close to the casting surface. A vacuum process is used to reduce gas content in the die cavity during the HPDC operation to avoid blistering during T6 solutionizing. The resulting gas level in the finished casting is approximately 5 cm^3/100 g. Application of vacuum in the range of approximately 1 to 30 mbar measured in the die cavity eliminates

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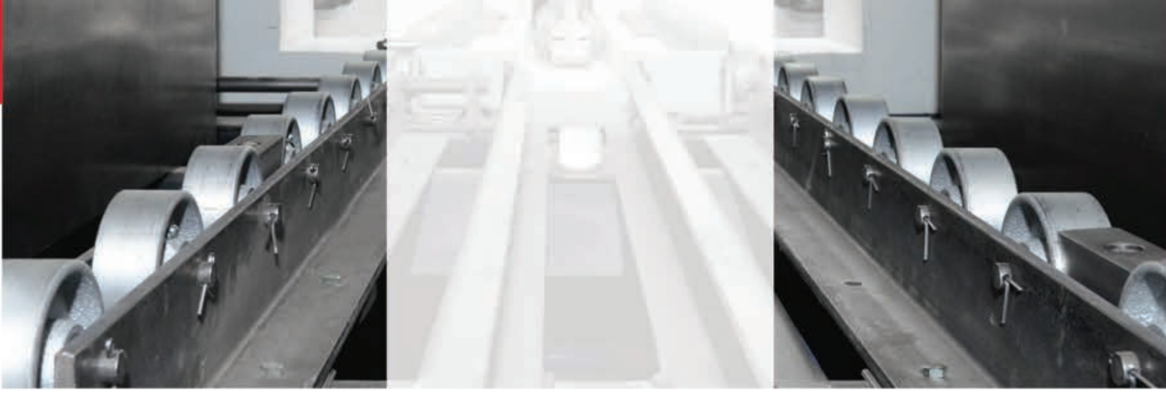

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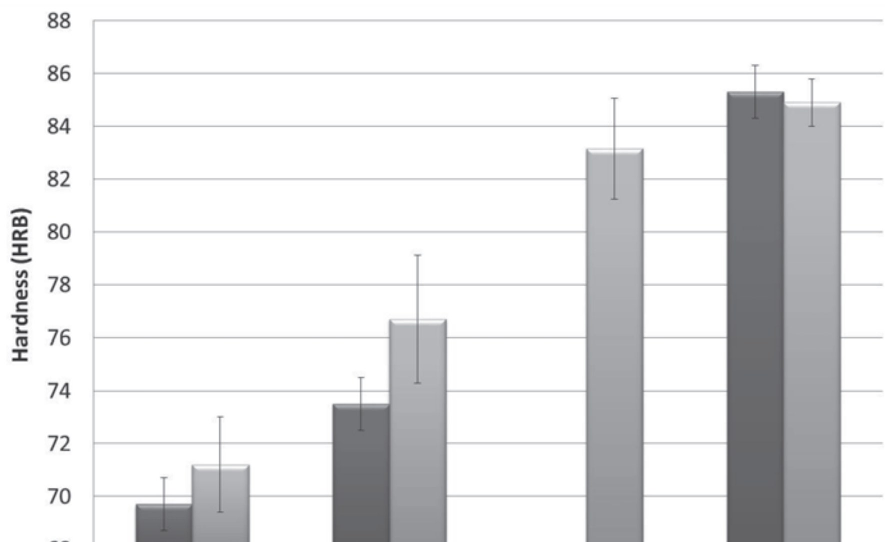
this effect. This process requires additional equipment with a corresponding higher manufacturing cost. Even with reduced heat treatment cycle times, the T6 temper is more costly than the T5 temper. Advantages of the T5 temper include reduced capital equipment cost due to eliminating the solutionizing treatment. The lower overall cycle time of the T5 temper (Fig. 5) reduces manufacturing cost while still achieving the required engine block hardness.

T5 temper optimization is being studied to find ways to increase hardness and reduce processing time. Artificial aging at 150°C for 72 hours, carried out after casting, de-molding, and water quenching, resulted in a maximum hardness of approximately 83.1 ± 1.9 HRB, while aging at 200°C resulted in a peak hardness of 76 ± 2.4 after 2 hours[1] (Fig. 6). Such a hardness range allows some flexibility to reduce temper duration while maintaining the hardness required to meet the critical tribological characteristics of the cylinder bore surface[2].



	T1	T5 (200C/2hrs)	T5 (150C/72hrs)	T6
NWQ	69.7	73.5		85.3
WQ	71.2	76.7	83.15	84.9

Fig. 6 — Casting hardness in the T1, T5, and T6 (510°C/0.5h and artificial aging at 200°C/2h) conditions. The differences between water quenched (WQ) and non-water quenched (NWQ) conditions are statistically significant except for the T6 temper[1].

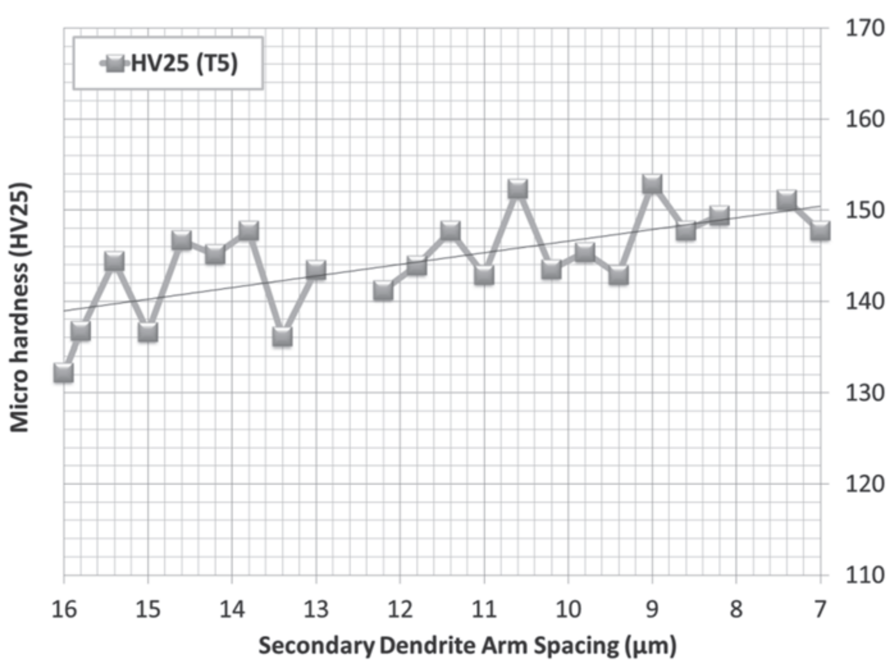


Fig. 7 — Increase in microindentation hardness (HV25) as a result of microstructure refinement for SDAS from 16 to 7 µm for the test casting T5 tempered at 150°C for 48 h. These data indicate that more refined structures offer higher hardness after tempering[1].

Casting solidification rate. During HPDC, die cavity liquid metal filling time is extremely lengthy, but could be as short as 50-100 ms[4]. Consequently, accurately determining the alloy solidification rate is difficult and imposes technical challenges. This is mainly due to the inability to collect adequate, unbiased temperature signals, i.e., signals that represent true thermal event history coming from the solidifying melt with minimum thermal inertia imposed by the casting die's large thermal mass. Direct placement of thermocouples in the HPDC die cavity is not a reliable method, and could result in sensor damage because the cavity is filled with superheated metal under high velocities and pressures. The estimated casting solidification rate could be as high as ~103°C/s, but the specific value depends on alloy composition, mold/part geometry, and process parameters[5].

Studies show that the fine microstructures (seconary dendrite arm spacing, or SDAS, between 5 and 30 µm) achieved in HPDC enable a significant reduction in heat treatment processing time for T6 as well as T5 tempered parts. A further increase in T5 temper hardness is possible via microstructure refinement. Figure 7 shows the increase in T5 hardness for samples with smaller SDAS size: 150 HV25 for 7 µm compared with 138 HV25 for 16 µm.

Casting de-molding temperature. Casting de-molding is typically carried out below the solidus temperature to ensure that the casting is 100% solid before ejection from the die. Typically, an exact temperature is not used in industrial process control because it is difficult to determine for cooling rates seen in the permanent mold casting process. Instead, the time corresponding to the casting de-molding operation is preferred because it can be easily controlled using programmed cycles of the casting machine. Generally, a DiASil cylinder block is de-molded at about 380°C, which is approximately 100°C below the alloy solidus temperature (end of the solidification process). This de-molding temperature is high enough to bring about the microstructural and related mechanical properties changes needed when the casting is subsequently quenched in water. Increasing the de-molding temperature enhances the casting response to the aging process upon water quenching, but could create the risk of ejecting the casting from the mold when it is not completely solid.

Water quenching after de-molding is typically used to cool castings for easier handling prior to the next manufacturing step, which could include heat treatment, machining, and inspection. Subsequent operations are sometimes carried out in a separate facility requiring transportation of castings. Besides

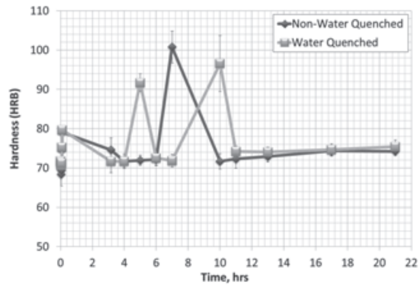


Fig. 8 — Variation in macrohardness for the test casting in the T1 as-cast condition as a function of natural aging time (days), i.e., delay between the completion of casting process and beginning of T5 temper for non-water quenched after casting de-molding and water quenched after casting de-molding[1].

water, quenching oils, emulsions, and compressed air can be used to cool the casting. Choosing the best cooling medium depends on overall process requirements including casting geometry, residual stress considerations, and subsequent processing steps. Quenching can also be used to retain some degree of solid solution resulting from nonequilibrium solidification, to prevent the diffusion of alloying elements. This supersaturated solid solution improves the precipitation process through artificial aging. Increasing the quenching rate and avoiding quenching delays enhances the aging response. Average casting quenching cooling rate in water is about 40°C/s, and is sufficient to observe an improvement in casting hardness[1]. Figure 6 shows the effect of water quenching on test casting coupon hardness for various temper conditions; hardness is increased by an average of up to 5% for water quenched castings.

Effect of time delay between casting and tempering operations. The time a casting is held at room temperature prior to heat treatment depends on the specific manufacturing cycle. For example, heat treatment done in-house as a continuous operation enables precise definition of cycles. For castings heat treated at a different facility, the duration of holding castings at room

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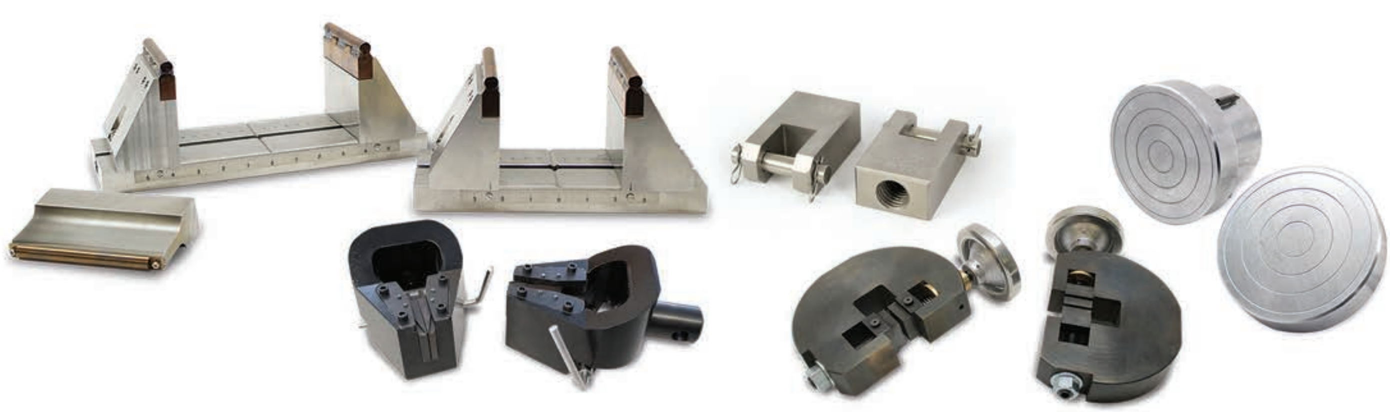

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temperature can vary[1]. This could result in castings having different initial hardness prior to the beginning of heat treatment. Studies show that casting hardness varies depending on the length of time at room temperature after completion of the casting process. Figure 8 shows hardness values for water and non-water quenched conditions. Based on these data, the recommended approach is to allow casting hardness to return to its approximate initial values; i.e., hold for 11 days (keeping in mind that the fully stable condition could take years to occur), or move to another operation before casting hardness increases as a result of natural aging. As shown in Fig. 8, hardness of non-water quenched castings increases after approximately six days, and after four days for water-quenched castings[1].

SUMMARY

Researchers at CanmetMaterials are exploring ways to maximize HPDC mechanical properties while reducing manufacturing time for automotive powertrain components. Results show that it is possible to increase hardness of hypereutectic Al-Si alloys by optimizing the water quenching rate and duration of room temperature hold, and producing castings with finer microstructures. For the alloy in this study, hardness can be increased up to 10%, but detailed optimization studies are required for specific casting part geometry and alloy chemical composition. For the engine block application, higher hardness together with primary Si morphology ensure that the required tribological characteristics of the engine bore surface[1] are achieved. **~AM&P**

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Acknowledgment

Research was conducted as part of a contract carried out under the Materials for Energy End Use in Transportation Program of Natural Resources Canada. The authors thank Gabriel Birsan, M.Sc., P.Eng., and Babak Shalchi Amirkhiz of CanmetMaterials for experimental and metallurgical analysis support.

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TECHNICAL SPOTLIGHT

AUTOMOTIVE INDUSTRY PARTNERSHIP PAVES THE WAY FOR ADVANCED HIGH-STRENGTH STEELS

Scientists and engineers working on behalf of the U.S. automotive industry are nearing completion of a multiyear effort to accelerate the incorporation of advanced high-strength steels in American-made cars and trucks.

The U.S. Automotive Materials Partnership (USAMP), an industry alliance representing Chrysler, General Motors, and Ford, has long been immersed in the collaborative development of lightweight metals for manufacturing cars and trucks. Now, the Southfield, Michigan-based organization is about to release the results of one of its most ambitious efforts yet, the development and validation of an integrated computational materials engineering (ICME) model optimized for third-generation advanced high-strength steels (3GAHSS). These high-tech materials have the potential to make vehicles lighter, safer, and more fuel efficient and reduce wear and tear on bridges and highways as well, but design and manufacturing complexities stand in the way.

USAMP, a wholly owned subsidiary of the U.S. Council for Automotive Research (USCAR), has been working on the 3GAHSS project since 2013 with help from Pacific Northwest National Laboratory, Brown University, The Ohio State University, the University of Illinois, Colorado School of Mines, Clemson University, AK Steel, Argonne National Laboratory, and the Auto/Steel Partnership (A/SP). So far, the project team has developed two new high-performance alloys and has successfully scaled up its steelmaking process from small heats made in the lab to large heats produced using factory-style equipment. Due to the scale-up, the team now has sufficient quantities of both new alloys to support extensive testing and continued efforts to calibrate and validate models.

Based on initial tests, one of the new alloys, a medium manganese (10 wt%) steel, has an ultimate tensile strength of 1200 MPa with 37% tensile elongation. These marks exceed DOE targets for *high-strength, exceptional-ductility* steel. The other alloy, a 3% manganese steel, has a tensile strength of 1538 MPa with 19% elongation, proving to be stronger but slightly less ductile than what DOE classifies as *exceptional-strength, high-ductility* steel. Microstructures of both alloys are shown in Figs. 1 and 2.

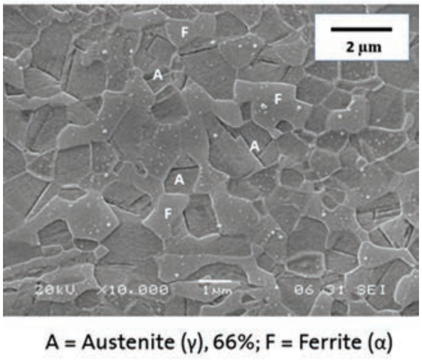

Fig. 1 – High-elongation 3GAHSS sample; medium manganese (10 wt%) transformation induced plasticity (TRIP) steel. Courtesy of Matt Enloe and McMaster University.

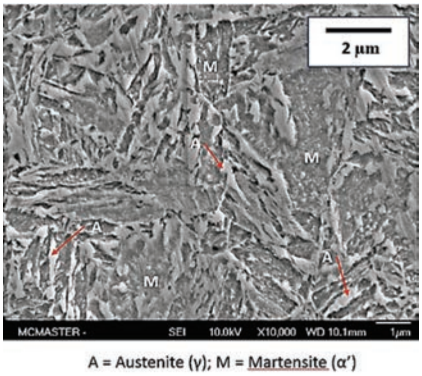

Fig. 2 – Strong and ductile 3GAHSS alloy sample (QP1500). Courtesy of Matt Enloe and McMaster University.

MATERIALS GENOME INITIATIVE

ICME and the methodology behind it closely align with the vision of the U.S. Materials Genome Initiative (MGI), which seeks to accelerate the discovery and application of new materials by seamlessly integrating theory, experiment, and data models. In the course of its work, the USAMP team set and completed several objectives on common ground with the goals of the MGI.

First, it brought relevant stakeholders together to develop new alloys from which experimental data were generated and then used to calibrate and validate length-scale models. These models were subsequently integrated into larger scale constitutive models developed to optimize forming operations and improve performance codes related to plasticity and fracture behavior. Second, it investigated microstructural processes at length scales that could be simulated to provide information for higher order models, thus reducing the amount of experimentation required. Third, it tested predictions from ICME models with a specially designed T-shaped component which, by virtue of its shape, subjects sample materials to a variety of strain paths and deformation modes.

Last but not least, the team established a data model for archiving and curating project data so others can tap into it to accelerate future work using computational techniques. Reuse of data is imperative for achieving the goals of the MGI and serves as a bridge between the known and unknown, where tomorrow's innovations lie. Such innovations require a well-developed data model because new steels are often synthesized by combining constituents and phases from existing steels.

TEAMWORK

Making data available for reuse also helps facilitate the MGI spirit of collaboration, without which the 3GAHSS project would not have succeeded. In fact, the project followed some of the basic tenets of "collaboration science," a separate area of study that has gained prominence in recent years. Collaboration science focuses on how to get people from diverse technical backgrounds—with different performance metrics—to work together in such a way that they freely share data prior to publication. Most of the collaborators in the 3GAHSS project did not know each other before the project began. This required the project management team to establish a high level of trust among participants early on.

AK Steel, one of the key contributors to the 3GAHSS work, was represented by some of its most skilled collaborators, members of its research and innovation team. This group worked closely with the Colorado School of Mines and other team members to design and produce prototype alloys made in AK Steel's research lab in Middletown, Ohio. The USAMP project team also worked closely with AK Steel's application lab in Dearborn, Mich., co-designing a unique stamping die and using it to make T-shaped test samples, representative of a critical section of an automotive body B-pillar, in order to demonstrate the potential of experimental alloys.

Beyond meeting or exceeding DOE targets, the collaboratively developed alloys were instrumental in the development and calibration of a functional 3GAHSS ICME model incorporating material and forming details. The team worked with several DOE labs to produce, test, and characterize the alloys for this portion of the research. And with DOE's help, it developed 3D representative volume elements of the microstructures, a critical component in the ICME models.

CRITICAL MEASUREMENT

Third-generation advanced high-strength steel alloys are complex multiphase materials with a metastable phase (austenite) that transforms to martensite when deformed. In the past, this has made modeling a challenge because the material phase composition and resulting mechanical properties change when being formed into components or during vehicle impact.

To effectively model the behavior of 3GAHSS alloys, the project team developed a new lab procedure for dynamically measuring retained austenite volume fraction as a function of strain path and deformation mode, e.g., tension, bending, or plane strain. Test setup is shown in Fig. 3. The new procedure, essentially an optical strain measurement, employs high energy synchrotron x-ray diffraction coupled with digital image correlation. It offers an unprecedented view of the materials science behind the austenite transformation and the extent to which it impacts strength and ductility using a test sample that closely simulates stamped automotive components. The USAMP team engaged with scientists at Argonne National Laboratory who used their Advanced Photon Source—one of the most powerful materials science diagnostic tools in the world—to acquire critical data for the volume fraction measurement.

USAMP's ICME model derives much of its predictive power from this information. The model's ability to make forming predictions is one example.

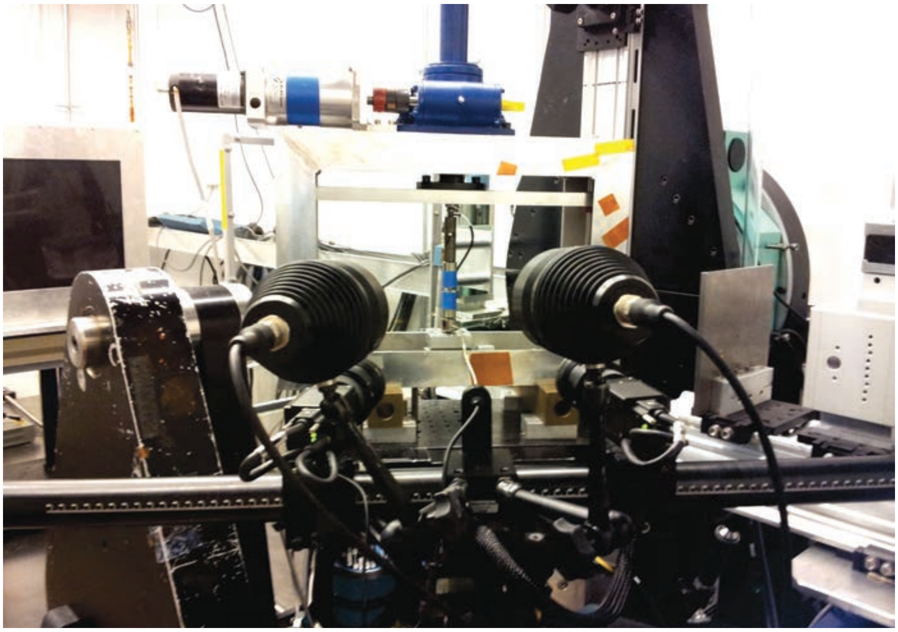

Fig. 3 – Dynamic setup for USAMP experiments at Argonne National Lab.

These predictions, relating stress, strain, and strain rate, are particularly valuable because they can be used in materials forming and vehicle performance codes, giving them tremendous reach. Volume fraction data also infuses the ICME model with an ability to predict changes in microstructure arising from manufacturing forming processes and in response to structural vehicle performance.

WEIGHT SAVINGS

As the project team winds down its work, perhaps the crowning prediction is the estimated weight savings that can be achieved with the new alloys. To that end, the team developed a baseline automotive side structure that suggests the two new 3GAHSS alloys have significant potential to reduce vehicle mass without sacrificing performance.

According to Lou Hector Jr., technical program lead and General Motors technical fellow, modeling results indicate that the new alloys can achieve a weight savings in the neighborhood of 20-30% without affecting stiffness or impact performance. One caveat, however, is that the team did not address joining. In the coming months, it intends to focus on validating the 3GAHSS ICME model through forming trials and improving model accuracy.

Fig. 4 – Lou Hector setting up static measurements in the lab.

"The ICME process is evolving as computer hardware gets faster, computer codes get more efficient and more comprehensive, and experimental techniques get closer to the data that we need," says Hector. "Different length scales calibrate the constitutive models for plastic flow, transformation kinetics, and fracture that are ultimately used in commercial finite element codes for forming and vehicle performance. We developed the capability of using the medium manganese steel and tested it with vehicle simulations. Accurate computer representations of 3GAHSS microstructures are critical for this process to work. When further refined, others will be able to use the model to do simulations, build structures, and run tests." **~AM&P**

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Acknowledgment

The USAMP 3GAHSS project is managed in collaboration with A/SP and its member companies and was funded in part by a competitively solicited $6 million award from the U.S. DOE in 2013.

VISUALIZING CELL PHONE COVER GLASS USING ADVANCED TESTING TECHNIQUES

Scanning electron microscopy and energy dispersive x-ray spectroscopy open new windows into glassmaking processes.

John Konopka, Thermo Fisher Scientific, Madison, Wis.*

Archeological investigations into the origins of glassmaking have been aided in recent years by a flood of new information obtained from scanning electron microscopes and x-ray spectrometers. These indispensable tools have helped researchers resolve conflicts and ambiguities that had persisted for decades by revealing new details in the microstructure and chemical composition of ancient glass items, some dating back to 4000 B.C.[1] In much the same way, advanced imaging and spectrographic technology is proving to be a valuable asset in the production of cell phone cover glass, which is as critical to the world's future as ancient glass artifacts are to the past.

COVER STORY

Cell phone cover glass plays an important role in the lives of more than six billion people. It also supports the booming smartphone industry and contributes in many ways to today's economy. Each year, specialty glassmakers produce and ship more than one billion cell phone covers, pushing the limits of materials science, manufacturing methods, and inspection techniques as they strive to make their products stronger, lighter, sleeker, and more resilient—without raising prices.

Cover glass, like most cell phone components, is a highly engineered product manufactured to exacting specifications. It consists of a high purity glass substrate topped with multiple surface enhancing layers. The substrates are chemically strengthened by placing them in a bath of molten salt, causing large ions from the solution to switch places with smaller ions on the glass surface. Once the glass cools and the lattice structure contracts, the larger ions create a state of compression that has a strengthening effect on the host material. Several layers of property altering materials are then deposited on the treated substrates, making the final product more resistant to scratches, reflections, and other hazards including microbial growth.

To determine if the various manufacturing steps went according to plan—or to investigate suspected abnormalities—glassmakers frequently employ a combination of scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDS). When used together, these analytical tools make it possible to visualize materials down to the nanometer level and evaluate chemical composition to within tens of nanometers. Such precision is essential for optimizing today's glassmaking processes and for identifying inclusions and other defects that may hold clues in cases where cover glass fails.

E-BEAMS AND X-RAYS

Scanning electron microscopy, as its name implies, works by scanning an electron beam over a target area. As the beam sweeps over the test sample, scattered electrons are collected at equidistant points on an imaginary grid and the resulting signal is converted to a high-resolution image. Incident electrons from the beam can also excite atoms along the beam path, causing them to emit x-rays that contain atomic information. X-ray emission energies correlate to atomic structure and are unique to each element. Scanning electron microscopes equipped to measure this dispersive energy can thus reveal the chemical composition of test samples as well.

Solid-state detectors for energy dispersive x-ray spectroscopy have been available for nearly 50 years. The earliest versions, which appeared in the late 1960s, are based on a silicon-lithium sensing mechanism that converts photon energy, through quantum collisions, to free electron charge. Si(Li) detectors excel at high-energy wavelengths, but they require liquid nitrogen cooling to suppress leakage current that would otherwise interfere with measurements.

Roughly 20 years after the debut of the first solid-state x-ray detectors,

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another version emerged that takes advantage of a sensing mechanism based on fully depleted high-resistivity silicon. These newer devices, called silicon-drift detectors (SDDs), have very low leakage current and can therefore operate close to room temperature. Besides eliminating the need for cryogenic cooling, SDDs are also faster, more scalable, and available in a wider range of sizes.

Using energy dispersive x-ray spectroscopy to analyze cell phone cover glass—even with the improvements in detector technology—still requires a fair amount of caution and care. For one thing, cover glass contains sodium ions that can become mobile when exposed to a strong electron beam. Any subsequent changes in composition could lead to false measurements if not accounted for. Cover glass is also nonconductive and must be modified to prevent unwanted buildup of charge during scans. This is typically done by coating the test sample with a thin layer of conductive material such as carbon, iridium, or another metal. Even then, it is still possible for residual charge to accumulate beneath the coating if the electron beam intensity is not carefully monitored.

GET THE DRIFT

Silicon drift detectors effectively mitigate many of the challenges presented by cell phone cover glass because they work faster and at lower beam currents than other detector types. SDDs with digital pulse processors operate with much less overhead than Si(Li) detectors, achieving significantly higher x-ray count rates. Today's silicon drift detectors can easily reach rates of 50,000 to 100,000 counts per second if sufficient signal is provided and if the sample can withstand the intensity of beam current exposure. Silicon-lithium versions, by comparison, are limited to about 3000 counts per second.

SDDs are also available in sizes of up to 100 mm^2 or more, which is anywhere from three to 10 times larger than Si(Li) detectors. And unlike their predecessors, SDDs see little degradation in resolution as their active area is increased. In fact, the largest SDDs are rectangular in shape, which allows them to get closer to the test sample where they can capture more x-ray signal for a given beam intensity.

The bottom line for manufacturers of cell phone cover glass is that, with the right SDDs, they can now obtain detailed compositional information about their products without having to crank up beam intensity to where it could damage or alter the test sample—and they can do it in a fraction of the time that it would have taken in the past. Where Si(Li) detectors might need almost two minutes to acquire a single spectrum, SDDs can typically produce equivalent if not better data in less than 10 seconds. This makes sample inspection much more immediate and interactive. An added benefit of using a lower beam current is that in some SEMs, it can greatly improve imaging resolution as well.

SEM/EDS DEMONSTRATION

To demonstrate the combined capabilities of SEM, EDS, and SDD technology, the author prepared and tested two glass samples, the results of which are presented below. The first sample is a coated glass cover slip meant to be attached as a protective layer over an existing cell phone display. In preparation for the test, pieces of the cover slip were mounted on edge in epoxy and polished to a smooth finish. Samples were then coated with a thin layer of conductive carbon to counter the unwanted charge accumulation.

An electron image of the cover slip is shown in Fig. 1 along with compositional spectra from three selected areas. Typical of EDS spectra, the graphs have a low-intensity background with a few sharp peaks characteristic of specific elements. System software can usually identify most peaks in a given spectrum, and often provides the option of charting intensities as simple counts, weights, or atomic percentages.

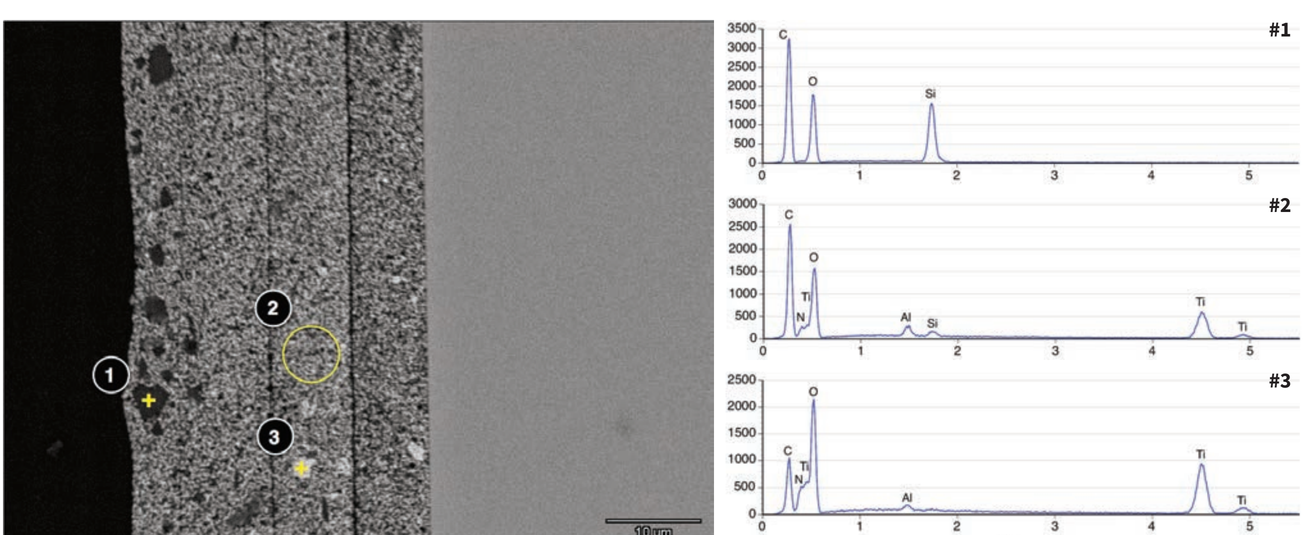

Fig. 1 – Electron image of glass cover slip cross section revealing surface layers and glass substrate. The three spectra were acquired from the indicated locations in the surface coatings.

In the SEM image, the cover slip surface is oriented to the left. The black area is the epoxy and to the right of that are four surface layers followed by the glass substrate. The bright particles scattered throughout the top layers are found to be rich in titanium and the darker particles rich in silicon. In this type of image, the brighter the area, the larger the average atomic number of the sample.

Based on the analysis, the surface coatings consist primarily of titanium, carbon, oxygen, and nitrogen. The large dark particles embedded in the top layer are most likely composed of silicon dioxide. If there were any contaminants or inclusions in the sample, they would be visible in the image.

DELVING DEEPER

A similar image of the cover slip along with a corresponding x-ray map is shown in Fig. 2. The map was acquired by scanning the electron beam across the sample and capturing x-ray spectra at each node of an imaginary grid. The procedure is automated and can find the distributions of all measurable elements without knowing their identities in advance. During the procedure, a live view of the map is displayed. Afterward, the spectra can be processed to reveal additional sample details.

The red overlay on the SEM image in Fig. 2, a potassium distribution map, is an example of such post-processing. It reveals a thin layer of potassium, about one micron thick, at the surface of the glass. The layer is rather nonuniform, alternating between areas of high concentration and areas with no potassium at all. Silicon-rich areas (likely SiO_2) are visible in the topmost layer, while titanium, oxygen, and carbon are distributed throughout.

Sodium and potassium distribution profiles were also extracted from the test data and are included as overlays on the sample image. The yellow trace represents potassium, while the green trace is sodium. Note how sodium concentration drops where potassium peaks. The potassium line scan was extracted from the full width of the map; each point represents a vertical column, which has an averaging effect on variances in concentration.

SCREEN TEST

The other sample selected for the demonstration is a piece of screen glass from an actual cell phone. Like the cover slip, it was mounted, polished, and coated prior to scanning. An SEM image and three compositional spectra are shown in Fig. 3. As before, the surface is oriented to the left and there are four layers topping the substrate. The surface layers again contain particles of what appears to be SiO_2 and combinations of titanium, nitrogen, oxygen, and a carbon-rich binder. The smallest discernable particles are roughly 100 nm in diameter.

X-ray maps of the cell phone glass are shown in Fig. 4. As before, left-to-right line profiles for sodium and potassium are superimposed on the SEM image. It is clear that sodium and potassium are distributed differently in the two samples. In the glass slip, potassium is concentrated at the surface of the substrate, but in the phone glass, it is observed in high levels to a depth of more than 25 microns—indicative of a wider region of ion-exchange strengthening. The sodium concentration, as expected, rises as the potassium concentration falls. Note that there is little or no change in the appearance of the glass in the electron image, indicating the presence of the potassium-rich region. Without EDS analysis, the depth, intensity, and shape of the enhanced potassium region would have gone unnoticed.

The silicon map in the lower left quadrant of the small image group reveals the presence of silicon (apparently SiO_2 particles) in the first of the four coating layers. Titanium is distributed evenly throughout the layers as are carbon, oxygen, and nitrogen. No other major constituent or particle was found.

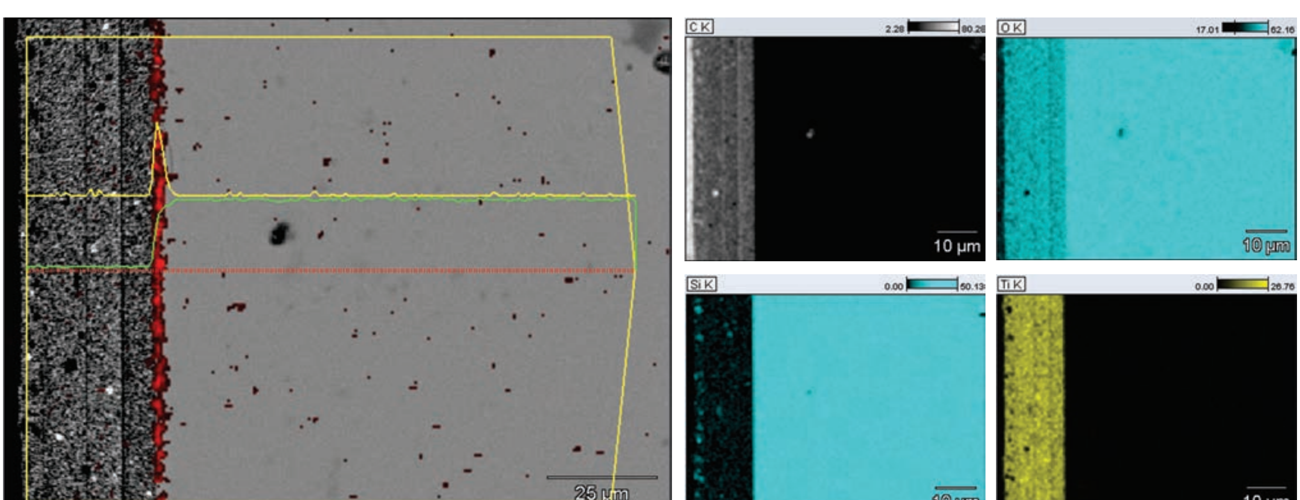

Fig. 2 – Electron image and EDS maps from the glass cover slip cross section. Overlaid on the electron image are extracted line scans for potassium and sodium and the potassium map.

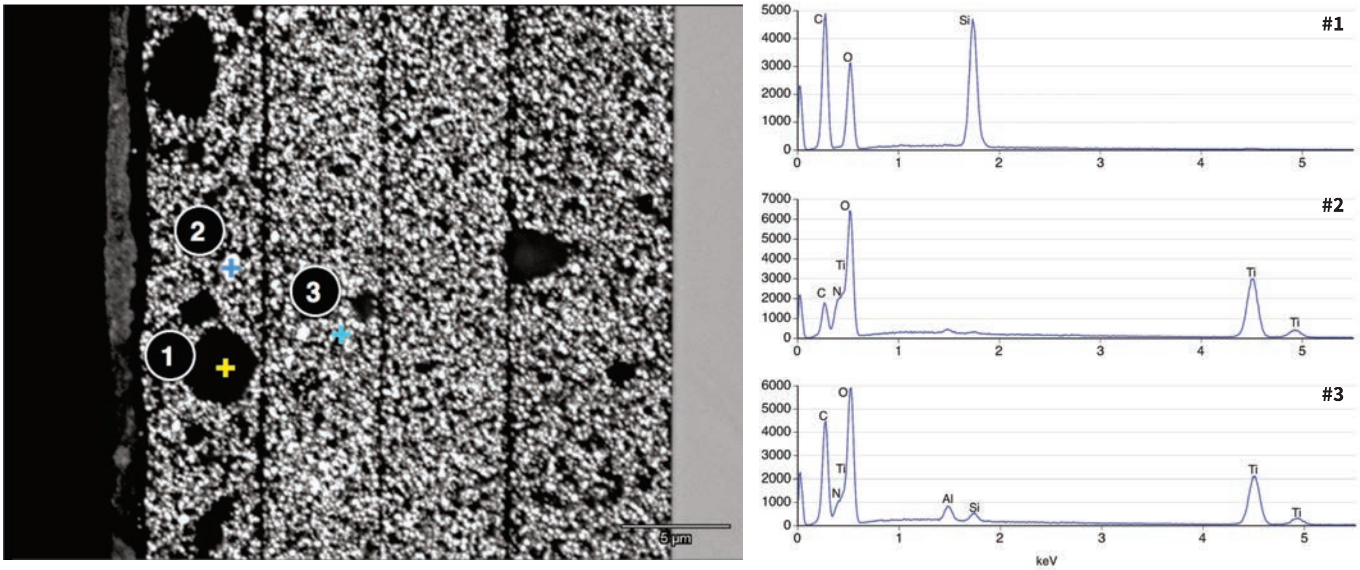

Fig. 3 – Image of a cross section of the cell phone glass surface, showing four surface coatings. The three spectra were acquired from the indicated locations.

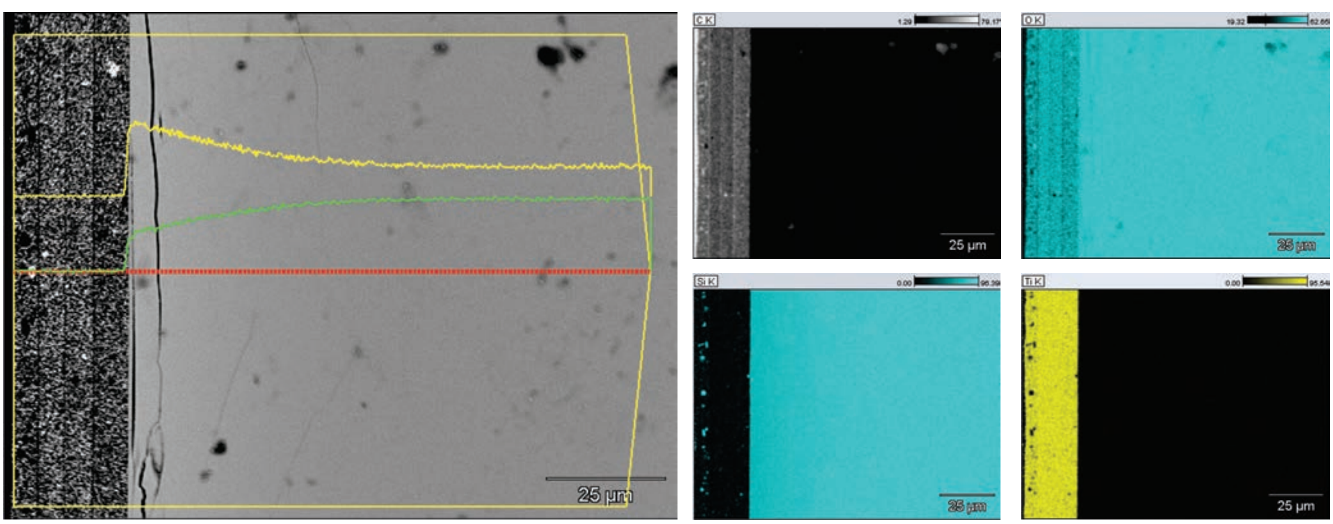

Fig. 4 – Electron image and EDS x-ray maps from a cross section of the cell phone glass surface. Extracted line scans for sodium and potassium are overlaid on the electron image.

CONCLUSION

SEM and EDS are effective tools for visualizing the appearance and composition of materials in extremely precise detail. With recent improvements in silicon drift detectors—even with challenging samples that are fragile, nonconducting, or prone to decomposing when exposed to an electron beam—analysis can be done safely, quickly, and in some cases, interactively. **~AM&P**

For more information: John Konopka is a microanalysis applications scientist for Thermo Fisher Scientific, 525 Verona Rd., Madison, WI 53711, 650.576.2312, john.konopka@thermofisher.com, www.thermofisher.com/pathfinder.

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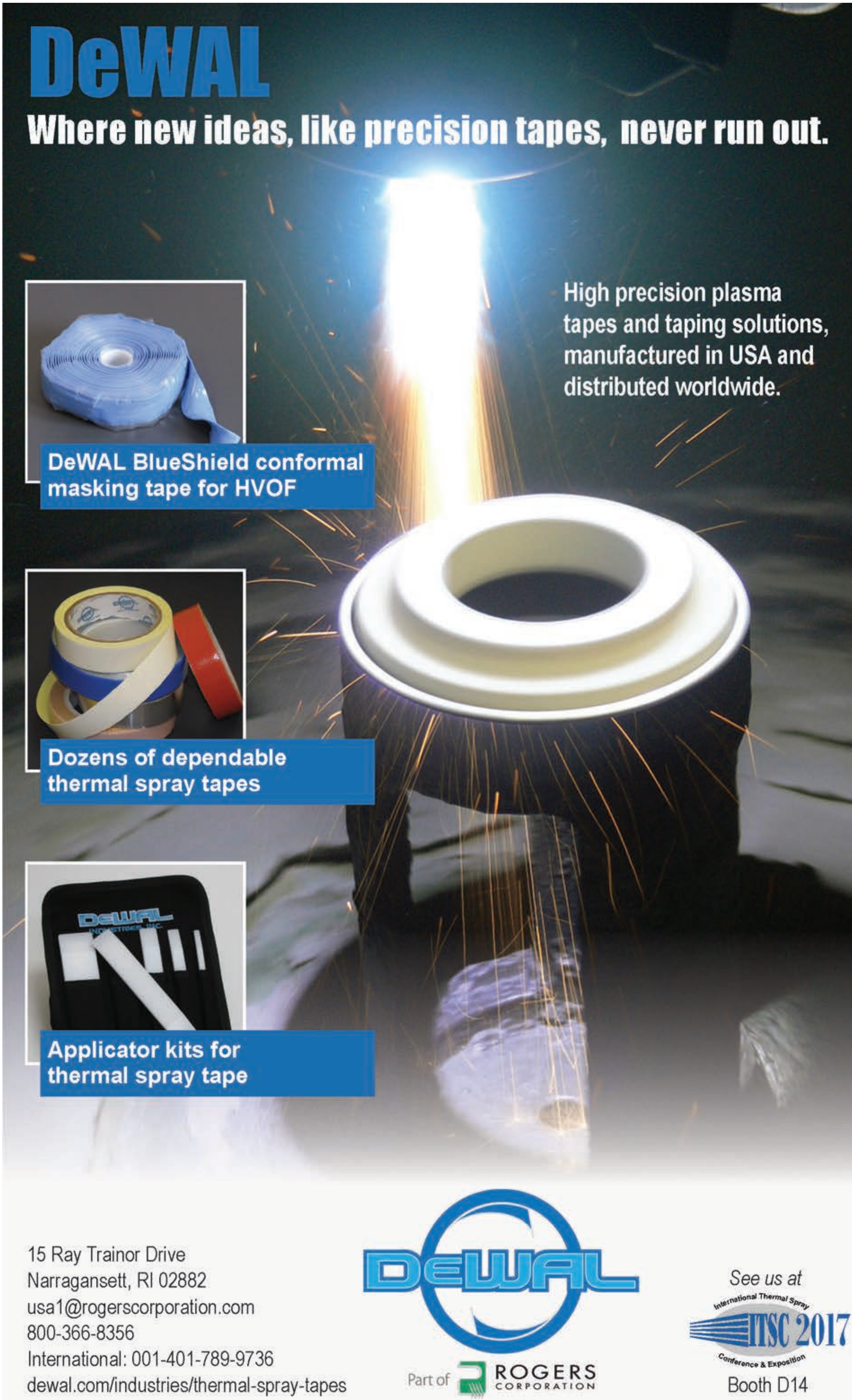
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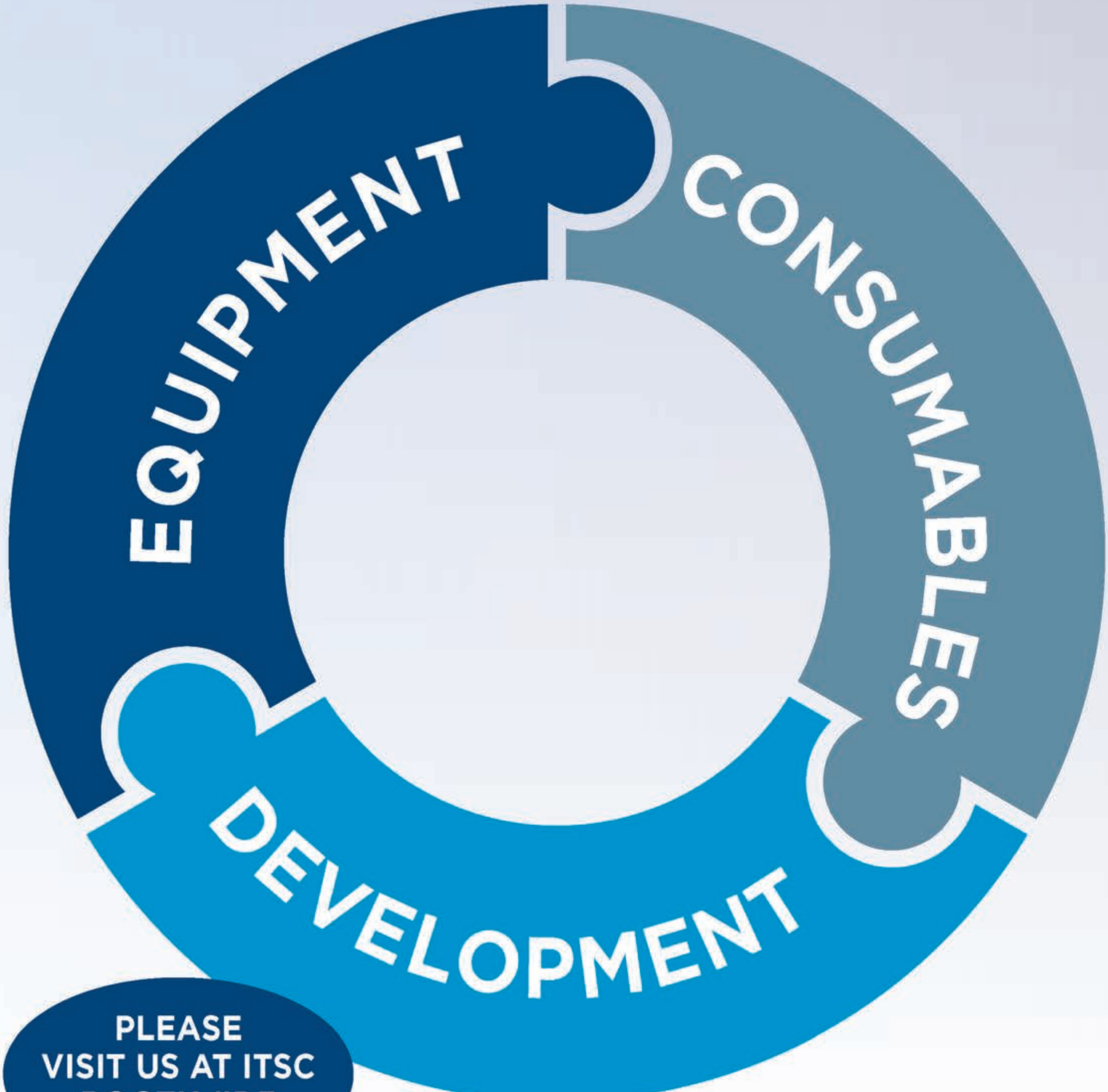

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EDITORIAL OPPORTUNITIES FOR iTSSe IN 2017

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

August:
Automotive & Industrial Applications

November:
Emerging Technologies/Applications & Case Studies

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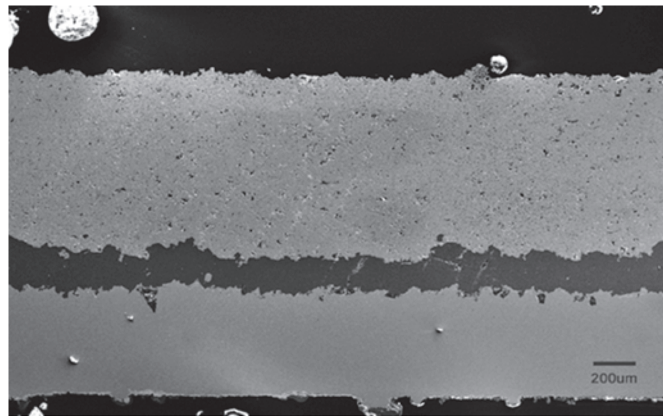

DEPARTMENTS

ABOUT THE COVER

Thermal spray coatings are often found in nuclear and power generation applications such as arc-sprayed iron-base coatings for erosion/corrosion protection of boiler tubes at elevated temperatures. On the cover is a large segmented seal ring used in a coal-fired boiler, with tungsten carbide being applied using HVOF. Courtesy of ASB Industries.

WILL THE REAL AUDIENCE PLEASE STAND UP?


Berndt

In 1994, I wrote a column titled, "Conferences and Meetings—Who's Holding the Gun?" The idea is that we were so busy going to meetings and conferences that we had no time to have fun and play in the spray booth or materials laboratory. It was tough to accomplish "real work" such as solving equipment malfunctions, sourcing new materials, and addressing customer issues. Has anything changed during the past 23 years?

Yes. We now have one international thermal spray conference per year—ITSC—rather than the two or three per year that existed two decades ago. We also have well-established thermal spray (TS) professional societies around the globe who look after their regional constituencies. We have seen consolidation of TS and surface engineering companies. We now have a dedicated journal and several newsletters that promote the industrial aspects of our technology. And there are many more instances where it can be said that thermal spray has advanced.

But it is not yet the household technology that many of us desire. For instance, TS is still a relatively unknown technology compared to traditional hard facing and the market size compared to other technologies is miniscule. This impasse in product recognition and branding has direct relevance for all of us. For example:

- The big TS companies need to repeatedly explain and define "what TS is" to potential clients who see it as only a loosely adhering particulate coating. The small applicators cannot survive on TS alone because the customers are not there to service.
- Universities find it difficult to attract high-caliber students who are inclined towards research because they may not have the required mechanical and materials education.
- Large consulting companies are relatively ignorant of TS, which is often perceived as a complex and costly process that can be undercut by methods such as painting and galvanizing.

TS will only become a household technology when we have gained technical recognition and respect. Conferences, education, applications, and other engineering outcomes are one pathway towards gaining this respect. However, these are largely audiences where we are preaching to the choir. What is really needed is the additional dimension of societal impact and this is where marketing and bona fide outreach plays a crucial role.

Now let us focus on this column's title, "Will the real audience please stand up?" The real audience is not the choir, but those who may not even appreciate that a TS choir exists. The inference is that TS is insular and will remain so if we do not stand up and speak to audiences outside of our comfort zone. We need to consider actions such as holding TS meetings in nontraditional locations, organizing TS sessions within the conferences of other professional societies, articulating in simple language where TS has demonstrated technical and commercial benefits, and providing a compendium of one-page case studies that share TS success stories.

Several of these outreach activities exist under singular banners of organizations. However, comparison with other engineering technologies indicates that TS pales under comparative measures. To be more specific, how will a new audience come to the TS table? Otherwise, TS will not grow; it may even wither due to undervaluing. My solution? We all need to stand up and become disciples, advocates, and even missionaries for the promotion of thermal spray.

Chris Berndt
Swinburne University of Technology

TSS REPRESENTATIVE ATTENDS ASM AFFILIATE OFFICER SUMMIT

ASM hosted an Affiliate Officer and ASM Management Summit on April 18 and 19 at its headquarters in Materials Park, Ohio. On hand to represent the interests of the Thermal Spray Society was **Douglas G. Puerta,** TSS president, who traveled from Happy Valley, Ore. The goal of the Summit is to strengthen relationships between the affiliate societies and ASM, and better align their activities with the ASM Renewal. Also in attendance were leaders from the Electronic Device Failure Analysis Society, Failure Analysis Society, Heat Treating Society, International Metallographic Society, and International Organization on Shape Memory and Superelastic Technologies, as well as members of the ASM management team.

SEEKING NOMINATIONS FOR THERMAL SPRAY HALL OF FAME

The Thermal Spray Hall of Fame, established in 1993 by the Thermal Spray Society of ASM International, recognizes and honors outstanding leaders who have made significant contributions to the science, technology, practice, education, management, and advancement of thermal spray. For a copy of the rules, nomination form, and list of previous recipients, visit tss.asminternational.org or contact joanne.miller@asminternational.org. Nominations are due **September 30.**

Front row, from left: Jaret Frafjord (IMS president), Othmane Benafan (SMST vice president), Ron Aderhold (ASM associate managing director and chief information officer), Ryan Milosh (ASM sales and marketing director), Lee Knauss (EDFAS vice president), Steve Kowalski (HTS president), Bill Mahoney (ASM managing director), and Zhiyong Wang (EDFAS president). Second row, from left: Burak Akyuz (FAS president), Jeremy Schaffer (EDFAS president), Jim Oakes (HTS vice president), Dan Dennies (IMS vice president-elect), and Doug Puerta (TSS president).

TSS president Doug Puerta (center), meets with Burak Akyuz, FAS president (left), and Susan Davis, ASM director of membership operations, during the Affiliate Summit at the ASM Dome.

WE NEVER HAVE ENOUGH ENERGY

Thermal spray plays a latent role in many energy generation applications. Strong R&D commitment is required to further expand its technological envelope.

Christopher C. Berndt, FASM, and Andrew Ang**
Swinburne University of Technology, Australia

Energy gluttony represents a $1.1 trillion global market. Electricity generation accounts for roughly half of this energy revenue (Fig. 1), with 85% of worldwide consumption dominated by traditional energy generation from liquids, coal, and natural gas. Figure 2 shows it is anticipated that these energy sources will be reduced to 79% as they are displaced by renewable resources. The global advanced energy market is highly complex and consists of a wide variety of technologies continually displacing each other as they reach different levels of maturity.

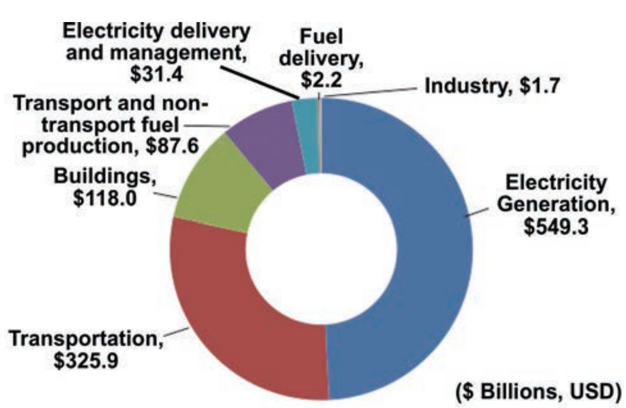

Fig. 1 — Advanced energy revenue by segment in world markets[1].

Each country's productivity (GDP), financial stability, and overall economy are tied to the amount of electrical energy generated. These numbers range from about $45K per capita (for U.S., Japan, France, Germany, UK, and Australia) to $5K per capita (for China, India, and Brazil)[3]. The corresponding primary energies per capita are 350 and 50 in gigajoule (GJ), respectively, for these country groups. A distinct positive correlation exists between GDP and energy use per capita.

Thus, energy production is vital to driving a nation's economy. Power generation authorities want to design plants to ensure continuous supply during periods of peak demand. Power shortages lead to inefficiencies, which in some countries leads to political debates and restructuring of government portfolios. Infrastructure costs of building and maintaining a power plant and its associated network run into billions of dollars. Materials engineering and materials selection are critical in cutting lifecycle costs and retaining sustainability.

THE LATENT ROLE OF THERMAL SPRAY

Thermal spray (TS) plays many important roles with regard to power generation. For example, it contributes to the efficiency gains and infrastructure maintenance of energy generation equipment. This is covered in the literature within many technical and scientific reports[4] and reviews[5,6], with

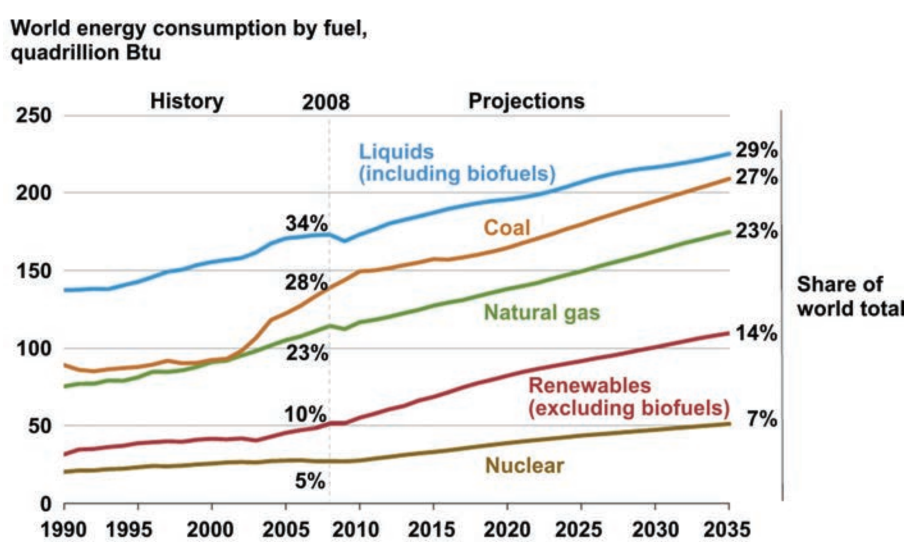

Fig. 2 — Renewables are the fastest growing source of energy consumption[2].

*Member of ASM International

an abundance of micrographs[7] and scientific data to show TS coatings applied as a thermal barrier. However, pedigreed financial data is lacking because the information is proprietary.

The point remains that thermal spray in a thermal barrier coating (TBC) application is worth the investment. For example, a study[8] by BCC Research notes that the global market for TBCs totaled $834.9 million in 2016 and should total nearly $1.1 billion in 2021 at a five-year compound annual growth rate (CAGR) of 5.6%. However, not all of this investment and growth is aimed toward TS because other advanced technologies compete for the TBC market. This raises the question: What is the future of TS in the energy sector?

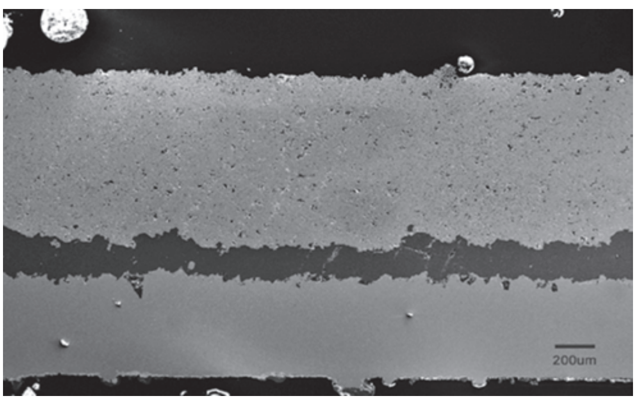

Fig. 3 — Micrograph of generation-1 thermal barrier coating (TBC) consisting of a plasma spray MCrAlY bond coat and ZrO_2-Y_2O_3 top coat.

IS TINKERING WITH COMPOSITIONS THE ANSWER?

This question may shock many researchers and engineers because their work has centered on finding and refining TBC layers and compositions that reflect known degradation and failure mechanisms. Figure 3 shows a typical generation-1 TBC consisting of a plasma sprayed, 100 to 150-µm thick MCrAlY bond coat under a 350-µm thick top coat of ZrO_2-Y_2O_3. Use of TBCs in gas turbine engines enables metal temperature reductions of about 190 K. Further, materials scientists and engineers have advanced TBC development over the past 70 years as shown in Fig. 4. Often, this is driven by the push for efficiency gains, more powerful turbine engines, and the need to address critical operational issues such as Si-Al-Mg-Ca (CMAS) oxides that attack and cause coating erosion in gas turbines. Figure 5 shows a typical generation-3 coating comprising a multilayer microstructure developed for use in a hypersonic application.

The science behind composition control is critical for TBCs because it strongly correlates to engine performance, efficiency, and lifecycle. The significance of the thermally grown oxide (TGO) that forms between the bond coat and ceramic overlay during service has been discussed extensively. The materials engineering approach has been to determine TGO growth rate and phase composition by measuring its thicknesses at specific temperatures after soaking for times that mimic service conditions. Composition control of input elements (bond coat and ceramic overlay) enable determining TGO characteristics and influence on TBC longevity. This

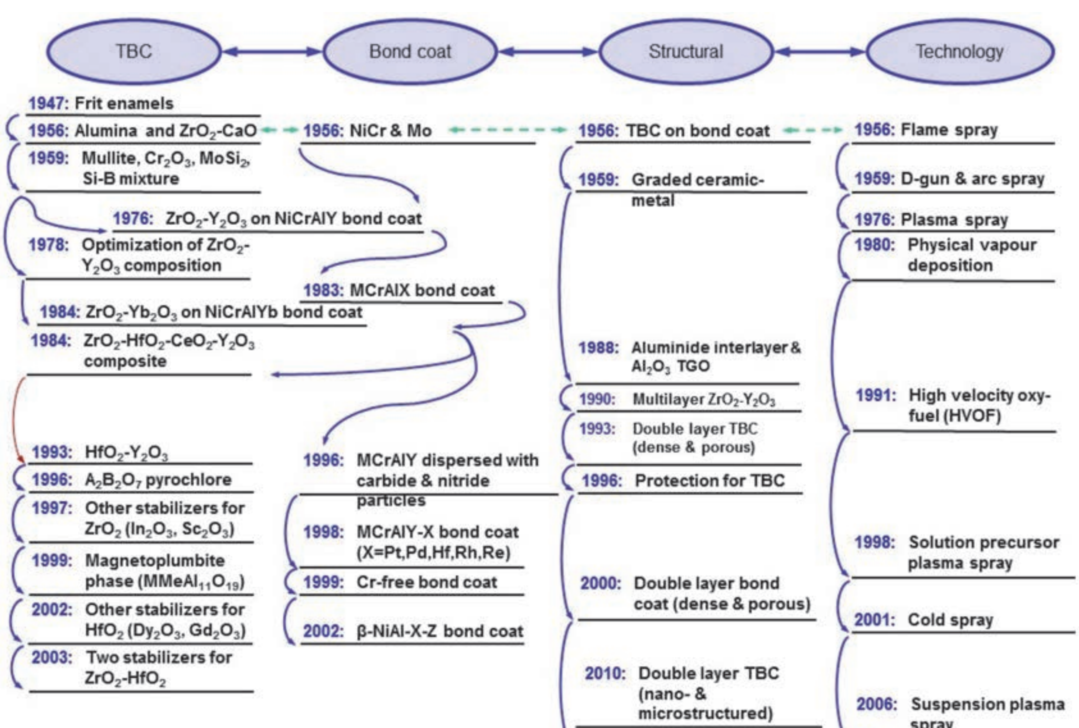

Fig. 4 — Development of TBCs over the past 70 years.

Fig. 5 — Multilayer TBC developed at Swinburne University of Technology for a hypersonic application (unpublished data).

has enabled down-selecting TBCs over the past 70 years to refined, specific chemistries. Thus, "fiddling with compositions" has positive engineering and economic outcomes. However, the critical evaluation of these methods is that society cannot wait another 70 years to evolve future generations of TBCs and other coatings that serve the energy sector.

LOOKING FOR THE LEAPFROG EVENT AND PATH

Demand for energy will continue to grow and the need for improved materials for infrastructure applications will drive materials engineering developments for both existing and new applications. Renewable energy platforms will also grow. These predictions are assured and they imply opportunities to grow the market for R&D in materials development. Following are some suggested directions:

Equipment growth. Cold spray has become a more prevalent and accepted TS technology over the past five years. Applications are emerging where cold spray[9] can play a dominant role in energy sectors. Aerosol deposition[10] is a technology akin to flame pyrolysis and deposition. It can be adopted as a thermal spray technology and evolve with instrumentation and techniques used for TS. Very low-pressure plasma spray, or VLPPS (0.75-3.75 torr compared with 37-150 torr for conventional LPPS), has the capability of manufacturing unique, oxygen-free structures, which would enhance bond coat chemistries to moderate TGO mechanisms.

Coatings for specialized energy-harvesting applications. Coatings are needed for fiber-reinforced polymer composites (FRPCs), heat sensitive substrates used in wind, solar, and photovoltaic energy-harvesting systems. A protective coating is required not only to resist erosion from dust and sand, but also to combat environmental pollution and corrosion. Hydropower and geothermal energy plants would benefit from coatings that resist cavitation, abrasion, and erosion. These coatings could require customized feedstocks, which presents opportunities for materials development[11].

General infrastructure maintenance. Corrosion control coatings (e.g., arc-sprayed zinc and zinc-aluminum coatings) provide substantial benefits for offshore and onshore installations.

Special needs for nontraditional energy-producing sectors. Energy produced from biomass, nuclear sources, fuel cells, and geothermal sources, as well as from an improved hydrogen economy and waste-to-energy plants, require materials and coatings that will enhance the lifecycle economics of producing energy. The leapfrog opportunity is to recognize that the materials structure must be designed appropriately for each particular energy sector, i.e., one microstructure does not fit all applications. The age of focusing on conventional yttria-stabilized zirconia chemistries is coming to an end. Generation 3, 4, and future coatings will evolve from scientific knowledge gathered over the past 20 years. The design of the void structure, ranging from 100% density to globular and interlamellar pores and micro and macrocracks orientated in certain directions, controls extrinsic materials properties, and hence the application.

SUMMARY

A previous commentary by Armelle Vardelle and Robert Vassen discussed the potential for thermal spray coatings in energy production sectors[12]. "To meet the projected increased demand of electricity, it is essential to improve efficiencies of all energy generation processes, and this includes the development of better materials, operation at higher temperatures, improved corrosion resistance, electricity storage capacity, and electrochemical or catalytic performance," they noted. "These specific materials properties are often attained by means of advanced coatings. Here the thermal spray technology offers a variety of different processes such as plasma, high velocity oxy fuel, or suspension spraying, which allow the design of innovative and highly effective coatings at affordable prices." **~iTSSe**

For more information: Christopher C. Berndt is a Distinguished Professor, Swinburne University of Technology, Victoria, Australia, +61 3 9214 8706, cberndt@swin.edu.au, www.swinburne.edu.au.

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BEYOND THERMAL BARRIER COATINGS

Applications for thermal spray have expanded beyond those for TBCs, as indicated by the 26 contributions published in the *Journal of Thermal Spray Technology* (Issue 5, Vol 22, June 2013), which focus on coatings for energy applications. Selected article titles are listed here as examples:

Thermal Barrier Coatings

- Advances in Thermal Spray Coatings for Gas Turbines and Energy Generation: A Review
- An Experimental Study of Microstructure-Property Relationships in Thermal Barrier Coatings
- Microstructure Evolution and Interface Stability of Thermal Barrier Coatings with Vertical Type Cracks in Cyclic Thermal Exposure

Solid Oxide Fuel Cells

- Thermal Plasma Spraying Applied on Solid Oxide Fuel Cells
- Characterization of High-Velocity Solution Precursor Flame-Sprayed Manganese Cobalt Oxide Spinel Coatings for Metallic SOFC Interconnectors
- Development and Application of HVOF Sprayed Spinel Protective Coating for SOFC Interconnects

Batteries, Capacitors, and Electronic Applications

- Fabrication of Thermoelectric Devices Using Thermal Spray: Application to Vehicle Exhaust Systems
- Flexible and Conducting Metal-Fabric Composites Using the Flame Spray Process for the Production of Li-Ion Batteries
- Pseudo-capacitors: SPPS Deposition and Electrochemical Analysis of α-MoO_3 and Mo_2N Coatings

Nuclear and Energy Production Applications

- Characterization of TiO_2-Doped Yttria-Stabilized Zirconia for Supercritical Water-Cooled Reactor Insulator Application
- The Role of Spraying Parameters and Inert Gas Shrouding in Hybrid Water-Argon Plasma Spraying of Tungsten and Copper for Nuclear Fusion Applications
- Cold-Sprayed Ni-Al_2O_3 Coatings for Applications in Power Generation Industry

Optimization of Thermal Spray Equipment

- Effect of Helmholtz Oscillation on Auto-Shroud for APS Tungsten Carbide Coating

This limited survey indicates that TS is not necessarily tied to a single market such as TBCs. For instance, there is potential for expansion of TS within the energy sector in areas of solid oxide fuel cell (SOFC) applications and the rehabilitation and maintenance of infrastructure associated with coal-fired boilers. TS use in the production of nuclear energy has not been documented to the same extent, but it could be due to the reluctance of this industry to publish in the open literature. Similarly, fabrication of devices for energy harvesting applications has not been described in great detail.

COLD SPRAY: ADVANCED CHARACTERIZATION METHODS—FOCUSED ION BEAM MACHINING AND ELECTRON PROBE MICROANALYSIS

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

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

Focused ion beam (FIB) systems are selectively used in cold spray coating characterization to gather information on the nature of splat formation, single splats, multiple splats, or the coating-substrate interface. FIB resembles scanning electron microscopy (SEM) except that instead of using a focused beam of electrons to raster the sample surface, it uses a focused beam of ions (usually gallium) either to image the sample (using low-beam currents) or to remove material by sputtering it away (high currents).

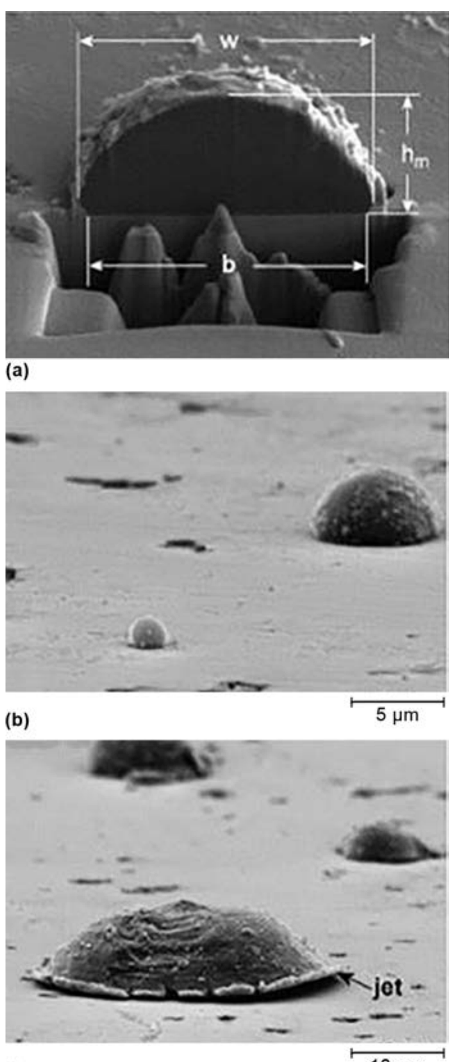

Fig. 1 — (a) Focused ion beam/scanning electron microscopy image of aluminum particle dissected using Ga+ ions. (b, c) Secondary electron micrographs of aluminum particles adhering to ceramic (lead-zirconium titanate) surface[1].

King and Jahedi[1] studied the effect of particle size and bonding for aluminum and copper particles and were able to make use of FIB machining to prepare sample sections and then view and analyze them by means of SEM (Fig. 1a). The particle-flattening ratios could be determined accurately using the FIB sections and used as inputs to feed into a model. Smaller particles were seen with a higher bow shock effect in the gas flow and exhibited greater resistance to deformation on impact. This result was further validated using an SE image with a stage tilt in the SEM >75° to precisely estimate the base and apex of individual particles (Fig. 1b).

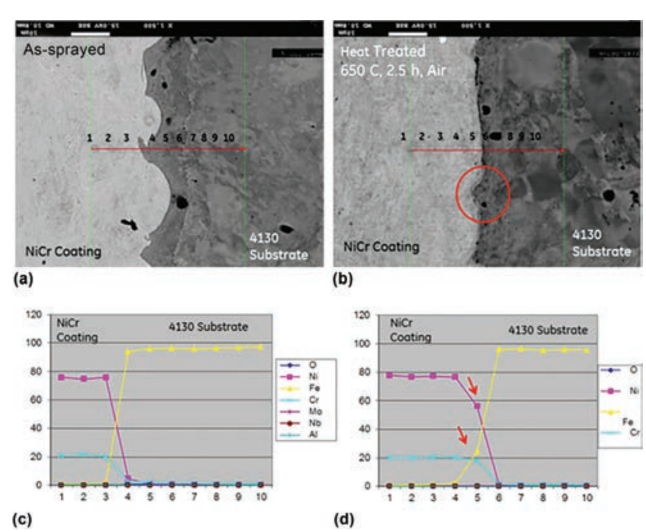

Fig. 2 — Representative scanning electron micrographs showing Ni-20Cr coating on AISI 4130 steel substrate interface, (a) as sprayed and (b) after heat treatment. (c, d) Corresponding electron probe microanalysis elemental profiles indicating the interdiffusion of elements at the interface[2].

The advantage of using FIB is to attain location-specific characterization of the cold-sprayed coating. Sometimes, FIB is used to enable preparation of thin electron-transparent samples for transmission electron microscopy.

Electron probe microanalysis is a spatially resolved, quantitative elemental analysis technique based on generating characteristic x-rays using a focused beam of energetic electrons. It is used to measure the concentration of elements at levels as low as 100 parts per million (ppm) and to develop lateral distributions by mapping, using both an energy-dispersive x-ray spectrometer and a wavelength-dispersive spectrometer. Electron probe microanalysis has been used in cold-sprayed coating characterization primarily to understand the bonding mechanism at the coating-substrate interface. It is a valuable characterization tool for accurately understanding the type of bonding, as shown in the case of a Ni-20Cr cold-sprayed coating on an AISI 4130 steel substrate in the as-sprayed versus heat treated condition (Fig. 2). It has been used to understand the coating relaxation process in the as-sprayed condition and after heat treatment in the vicinity of the substrate. **~iTSSe**

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

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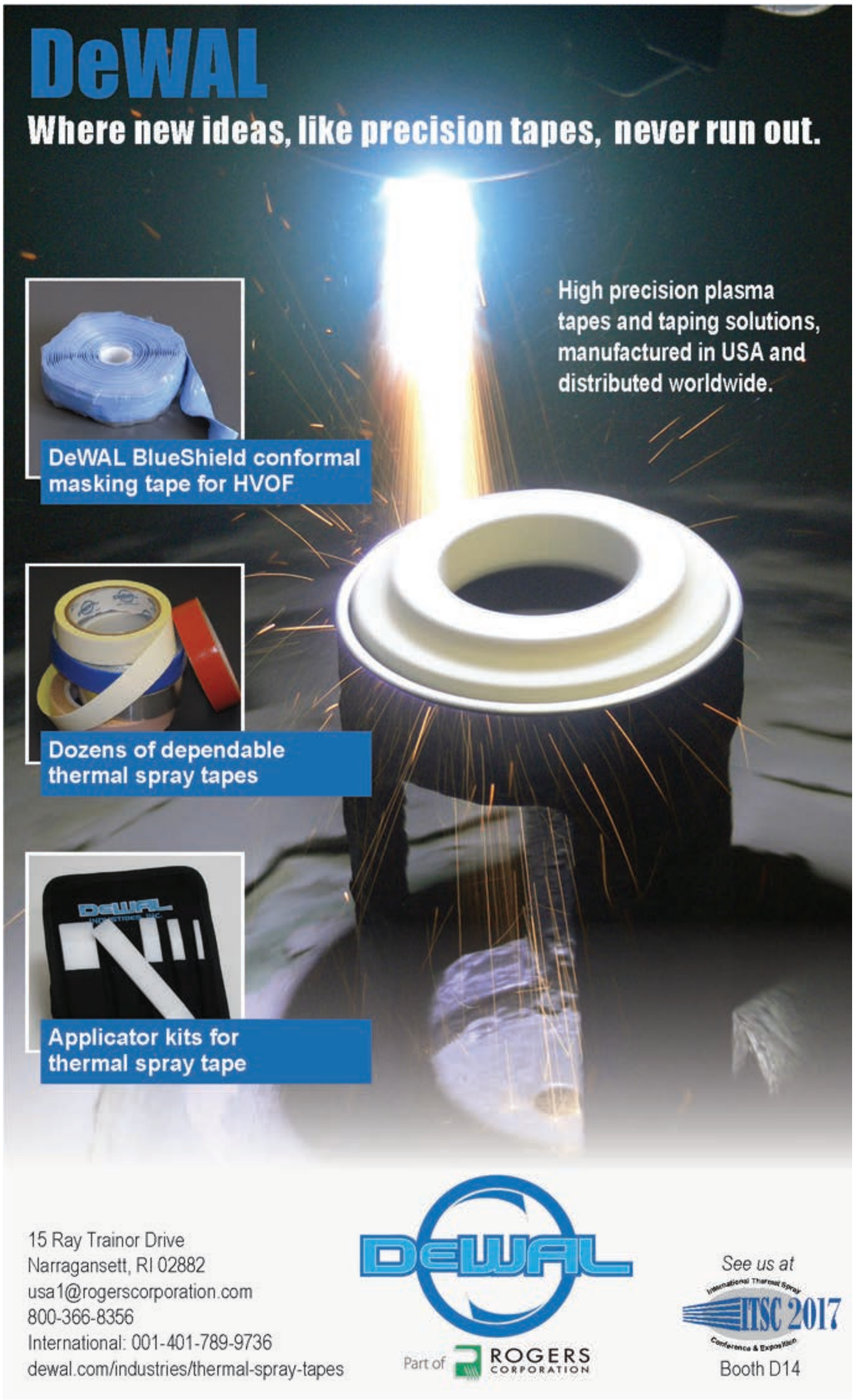

CARBIDE THERMAL SPRAY SURFACING PROTECTS BLOW MOLD HEAD TOOLING

REASON TO CONSIDER SURFACING

Finished surface quality is of paramount importance to parts that are mass-produced using blow molding and plastic injection molding technologies. Wear that causes dimensional changes in tooling (and final parts) can be greatly reduced by applying a wear-resistant carbide, stainless steel, or ceramic surface to tooling components via thermal spray. Carbide thermal spray surfacing is an established additive surfacing technique used in many plastic material processing applications. New parts processed with a wear-resistant thermal spray coating give tooling components remarkably greater service life. During routine maintenance, worn parts often can be resurfaced back to OEM specifications, significantly reducing replacement costs.

ASB Industries works with OEMs and rebuilders to protect and maintain quality tooling components to meet equipment design specifications. ASB recently worked with a local manufacturer of blow molded and injection molded products. This application is discussed here.

ISSUES

Blow mold head tooling wear was being caused by glass-filled nylon material. This tooling wear was creating die gap issues, disrupting material flow during production, and causing nonconforming parts to be manufactured.

OPTION

ASB Industries applied a commercially available tungsten carbide coating on the head tooling using the high velocity oxy-fuel (HVOF) process. A coating thickness of 0.010 in. per side is applied to the die component ID and to the pin component OD. Each component requires diamond finish grinding to achieve the final dimensions and a surface finish of 32 Ra micro-in.

Fig. 1 – Blow mold head tooling (die and pin) coated with a tungsten carbide/cobalt matrix after 19 months in service.

Fig. 2 – Non-coated blow mold head tooling (pin) after 17 months in service.

BENEFITS

Tooling that was not coated with tungsten carbide began to show wear and create die gap issues after only eight months of runtime, but continued to be used in production. Worn tooling was eventually replaced with newly coated components.

Tooling service life went from just eight months to more than 23 months so far; the customer is experiencing less downtime and labor to remove worn components.

As of this writing, the manufacturer has plans to install a new set of nitride components due to less cost compared to the HVOF carbide coating. Some of the engineers and maintenance personnel believe a quick repair is easier than the two or three weeks of turnaround time for coating removal, carbide coating, and diamond grinding. The other engineers and maintenance personnel believe the HVOF carbide coating is a better value. This will be an ongoing case study. **~iTSSe**

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The *Journal of Thermal Spray Technology (JTST),* the official journal of the ASM Thermal Spray Society, publishes contributions on all aspects—fundamental and practical—of thermal spray science, including processes, feedstock manufacture, testing, and characterization. As the primary vehicle for thermal spray information transfer, its mission is to synergize the rapidly advancing thermal spray industry and related industries by presenting research and development efforts leading to advancements in implementable engineering applications of the technology. Articles from the February and April issues, as selected by *JTST* Editor-in-Chief Armelle Vardelle, are highlighted here. The April issue contains a special focus on "Metal Additive Manufacturing," organized by guest editors Bertrand Jodoin, Mathieu Brochu, Jean-Yves Hascoet, and Todd Palmer. The third, fourth, and fifth articles highlighted here are from this special focus. In addition to the print publication, *JTST* is available online through springerlink.com. For more information, visit asminternational.org/tss.

ROLE OF OXIDES AND POROSITY ON HIGH-TEMPERATURE OXIDATION OF LIQUID-FUELED HVOF THERMAL-SPRAYED NI50CR COATINGS

B. Song, M. Bai, K.T. Voisey, and T. Hussain

High chromium content in Ni50Cr thermally sprayed coatings can generate a dense and protective scale at the coating surface. Thus, the Ni50Cr coating is widely used in high-temperature oxidation and corrosion applications. A commercially available, gas atomized Ni50Cr powder was sprayed onto a power plant steel (ASME P92) using a liquid-fueled HVOF thermal spray with three processing parameters in this study. The microstructure of as-sprayed coatings was examined using oxygen content analysis, mercury intrusion porosimetry, scanning electron microscopy (SEM), energy-dispersive x-ray spectroscopy (EDX), and x-ray diffraction (XRD). Short-term air oxidation tests (4 h) of freestanding coatings (without boiler steel substrate) in a thermogravimetric analyzer at 700°C were performed to obtain the kinetics of oxidation of the as-sprayed coating. Long-term air oxidation tests (100 h) of the coated substrates were performed at the same temperature to obtain the oxidation products for further characterization in detail using SEM/EDX and XRD. In all samples, oxides of various morphologies developed on top of the Ni50Cr coatings. Cr_2O_3 was the main oxidation product on the surface of all three coatings. The coating with medium porosity and medium oxygen content had the best high-temperature oxidation performance in this study (Fig. 1).

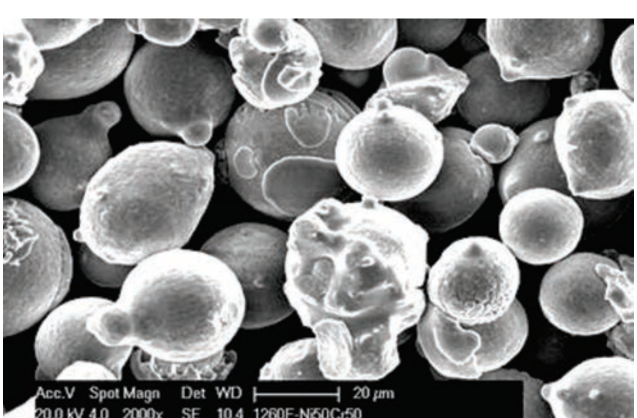

Fig. 1 – SEM image of as-received powder particle morphology.

THERMALLY SPRAYED LARGE TUBULAR SOLID OXIDE FUEL CELLS AND ITS STACK: GEOMETRY OPTIMIZATION, PREPARATION, AND PERFORMANCE

Shan-Lin Zhang, Cheng-Xin Li, Shuai Liu, Chang-Jiu Li, Guan-Jun Yang, Peng-Jiang He, Liang-Liang Yun, Bo Song, and Ying-Xin Xie

In this study, a large tubular solid oxide fuel cell (SOFC) design was developed with several cells in series on a porous cermet support with characteristics such as self-sealing, low ohmic loss, high strength, and good thermal expansion coefficient matching. Aspects of the cell design, manufacture, performance, and application are investigated. First, the cell length and number of cells in series are optimized by theoretical analysis. Thermal spray is then applied as a cost-effective method to prepare cell components. Finally, performance of different types of cells and two types of stacks is characterized. The maximum output power of one tube, which has 20 cells in series, reaches 31 W and 40.5 W at 800°C and 900°C, respectively. Moreover, the output power of a stack assembled with 56 tubes, each with 10 in series, reaches 800 W at 830°C. Excellent single tube and cell stack performance suggests that thermally sprayed tubular SOFCs have significant potential for commercial applications (Fig. 2).

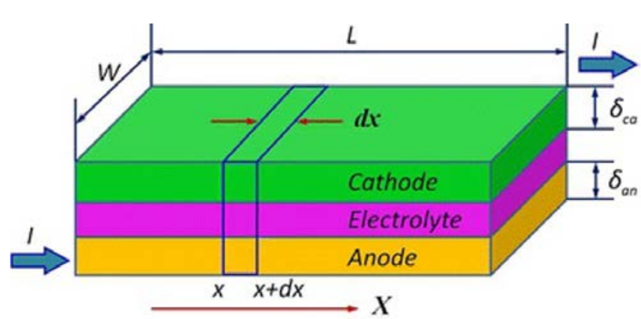

Fig. 2 – Schematic of the current flow inside a single cell in SS-SOFC design.

ADDITIVE MANUFACTURING OF ALSI$_{10}$MG ALLOY USING DIRECT ENERGY DEPOSITION: MICROSTRUCTURE AND HARDNESS CHARACTERIZATION

M. Javidani, J. Arreguin-Zavala, J. Danovitch, Y. Tian, and M. Brochu

This paper aims to study AlSi$_{10}$Mg alloy manufacturing with the direct energy deposition (DED) process. Following fabrication, the macro- and microstructural evolution of the as-processed specimens were initially investigated using optical microscopy and scanning electron microscopy. A columnar dendritic structure was the dominant solidification feature of the deposit; nevertheless, detailed microstructural analysis revealed cellular morphology near the substrate and equiaxed dendrites at the top end of the deposit. Moreover, the microstructural morphology in the melt pool boundary of the deposit differed from the one in the core of the layers. The remaining porosity of the deposit was evaluated by Archimedes' principle and by image analysis of the polished surface. Crystallographic texture in the deposit was also assessed using electron backscatter diffraction (EBSD) and x-ray diffraction analysis. The dendrites were unidirectionally oriented at an angle of ~80° to the substrate. EPMA line scans were performed to evaluate the compositional variation and elemental segregation in different locations. Eventually, microhardness (HV) tests were conducted in order to study the hardness gradient in the as-DED-processed specimen along the deposition direction. The results, which exhibit a deposit with an almost defect-free structure, indicate that the DED process is suitable for the deposition of Al-Si-base alloys with a highly consolidated structure (Fig. 3).

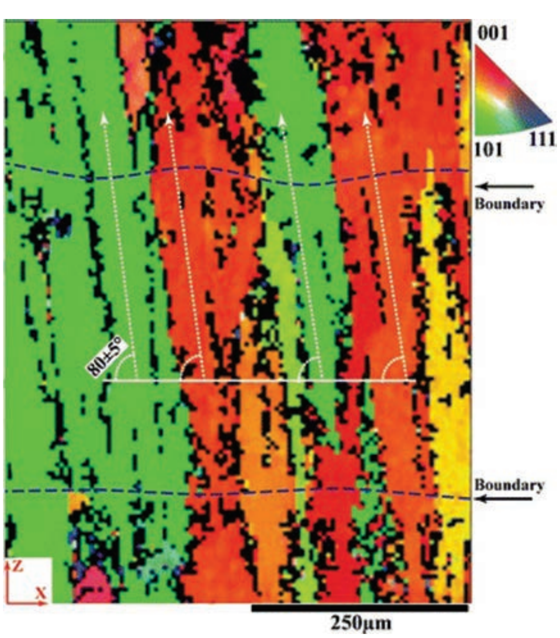

Fig. 3 – EBSD mapping at middle (half height) of specimen; inverse pole figure (IPF) colored orientation image map, with IPF.

PROCESS-STRUCTURE-PROPERTY RELATIONSHIPS FOR 316L STAINLESS STEEL FABRICATED BY ADDITIVE MANUFACTURING AND ITS IMPLICATION FOR COMPONENT ENGINEERING

N. Yang, J. Yee, B. Zheng, K. Gaiser, T. Reynolds, L. Clemon, W.Y. Lu, J.M. Schoenung, and E.J. Lavernia

This study investigates the process-structure-property relationships for 316L stainless steel prototyping utilizing 3D laser engineered net shaping (LENS), a commercial direct energy deposition additive manufacturing process. The study concludes that the resultant physical metallurgy of 3D LENS 316L prototypes is dictated by interactive metallurgical reactions during instantaneous powder feeding/melting, molten metal flow, and liquid metal solidification. The study also shows that 3D LENS manufacturing is capable of building high strength and ductile 316L prototypes due to its fine cellular spacing from fast solidification cooling, and well-fused epitaxial interfaces at metal flow trails and interpass boundaries. However, without further LENS process control and optimization, deposits are vulnerable to localized hardness variation attributed to heterogeneous microstructure, i.e., the interpass heat-affected zone (HAZ) from repetitive thermal heating during successive layer depositions. Most significantly, current deposits exhibit anisotropic tensile behavior, i.e., lower strain and/or premature interpass delamination parallel to build direction (axial). This anisotropic behavior is attributed to the presence of interpass HAZ, which coexists with flying feedstock inclusions and porosity from incomplete molten metal fusion. The current observations and findings contribute to the scientific basis for future process control and optimization necessary for material property control and defect mitigation (Fig. 4).

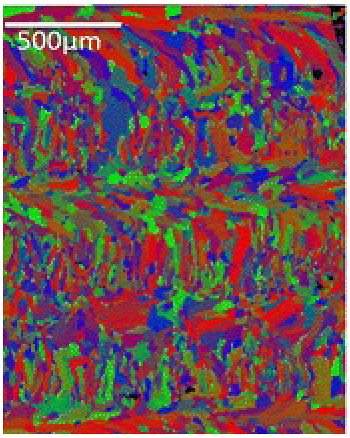

Fig. 4 – Morphology, size, and crystal orientation for the solidification cells: EBSD orientation map.

COLD SPRAYING OF ARMSTRONG PROCESS TITANIUM POWDER FOR ADDITIVE MANUFACTURING

D. MacDonald, R. Fernández, F. Delloro, and B. Jodoin

Titanium parts are ideally suited for aerospace applications due to their unique combination of high specific strength and excellent corrosion resistance. However, titanium bulk material is expensive and challenging to machine. Production of complex titanium parts through additive manufacturing looks promising, but there are still many barriers to overcome before reaching mainstream commercialization. The cold gas dynamic spraying process has potential for additive manufacturing of large titanium parts due to its reduced reactive environment, simple operation, and high deposition rates. However, a few challenges must first be addressed. In particular, it is known that titanium is easy to deposit by cold gas dynamic spraying, but the deposits are usually porous when nitrogen is used as the carrier gas. In this work, a method to manufacture low-porosity titanium components at high deposition efficiencies is revealed. Components are produced by combining low-pressure cold spray using nitrogen as the carrier gas with low-cost titanium powder produced using the Armstrong process. The microstructure and mechanical properties of additively manufactured titanium components are investigated (Fig. 5).

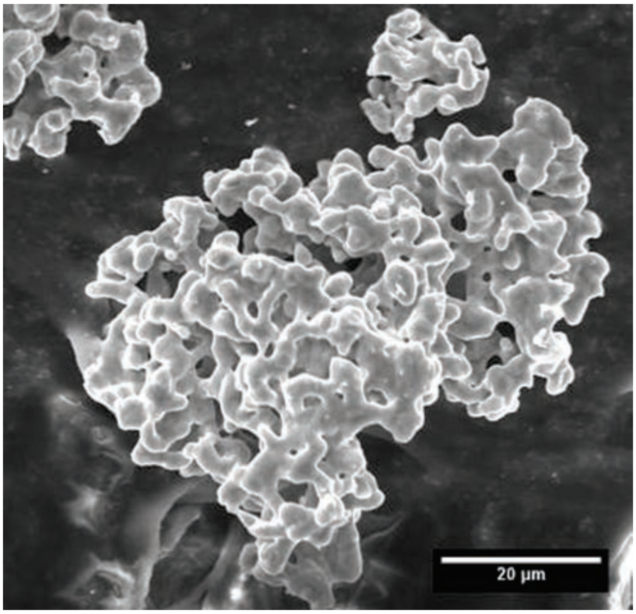

Fig. 5 – SEM image of coral-shaped titanium powder produced using the Armstrong process.

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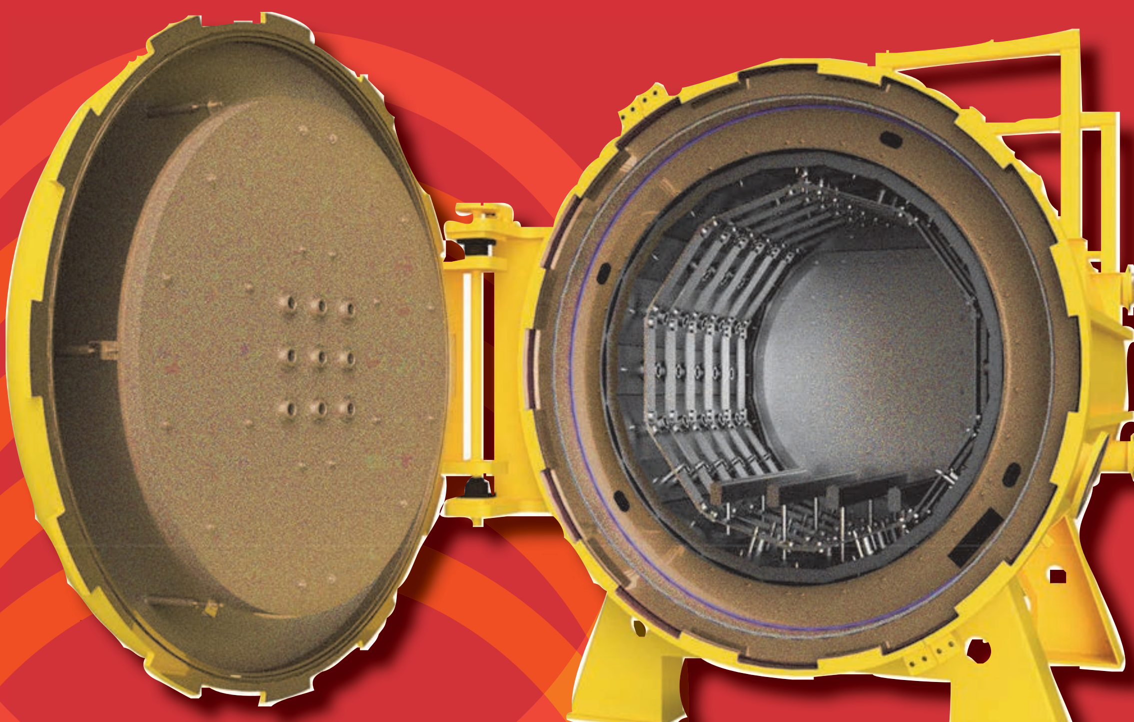

HOT ZONE DESIGNS FOR VACUUM FURNACES
6

GAS QUENCHING: BETTER TEST METHODS
10

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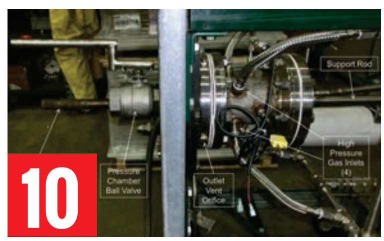

EDITORIAL OPPORTUNITIES FOR HTPro IN 2017

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

September Thermal Processing in On/Off Highway Applications

November Atmosphere/Vacuum Heat Treating

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

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

DEPARTMENTS

ABOUT THE COVER

Shown here is the latest in hot zone designs from Solar Manufacturing Inc., highlighting the new HEFVAC (high efficiency vacuum) insulating graphite board along with segmented, flat graphite heating elements. Courtesy of Solar Atmospheres Inc., solaratm.com.

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AEROSPACE HEAT TREATMENT: ADVANCES THROUGH MODELING AND DATA

Heat treatment is a critical manufacturing process that drives the final mechanical properties and performance of metallic components and subsequent systems. Unique mechanical properties are often the target for specific heat treating processes, but other attributes are extremely important for the aerospace heat treating industry, including understanding and controlling final part residual stress and distortion.

Residual stress that results from heat treating processes can cause two major issues: distortion and lack of dimensional control during final machining processes, and interaction with applied application stresses that can greatly impact part performance or even part life. The aerospace industry strives for enhanced component capabilities that enable overarching systems improvements, especially those that provide tangible benefits to final customers, such as initial system costs, fuel efficiency, and durability. Manufacturing yield and component dimensional control are key attributes.

Many organizations have focused activities aimed at mitigating heat treatment-induced residual stresses. Modeling has advanced to the point where efforts should be taken to enable industrywide standards for modeling, prediction, and control of these stresses. There is a need for residual stresses to be systematically incorporated into product definitions, which the thermal processing industry can address.

Current approaches of leaving residual stresses as an afterthought that machining suppliers need to worry about will not work for the future. Defining and controlling residual stresses within heat treated products is required to enable controlled, repeatable machining of tight-tolerance component geometries. Modeling and simulation tools of various types are commercially available to provide prediction of thermal stresses and subsequent residual stresses. Additionally, the input material data required for such modeling and simulation is critical for accurate, quantitative predictions. A new entity called the Center for Materials Processing Data is being formed at Worcester Polytechnic Institute to support industry with materials property data at manufacturing process-relevant conditions. The combination of commercial software and accurate materials data will enable increased application of modeling and simulation.

In addition to modeling and simulation, advances in process monitoring, data capture, and data analytics are becoming commonplace and are a needed pillar for required process control and continuous improvement. The heat treating industry must take on “Big Data” as equipment and processes become more complex and final product requirements become more demanding. The combination of computational modeling and use of data will drive the heat treating industry forward to meet the evolving demands of the aerospace industry.

David Furrer, FASM
Senior Fellow Discipline Lead
Manager, Manufacturing Technologies
Pratt & Whitney, Materials and Processes Engineering

HTS REPRESENTATIVES ATTEND ASM AFFILIATE OFFICER SUMMIT

ASM hosted an Affiliate Officer and ASM Management Summit on April 18 and 19 at its headquarters in Materials Park, Ohio. On hand to represent the interests of the Heat Treating Society were **Stephen G. Kowalski,** HTS president, president of Kowalski Heat Treating Co. and **James P. Oakes,** HTS vice president, vice president of business development at Super Systems Inc. The objective of the Summit was to strengthen the relationships between the Affiliates and ASM, and better align their activities with the ASM Renewal.

Also in attendance were leaders from the Electronic Device Failure Analysis Society, Failure Analysis Society, International Metallographic Society, International Organization on Shape Memory and Superelastic Technologies, and the Thermal Spray Society, as well as members of the ASM management team.

HTS president Steve Kowalski (left) meets with HTS vice president Jim Oakes during the Affiliate Summit at the ASM Dome.

MARK YOUR CALENDARS

As HTS gears up for its big event in Columbus, Ohio, this October—with registration opening in June—plans are in the works for other heat treating conferences as well. For details, visit asminternational.org/web/hts/events.

PLAN TO ATTEND:

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Front row, from left: Jaret Frafjord (IMS president), Othmane Benafan (SMST vice president/finance officer), Ron Aderhold (ASM associate managing director and chief information officer), Ryan Milosh (ASM sales and marketing director), Lee Knauss (EDFAS vice president), Steve Kowalski (HTS president), Bill Mahoney (ASM managing director), Zhiyong Wang (EDFAS president). Second row, from left: Burak Akyuz (FAS president), Jeremy Schaffer (EDFAS president), Jim Oakes (HTS vice president), Dan Dennies (IMS vice president-elect), and Doug Puerta (TSS president).

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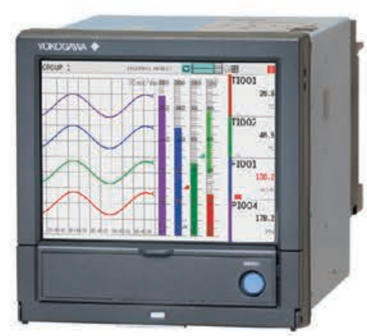

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NEW DEVELOPMENTS IN VACUUM FURNACE HOT ZONE DESIGN

A novel hot zone design featuring new graphite boards reduces heat loss and improves overall hot zone power requirements.

Real J. Fradette,* Virginia Osterman,* and William R. Jones, FASM*
Solar Atmospheres Inc., Souderton, Pa.

Current vacuum furnace hot zone designs include all-metal shielding, ceramic fiber (kaowool), and graphite fiber, foil, and board combinations. Typically, a stainless steel ring structure supports the insulation package within the hot zone (Fig. 1). Energy studies shows that the all-metal hot zone is the least efficient, requiring a larger and more expensive power supply when operating at temperatures around 1150°C (2100°F). All-metal designs usually include a combination of thin molybdenum and stainless steel shields. These hot zones typically offer better vacuum levels and super clean work compared to other options. However, they are more expensive, 30% less efficient, and usually last about half the time of other insulated hot zones.

Ceramic fiber provides superior insulating properties, but it tends to absorb substantial amounts of water vapor when opened to air. This leads to longer evacuation times, especially during high-humidity days. In addition, ceramic fibers shrink at high temperatures and create gaps within the support ring that result in additional energy losses.

The majority of all-purpose vacuum furnaces manufactured today use a combination of graphite felt and foil and graphite felt and board. For example, most modern furnaces contain four 0.5-in. thick layers of graphite felt with either a graphite foil hot face or a rigid graphite board hot face (primarily used in high-pressure gas quench furnaces). Graphite felt has a tendency to absorb water vapor, but not to the same extent as ceramic fibers. Care must be taken to keep the furnace closed as much as possible. With correctly sized vacuum pumps and proper maintenance and operating practices, this type of furnace is capable of producing very clean work.

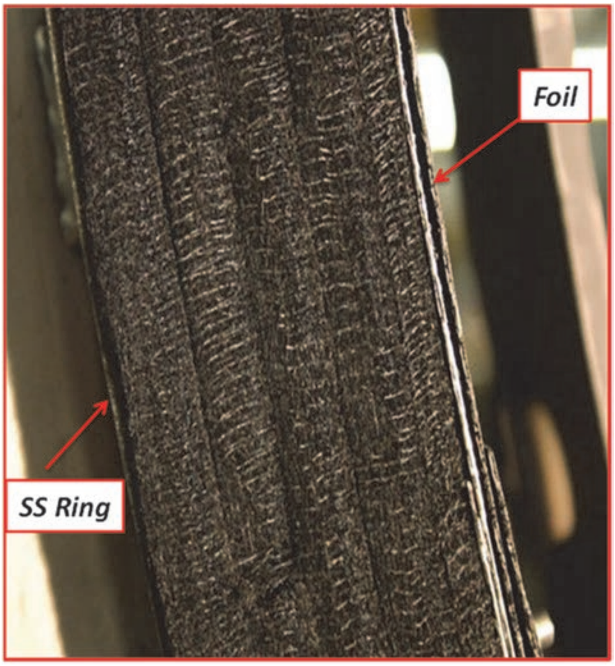

Fig. 1 — Graphite hot zone in which stainless steel support ring holds insulation package in place.

*Member of ASM International

Recently, Solar Manufacturing and Solar Atmospheres compared a new graphite board with current products. The new board (a standalone insulation package produced by Graphite Machining Inc., Topton, Pa.) is a 2-in. thick, high-density compressed graphite fiberboard sealed with a proprietary graphite polymer to minimize porosity and moisture absorption.

COMPARISON OF POWER LOSS AND INSULATION

To conduct experimental work, a standard vertical laboratory-type vacuum furnace (12-in. diameter by 18-in. high) was modified with an extension piece placed on the main chamber (Fig. 2). The extension provided a space to add thicker insulation packages to the top of the furnace hot zone. The temperatures of the furnace hot zone and outer stainless steel lid were measured using calibrated Inconel thermocouples at three different stabilized furnace temperatures.

The temperature of the outer stainless steel lid represents the temperature of support ring "A" (Fig. 3) adjacent to the furnace cold wall "B." The major thermal loss in a vacuum furnace stems from the ring radiating energy to the furnace cold wall. Other losses via hearth pins and nozzle direct radiation losses are not included in the analysis.

Total energy radiated by a black body is given by the Stefan-Boltzmann law:

$$P = \varepsilon\sigma A(T^4 - T_c^4)$$

where P is net radiated power, ε is emissivity of the radiating surface (0.55 for stainless steel), σ is the Stefan-Boltzmann constant (5.670367×10^{-8} W · m^2 · K^{-4}), A is the radiating sur-

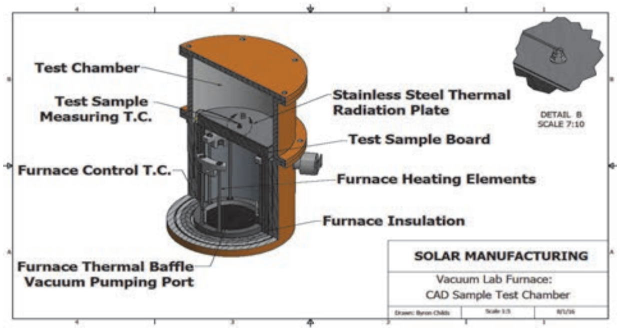

Fig. 2 — Schematic of test chamber showing extension for test sample placement.

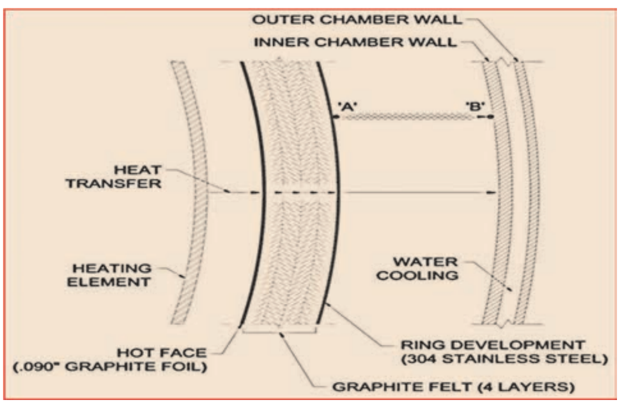

Fig. 3 — Schematic of furnace wall cross section: Radiation heat transfer from ring wall "A" to cold wall "B" largely contributes to heat loss within the furnace hot zone.

face area, T is the radiating surface temperature (K) of the support ring, and T_c is the temperature (K) of the surrounding surface chamber wall. The Stefan-Boltzmann law also applies to power losses at radiating surfaces. The equation shows that energy loss is proportional to the fourth power of the ring temperature (walls "A" and "B" in Fig. 3). Reducing the temperature of wall "A" is a key factor in improving energy efficiency in the vacuum furnace.

TABLE 1 – COMPARISON OF PRIOR INSULATION TEST RESULTS AND NEW BOARD RESULTS

Insulation type	Hold temperature, °F 1750	2000	2250
All metal (3 Mo, 2 SS)	551	650	733
Foil/2-in. kaowool	452	548	640
Foil/2-in. rayon graphite felt	456	544	616
Foil/2-in. pan graphite felt	490	574	659
Standard graphite board (avg.)	517	572	622
New 2-in. board with foil facing*	334	367	405

*New graphite board material from Graphite Machining Inc.

Table 1 shows prior insulation test results and results using the new board (last row in table). Figure 4 shows the improvement in thermal efficiency for the new graphite board compared with other modern designs.

CURRENT DESIGN VERSUS NEW DESIGN

Based on improved results from using the new graphite board, Solar named the board HEFVAC for high efficiency vacuum capabilities and applications, and will introduce a new hot zone design that incorporates the more energy efficient insulating board. Until now, the foil/2-in. thick rayon felt combination offered the best energy efficient graphite vacuum furnace (Table 1 and Fig. 4). The new design offers a significant improvement over the current design. The HEFVAC lowers the ring temperature by nearly 200°F at a hold temperature of 2250°F. At a hold temperature of 2000°F, a 61% improvement in temperature loss occurs (Table 2).

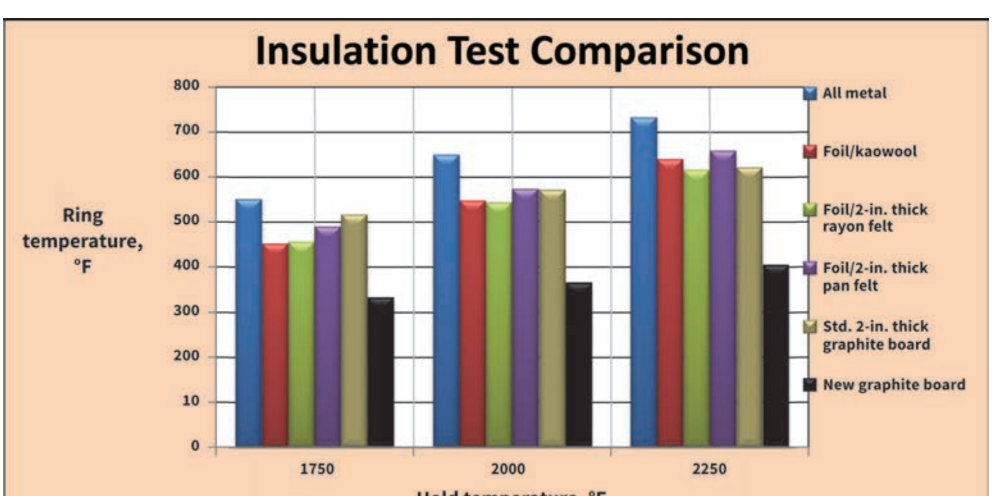

Fig. 4 — Comparison of thermal efficiency of furnace insulation package.

The hold temperature is the outer temperature of the stainless steel ring that supports the internal insulation with the ring radiating to the furnace cold wall, which represents the radiation losses.

TABLE 2 – REDUCTION IN RING TEMPERATURE FOR NEW AND CURRENT HOT ZONE DESIGNS

Insulation type	Hold temperature, °F 1750	2000	2250
Standard - foil/4 layers 0.5-in. rayon felt/ring	456	544	616
New 2-in. HEFVAC board/foil face	334	367	405
Temperature difference	122	177	211

TABLE 3 – BOARD-TO-RING GAP TEMPERATURE IMPROVEMENT WITH FLAT VERSUS CURVED PLATE

Insulation type	Hold temperature, °F 1750	2000	2250
2-in. HEFVAC board with flat plate	334	367	405
2-in. HEFVAC board with curved plate	309	332	365

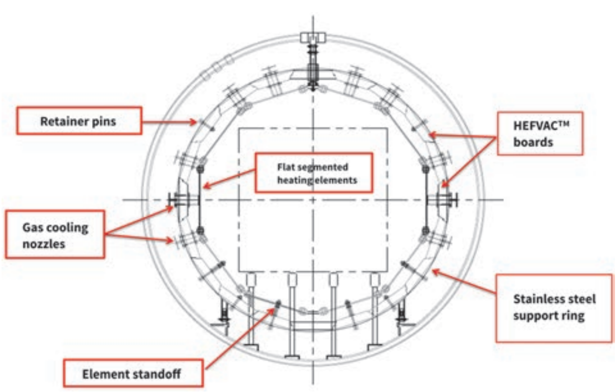

Fig. 5 — Schematic of new furnace design using HEFVAC board.

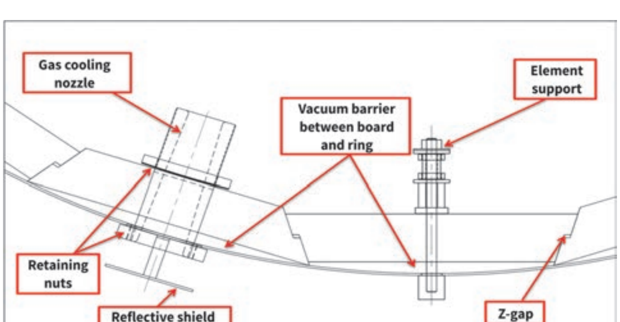

Fig. 6 — Schematic of HEFVAC board cross sections showing Z-shaped design.

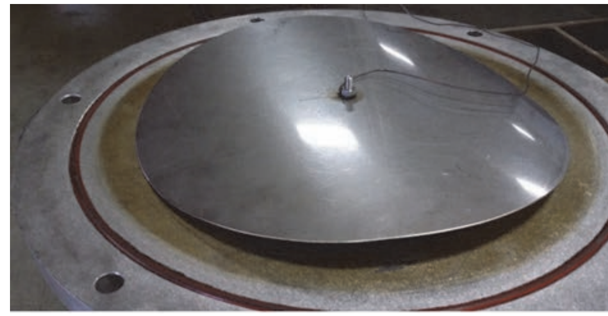

Fig. 7 — Board/ring vacuum gap test.

NEW BOARD HOT ZONE DESIGN

The new hot zone design is shown in Figs. 5 and 6. It features HEFVAC boards connected in a segmented design to form a polygon within the support ring with the boards abutting each other to provide a strong rigid support base. Gas cooling nozzles, graphite, and heating element supports hold the felt in place, replacing many types of retaining pins used in previous designs. This limits the number of retaining pins required and thus reduces conductive losses through the pins.

The flat boards only make direct contact with the support ring along the edge, creating a vacuum barrier between the board and support ring, further improving thermal losses. In addition, each board has a Z-shaped notch manufactured on both edges for easy installation. This shape also allows for thermal growth between boards during the heating cycle and closes any gaps, which further reduces direct radiation loss from the interior of the hot zone to the support ring.

The graphite heating elements are flat, segmented graphite sections of equal dimensions. The heating elements connect via a graphite splice joint that features a threaded graphite bolt and nut, providing a quick and simple configuration for replacement.

BOARD-TO-RING GAP THERMAL IMPROVEMENT

Table 3 shows an example of the new HEFVAC board's projected temperature improvement with a flat plate versus a curved plate (Fig. 7), representing the shape of the support ring (thermocouple at center of both plates). This gap further improves the thermal loss by approximately 10%. The new HEFVAC design is expected to reduce overall power losses when holding at elevated temperatures by 30-40%. **~HTPro**

For more information: Real Fradette is senior technical consultant, Solar Manufacturing Inc., 1983 Clearview Rd., Souderton, PA 18964, 267.384.5040 ext. 1560, real@solaratm.com, www.solaratm.com.

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GAS QUENCHING: LINKING STEEL HARDENABILITY AND FURNACE COOLING CAPABILITY TESTS

New methods evaluate steel hardenability in a standard gas quench test and HTC variation within a furnace gas quench chamber.

Yuan Lu* and Richard Sisson, Jr., FASM,* CHTE, Worcester Polytechnic Institute, Mass., and **Michael Pershing,*** Caterpillar Inc., Peoria, Ill.

Gas quenching is widely used in the aerospace and automotive industries for medium and high hardenability steels[1]. However, two areas of uncertainty in gas quenching include hardenability measurement and cooling characteristics of vacuum or non-vacuum furnace quench chambers. Two questions arise regarding hardenability: How does alloy variability within a steel grade impact hardening characteristics? And how does it alter the martensite percent versus depth curve on carburized and direct hardened components? Questions with respect to cooling include: What does a "10 bar nitrogen quench" furnace mean? And what is the heat transfer coefficient (HTC) at the surface of a part in different areas of the furnace? The Center for Heat Treating Excellence (CHTE) at Worcester Polytechnic Institute (WPI) developed methods to evaluate steel hardenability on medium and high hardenability steels in a standard gas quench test and to evaluate HTC variation within a furnace gas quench chamber[2].

The method for evaluating medium and high hardenability steels in a gas quench uses a Grossman-like hardenability approach and establishes a critical HTC for a 25-mm (1-in.) diameter specimen. The test can be modified for larger diameters, which is required for high hardenability steels. Critical HTC is defined as the surface heat transfer coefficient required to obtain 50% martensite in the center of the 25-mm specimen. Understanding both the approximate range of HTCs in a given furnace and the critical HTC for the steel being processed enables using both tests in tandem to provide excellent furnace HTC mapping for any load.

PROPOSED GAS QUENCH FURNACE EVALUATION PROCEDURE

Linking the gas quench steel hardenability test with the furnace quench capability test is best explained by following the procedure used to determine furnace quench capability and uniformity. Cylindrical test bars are used, with the number and location of bars varying according to how essential it is to understand cooling uniformity at all parts in the load. The bars can evaluate standard loading or be used without any other parts. Hardness at the center of the bar is ultimately correlated to a surface HTC. The relationship is established using either the standard gas quench hardenability method or a heat treat simulation code such as Dante, from Dante Solutions, Cleveland[3].

**Member of ASM International*

Heat treat simulation steps are as follows:

1. Estimate HTC range for furnace to be tested.
2. Select proper sample size and alloy.
3. Carry out heat treat cycle with gas quench.
4. Measure hardness.
5. Establish HTC for each specimen location.

Estimate HTC range for furnace to be tested. Figure 1 shows that gas quenching in vacuum furnaces, whether for direct hardening or carburizing, provides surface heat transfer coefficients (*h*, or HTC) ranging between 100 and 2000 $W/m^2 \cdot K$.

Select proper sample size and alloy. The heat treater or final user should select the alloy for a critical component and then select the proper size for that alloy. The correct size is that which will provide a range of percent martensite at the center (ideally between 50% and 90%). For carbon steels with 0.40% C, such as AISI 4140 and 4340, this results in hardness of 42-50 HRC at the center of the bar. For grade 4140, a

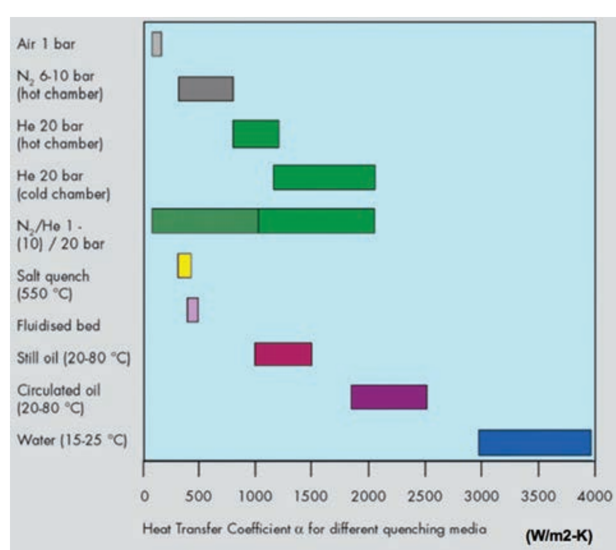

Fig. 1 — Heat transfer coefficients for different quenching media[1].

25-mm (1-in.) diameter bar works well for evaluating furnaces with an HTC ranging between 250 and 650 W/m^2 · K. This covers 5-10 bar N_2 gas quench furnaces with a hot chamber. Cold chamber quenching, higher pressure quenching, and He gas quenching require a larger diameter 4140 bar to evaluate HTC throughout the quench chamber.

This was determined at CHTE by performing tests on a standard gas quench unit (Fig. 2) developed by Praxair Inc., Danbury, Conn. Figure 3 shows the results of quenching four 25-mm diameter bars under different gas quench conditions (pressure and gas velocity). Hardness was measured at the center of each bar. The plot shows the corresponding HTC for 41-43 HRC (hardness for 50% martensite for 0.40% C), designated as the critical HTC. It can be used as a measure of gas quench hardenability. More importantly, the range of HTC values indicates what works to understand HTC variation in a gas quench furnace in the 250-650 W/m^2 · K range. HTC was determined by the equation[4]:

$$h = \frac{k}{L} 0.023 \left(\frac{PVL}{\mu ZRT}\right)^{0.8} \left(\frac{\mu C_P}{k}\right)^{0.33}$$

where *h* is heat transfer coefficient (W/m^2 · K), *P* is gas pressure (Pa), *V* is gas velocity (m/s), *L* is characteristic length or part diameter (m), *μ* is dynamic viscosity (kg/ms), *Z* is gas compressibility and density, *R* is gas constant (J/Kmol), *T* is gas temperature (K), C_p is gas specific heat (J/kg K), and *k* is thermal conductivity (W/m · K). This equation works well over a range of different pressures, gas temperatures, and gas velocities. It also compares well with different Dante heat treat simulations[5].

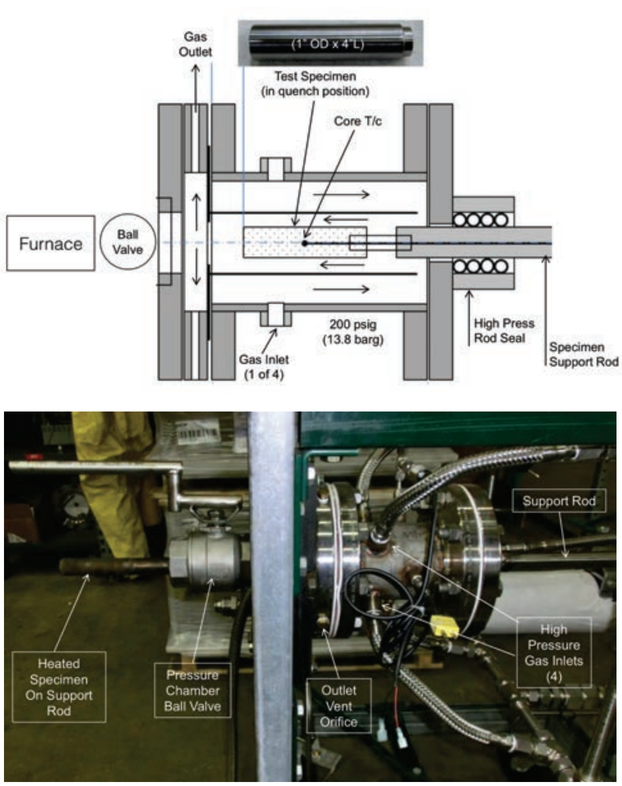

Fig. 2 — Schematic of Praxair gas quench system shown with a 25-mm diameter × 100-mm long (1 × 4-in.) specimen.

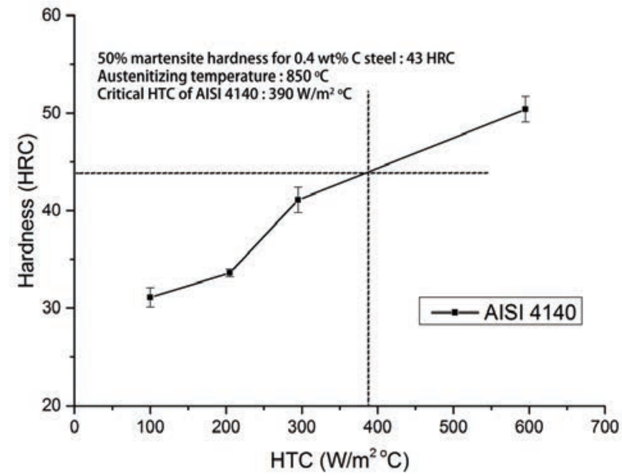

Fig. 3 — Hardness results from various surface HTC settings in the standard quench system for 25-mm (1-in.) diameter AISI 4140 steel.

Heat treat cycle with gas quench. Place specimens at desired locations in the gas quench furnace; for example, in Fig. 4, samples are dispersed focusing on the ends of the furnace. Test bars are austenitized at the appropriate temperature (e.g., 850°C for AISI 4140) and quenched, recording quench conditions (gas temperature, furnace pressure, and gas velocity).

Hardness measurements. A slightly larger than 13-mm (0.5-in.) disc is taken from the center of each specimen so one side is from a transverse cut at the center of the bar and hardness is measured at the center of the disc.

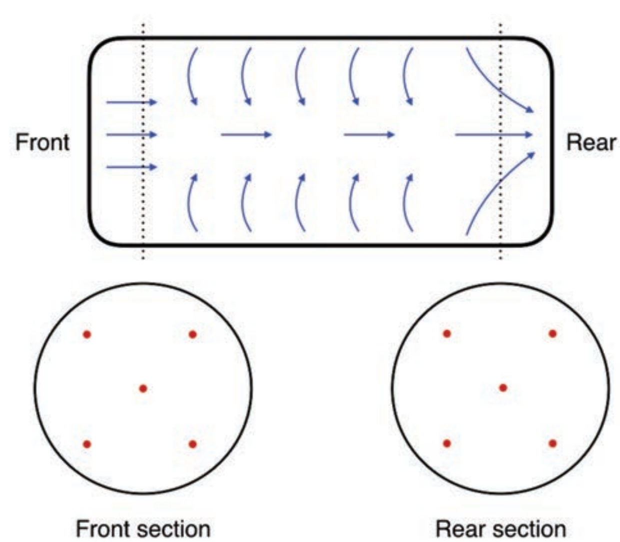

Fig. 4 — Gas flow direction and sample location in the furnace.

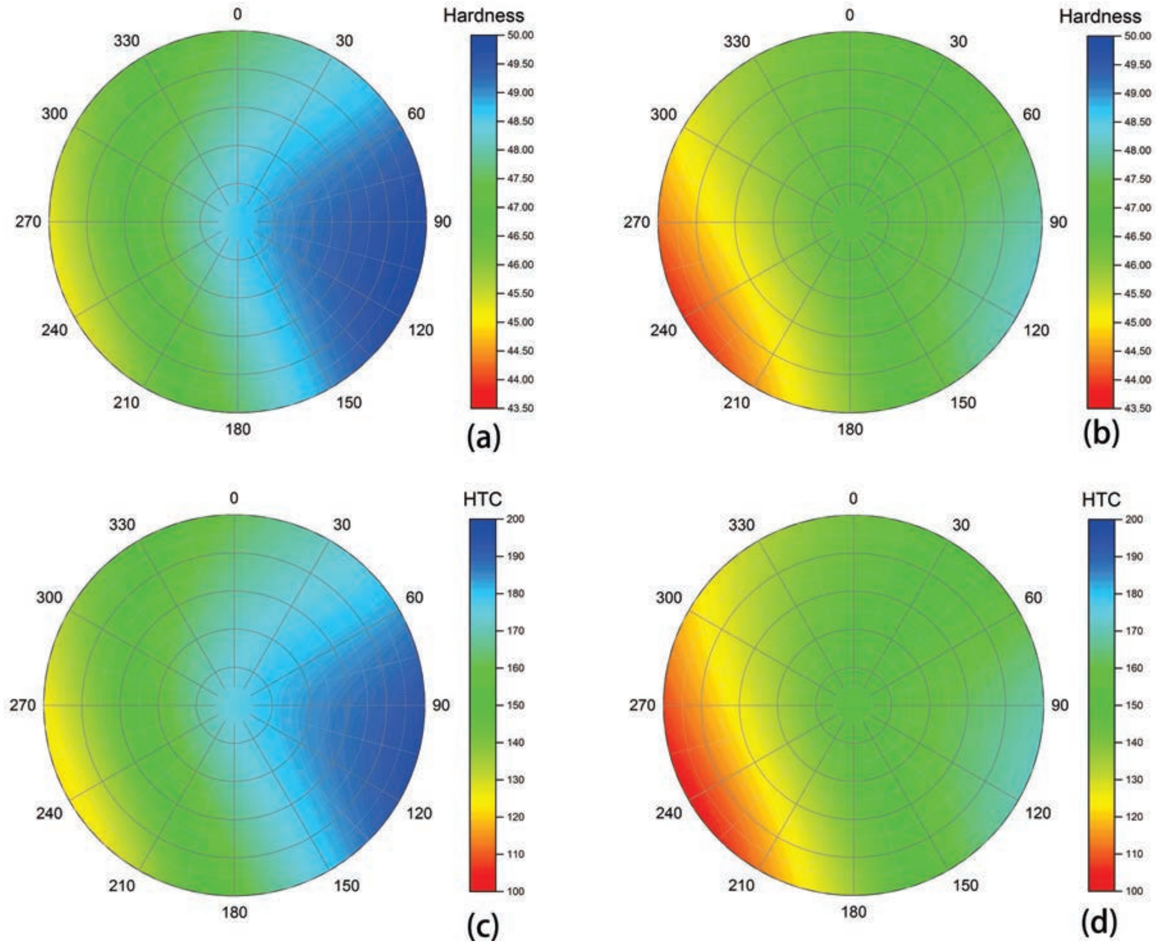

Fig. 5 — Hardness and HTC of samples placed to test the front and rear of the furnace: (a) hardness of front side, (b) hardness of rear side, (c) HTC distribution of front side, and (d) HTC distribution of rear side.

Establish HTC for each specimen location. Two methods are used to correlate hardness measurements to HTC. One method uses results from the standard gas quench using the Praxair-type unit (Fig. 2). If the same heat of steel is used to develop the center hardness versus the HTC curve using the same standard cooling tests as in the furnace quenching evaluation, then that base curve can be used to apply an HTC to each specimen (or each location) for the furnace. Another method employs a heat treat simulation package such as Dante to determine the HTC that produces the measured hardness value at the center of those specimens.

For a furnace with very slow cooling (HTC values below 200 $W/m^2 \cdot K$), it is difficult to use a common diameter specimen between the Praxair standard test and a furnace evaluation. The Praxair test cannot accurately create a slower cooling standard. The furnace evaluation also requires a high hardenability material and possibly a smaller diameter to differentiate surface cooling rates in all areas of the furnace. Heat treat simulation must be used when the standard Praxair-type test cannot be used.

Figure 5 shows results for 13-mm diameter by 100-mm long (0.5 by 4 in.) AISI 4340 bars tested in a 2-bar nitrogen furnace with gas flow direction as shown in Fig. 4. Samples were placed to test primarily the front and rear of the furnace. Core hardness varies from 44 to 49.5 HRC, which contains 50% to 90% martensite[1]. Figures 5(a) and 5(c) show that the front provides higher gas quench intensity compared with the rear (the strongest quench intensity is at right side of the front). The weakest quench intensity is at the lower left corner of the rear as shown in Figs. 5b and 5d. Based on measured hardness, a Dante simulation was conducted to determine the surface HTC (Figs. 5c and 5d). A 4340 13-mm test is appropriate to quantify quench intensity and uniformity in a 2-bar nitrogen gas quench furnace. **~HTPro**

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Acknowledgment

The authors would like to thank Praxair Inc. for support of the gas quench experiment. They are also grateful for the support of Alex Brune from Sikorsky Aircraft Corp. and Mike Arnold from ALD Vacuum Systems Inc. This work was sponsored by the Center for Heat Treating Excellence (CHTE), Worcester Polytechnic Institute.

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ASMNEWS

BOARD NOMINEES ANNOUNCED

Furrer for VP; Clauser for Treasurer; Aurora, Moore, and Todd for Trustees

The ASM Nominating Committee, chaired by Professor C. Ravi Ravindran, FASM, announce the nominees for ASM vice president and trustee for 2017-18 and three members of the Board of Trustees for 2017-20.

In accordance with the ASM Constitution, these nominees will be voted on at the ASM Annual Business Meeting on October 9, during MS&T17 in Pittsburgh. Once elected, the vice president will automatically become ASM president for 2018-19. In accordance with Article IV, Section 3 of the ASM Constitution, the ASM Board of Trustees has also announced its nominee for ASM Treasurer for 2017-2018.

Officers and members of the Board who will continue in office for 2017-2018 include: Dr. Frederick E. Schmidt, P.E., FASM, who will become president in October, Dr. William E. Frazier, FASM, who will serve as immediate past president; and trustees Dr. Ellen K. Cerreta, FASM, Dr. Ryan M. Deacon, Prof. Sudipta Seal, FASM, Larry D. Hanke, FASM, Roger A. Jones, and Dr. John D. Wolodko.

Retiring from the Board at this year's Annual Business Meeting will be immediate past president, Jon D. Tirpak, P.E., FASM, and trustees Dr. Kathryn Dannemann, FASM, Dr. Tirumalai Sudarshan, FASM, and Prof. David B. Williams, FASM.

ASM's 2017 Nominating Committee, from left: Khinlay Maung, Mark Hineman, Robert Hyers, Michael Hahn, FASM, Phil Maziasz, FASM, C. Ravi Ravindran, FASM (chair), Rod Boyer, FASM, Erhan Ulvan, B.S. Murty, FASM, and Arun Kumar. The committee met at ASM Headquarters in late April and posed for this picture under the Dome, in the historic mineral garden.

Nominating Committee Pit Crew Works Tirelessly

At 8:00 a.m. on the morning of the Nominating Committee meeting, it was discovered that Erhan Ulvan had a flat tire. As many of the committee members had stayed at the same hotel, one of them suggested they all work together to quickly change the tire. Business attire aside (no pun intended), the impromptu pit crew was a total success—with the exercise serving as a proper warmup for the teamwork required by the nominating process.

In This Issue

Submit news of ASM and its members, chapters, and affiliate societies to Frances Richards, editor, ASM News | ASM International
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About the President-Elect and Board Nominees

Dr. Frederick E. Schmidt, P.E., FASM

President-Elect

Schmidt

Dr. Frederick E. Schmidt, Jr., retired in 2015 after 17 years as a senior managing consultant at Engineering Systems Inc. (ESI). He served as technical director of materials engineering at ESI for many years. He was responsible for a very broad professional engineering practice, which used interdisciplinary teamwork with clients and other experts while working to solve complex "mission impossible" problems. Prior to ESI, he served as chief metallurgist for Remington Arms, a subsidiary of E.I. DuPont De Nemours. He designed and specified all materials, coatings, and processes for advanced weapons, i.e., Navy SEALs, sniper firearms, commercial products, and ammunition optimization for the U.S. Army.

Schmidt was employed by DuPont from 1972 to 1993 as an R&D coordinator of inter-department projects at the Experimental Station, Wilmington, Del. He was appointed a research fellow in 1989 in recognition of his creative solutions to proprietary electronic and materials processing quality control issues. He was also the designated liaison to the engineering development laboratory and DuPont legal department tasked to invent unique products and processes.

Schmidt was commissioned in the U.S. Army in 1968. He served for 12 years in various command positions, as a combat qualified reserve officer, and retired in 1980 as Captain in the Corps of Engineers.

Schmidt is a Fellow of ASM International and past president of Alpha Sigma Mu (2017-19). He served on the ASM Board of Trustees from 2004-2007 as well as serving on the ASM Materials Education Foundation Board as Trustee from 2007-2010. Schmidt received the ASM International Allan Ray Putnam Service Award in 1991 and the William Hunt Eisenman Award in 2015. He has a Ph.D. and M.S. in materials science and engineering from Drexel University, and a B.S. in metallurgical engineering from Drexel Institute of Technology. He became a professional engineer in the state of Pennsylvania in 1981 and currently holds P.E. licenses in eight states. Schmidt has earned the National Council of Examiners for Engineering and Surveying (NCEES) designation as a Model Law Engineer.

Dr. David U. Furrer, FASM

Nominee for Vice President

Furrer

Dr. David U. Furrer is senior fellow discipline lead for the Materials and Processes Engineering organization at Pratt & Whitney. In this role, he leads the Pratt & Whitney Materials Discipline Chiefs and Materials Fellows in development of technical strategies and engineering standards and procedures. Furrer supports the development, design, and deployment of new materials and associated manufacturing processes. He is responsible for manufacturing technologies development and maturation, including computational tools and methods to support legacy and emerging manufacturing process application and design for manufacture. He is involved in additive manufacturing process development along with other emerging manufacturing processes.

Prior to Pratt & Whitney, Furrer was chief of strategic materials and process technology and fellow of materials and process modeling at Rolls-Royce, where he led the strategy for materials modeling tools and methods, and the development and acquisition of advanced materials and processes. Furrer also held various roles at Ladish Co. Inc. (now ATI Forged Products) where he developed and delivered unique thermo-mechanical processing technology for aerospace and general industrial industries. He has over 25 years of experience in the areas of aerospace materials engineering, development and application of computational modeling and simulation tools for engineering materials and manufacturing processes, and data analytics.

In addition to working within the aerospace and forging industry, he has been an adjunct professor at the Milwaukee School of Engineering, where he taught materials and manufacturing technology courses within the mechanical engineering department.

Furrer is a Fellow of ASM International and has served on the ASM Board of Trustees from 2010-2013. He is also a member of the Connecticut Academy of Science and Engineering. Furrer received his bachelor's and master's degrees in metallurgical engineering from the University of Wisconsin-Madison, and a doctorate of engineering from the Universität Ulm in Germany.

Craig D. Clauser
Nominee for Treasurer


Clauser

Craig D. Clauser is president and owner of Craig Clauser Engineering Consulting Inc., which he founded in 2005. The company provides metallurgical engineering services nationwide, primarily in failure analysis and process improvement.

Clauser is a magna cum laude graduate of Lehigh University with a B.S. and M.S. in metallurgical engineering and materials science and is a registered professional engineer. He joined Westinghouse Electric Power Generation as a metallurgical engineer in the Materials Engineering Laboratory after graduating and subsequently became laboratory manager. The laboratory serviced the steam turbine, gas turbine, and heat transfer divisions at Lester, Pa. In 1977, Clauser joined Phoenix Steel Corp. where he served as technical director. Phoenix produced carbon and alloy plate in Claymont, Del., and heavy wall, pilger forged tubing in Phoenixville, Pa., and was a leader in clean steel technology. In 1986, he joined Consulting Engineers and Scientists Inc. in Malvern, Pa., where he was an engineer and senior vice president until starting his own firm.

Clauser joined ASM in 1967 and was the Philadelphia Chapter chairman in 1983. He also served as chairman of the ASM Chapter Operations Committee and the Handbook Committee. He is currently a member of the ASM Failure Analysis Society and the ASM Handbook Committees as well as the ASM Finance and Investment Committees. He was the Delaware Valley Metals Man of the Year in 1993, Philadelphia Liberty Bell Chapter Albert Sauveur Lecturer in 2001, and Eisenman Night Speaker in 2016. Clauser is also a member of NSPE, ASTM, NACE, ASME, AFS, and AWS.

Prem K. Aurora
Nominee for Trustee


Aurora

Prem Kumar Aurora has been an active member of ASM International since 1986. He received his bachelor's degree from Mumbai University in 1975 and completed his master of science degree from Kansas State University in 1978. His master's project was on vibrations of anisotropic plates, which was published in the *Journal of Vibrations* in 1978-79.

Aurora started his career as a design engineer at Chemtron Fire Systems in Monee, Ill., and was there for two and a half years before joining his family business of manufacturing heat treatment furnaces in 1981. During his 36 years in the industry, Aurora has been involved with major projects at Bhabha Atomic Research Centre, Air India, Defence Metallurgical Research Labs, Midhani, IIT, ISRO, Tech Institutes, and others. Projects involved the design and manufacture of a wide range of furnaces, from laboratory models to computerized SCADA production furnaces.

Aurora has been actively involved as a convenor and organizing secretary at various conferences and exhibitions in India to present the latest in materials science and technology to industry participants. These events include heat treat shows (HTS), materials engineering technology (MET), melting metallurgy and technology (MELTMETTECH), transportation materials (TRANSMAT), microstructure analysis of failure investigation of industries (MAFII) and international space enabling materials and processes (ISEMP). Aurora also has the privilege of serving as chairman of three national institutes—the Indian Institute of Metals (IIM), Institute of Indian Foundrymen (IIF), and ASM International India Chapter and India National Council.

Dr. Thomas M. Moore, FASM
Nominee for Trustee


Moore

Dr. Thomas M. Moore received his bachelor's degree in physics (1976), and his master's degree and Ph.D. in materials science and engineering (1978, 1981) from the University of Virginia. He worked for 21 years in the Texas Instruments (TI) Central Research Labs where he managed the scanning electron microscopy, transmission electron microscopy, focused ion beam, and scanning acoustic microscopy labs. Moore developed and productized the first digital acoustic microscope for automated IC package inspection. He later managed TI's Silicon Technology Ramp and Advanced Characterization group during TI's conversion to copper and low-k dielectric processes. He left TI as a Distinguished Member of the technical staff to found Omniprobe in 2001.

Omniprobe was acquired by Oxford Instruments in 2011. Moore retired from Omniprobe in 2013 and is now president of Waviks Inc. in Dallas. Waviks develops advanced characterization processes and tools for nano-analysis. Moore has been publishing and presenting at the International Symposium for Testing and Failure Analysis (ISTFA) since 1989. He also coauthored a chapter for ASM's "Microelectronics Failure Analysis Desk Reference" on Acoustic Microscopy of Semiconductor Packages. Moore has presented extended tutorials at ISTFA on package analysis (1996) and acoustic microscopy and x-ray radiography (1991-1997 and 2007-present, respectively) and served as a session chair for several years for Packaging, FIB, and Advanced Techniques.

Moore was the general chair for ISTFA 2003, was elected to the Electron Device Failure Analysis Society (EDFAS) board of directors (2005-2014) and served as EDFAS president from 2010-2011. He became an ASM Fellow in 2015. He also served as general chair of the IEEE-sponsored International Reliability Physics Symposium (IRPS 2010) and was president of the IRPS board of directors in 2012. Moore has published over 90 technical papers and chapters and holds over 20 patents.

Dr. Judith A. Todd, FASM
Nominee for Trustee


Todd

Dr. Judith A. Todd is department head, P.B. Breneman Chair, and professor of engineering science and mechanics at Penn State University. Prior to joining Penn State in 2002, Todd was the associate dean for research, professor of mechanical and materials engineering, and associate chair (six years) for the materials science and engineering program, department of mechanical, materials and aerospace engineering, Armour College of Engineering and Science, at the Illinois Institute of Technology. She was an Iron and Steel Society professor, Iron and Steel Society, American Institute of Mining, Metallurgical and Petroleum Engineers, from 1996-2002.

Todd's ASM International service includes: Chair of the Los Angeles Chapter (1986-1987); and member of the History and Archaeology of Materials Committee; West Coast Extension Liaison Committee; Materials Science Division Council; Education Affairs Committee; Awards Policy Committee; Council of Fellows Committee; Albert Easton White Distinguished Teacher Award Committee (chair in 2012); and chair of the Women in Materials Engineering Subcommittee on Recognition and Promotion. She was vice president for manufacturing, American Society of Mechanical Engineers (ASME) from 2002-2005 and the 2009 president of the Society of Engineering Science.

Todd's research interests include development of advanced materials and manufacturing processes; laser-sustained plasma and laser-materials interactions; mechanical behavior; nondestructive evaluation of materials; and archaeometry. She has published over 100 technical papers and holds two U.S. patents. She is a Fellow of ASM, ASME, and the Association of Women in Science. Todd's awards include the Vanadium Award, British Institute of Materials, and the ASME Board on Minorities and Women Award. She also received the Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring from President Bush in 2007. She received her B.A., M.A., and Ph.D. degrees in materials science from Cambridge University and is a Chartered Engineer in the United Kingdom.

ASM Nominations

The ASM International Constitution provides that members of the Society may submit additional nominations after the Nominating Committee has made its official report. Article V, Section 6 of the ASM Constitution reads: "After publication of the Nominating Committee's report on nominees, and the Board report on its nominee for Treasurer, and at any time prior to July 15 of the same year, additional nominations for any or all of the vacancies may be made in writing to the Secretary at Headquarters. Such nominations must be signed by at least five individuals or Chapter Sustaining Members, each from any combination of at least 10 Chapters and/or ASM Committees. Such nominees shall be processed by the Secretary for compliance with Section 4 of this Article. This shall be the only way in which additional nominations may be made. The membership of ASM International shall be duly notified of such additional nominations."

MS&T17 Technical Meeting and Exhibition
MATERIALS SCIENCE & TECHNOLOGY

Official ASM Annual Business Meeting Notice

The Annual Business Meeting of members of ASM International will be held in conjunction with MS&T17 on:

Monday, October 9
4:00 - 5:00 p.m.
David L. Lawrence Convention Center
Pittsburgh

The purpose of the ASM Annual Business Meeting is the election of officers for the 2017-18 term and transaction of other Society business.

SOLAR SUPPORTS ASM RENEWAL

The management team of ASM International visited Solar Atmospheres on March 22 to renew stronger relationships with its supporting companies and to gain a better understanding of Solar's commitment and involvement with the society. ASM managing director Bill Mahoney along with Ron Aderhold, ASM associate managing director and chief information officer, Fred Schmidt, ASM vice president, and Rachael Stewart, student board member, met with representatives from Solar and toured the facility. ASM presented information on the progress and goals of the ASM Renewal, spearheaded by Mahoney. Solar employees expressed a high level of confidence with the new ASM team and say they are encouraged with early results of the renewal efforts.

BUEHLER CONTINUES ASM COLLABORATION

Buehler, an ITW Company, recently renewed its collaboration with ASM by supporting the society's world training center in Materials Park, Ohio. Through this continued effort, ASM will include Buehler's newest metallographic preparation equipment, the EcoMet 300 polisher/grinder, the IsoMet high-speed precision saw, and the SimpliMet 4000 duplex mounting press. In addition, Buehler's Wilson VH Series hardness testing equipment with automated DiaMet hardness testing software and a multitude of consumables from abrasive discs to epoxies to hardness blocks will be available at the training center. ASM will use the new instruments in advanced metallography courses designed to teach participants about high precision manufacturing and materials testing techniques.

From left, Jim Nagy, president of Solar Manufacturing, Don Jordan, VP/corporate metallurgist for Solar Atmospheres, Bill Mahoney, Fred Schmidt, Ron Aderhold, Rachael Stewart, Jamie Jones, VP of operations, Solar Atmospheres, and Roger Jones, corporate president of Solar Atmospheres.

FROM THE PRESIDENT'S DESK

Frazier

ASM Renewal Continues

During the course of the past year, ASM International has taken some bold steps designed to provide enhanced member value. In last month's issue of *AM&P,* we published the ASM Strategic Plan. Central to that plan is the belief that the Society's maximum value is found at the intersection of materials, design and engineering, and manufacturing. It focuses on three strategic imperatives: membership value, technical excellence, and strategic collaboration and partnerships.

Shaping our thoughts is the concept that ASM International must deliver the products and services demanded by its members. Figure 1 depicts where the product "center of gravity" for ASM resides. Invention, research and development for a purpose, and manufacturing are integral to our members' success. Stating this somewhat differently, the bulk of our members are employed in work that spans Technology Readiness/Manufacturing Readiness Levels 5 to 9. This work requires pedigreed materials science, engineering, and process information. To be relevant to tomorrow's workforce, it must be delivered in the form and manner required.

To this end, ASM has embarked on a three-year digital transformation/content enrichment program. The first manifestation of this is being rolled out in May and involves improved web/mobile transactions and collaboration. Improved content values and usability will be observed in the October 2017 timeframe.

In terms of enhanced technical content, the ASM Board of Trustees has decided to hold an entirely new conference, AMTECH 2020, in lieu of MS&T. ASM's six affiliate societies will offer enhanced technical programing. In the spirit of strategic collaboration to enhance membership value, we remain open to partnering with other professional societies in this endeavor. Additionally, as we move boldly to deliver enhanced technical content, restructuring of ASM committees is being thoughtfully examined. Our technical committees must serve as the engine of technical content generation and dissemination as well as function as a technical entry point for members seeking to participate in our society.

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

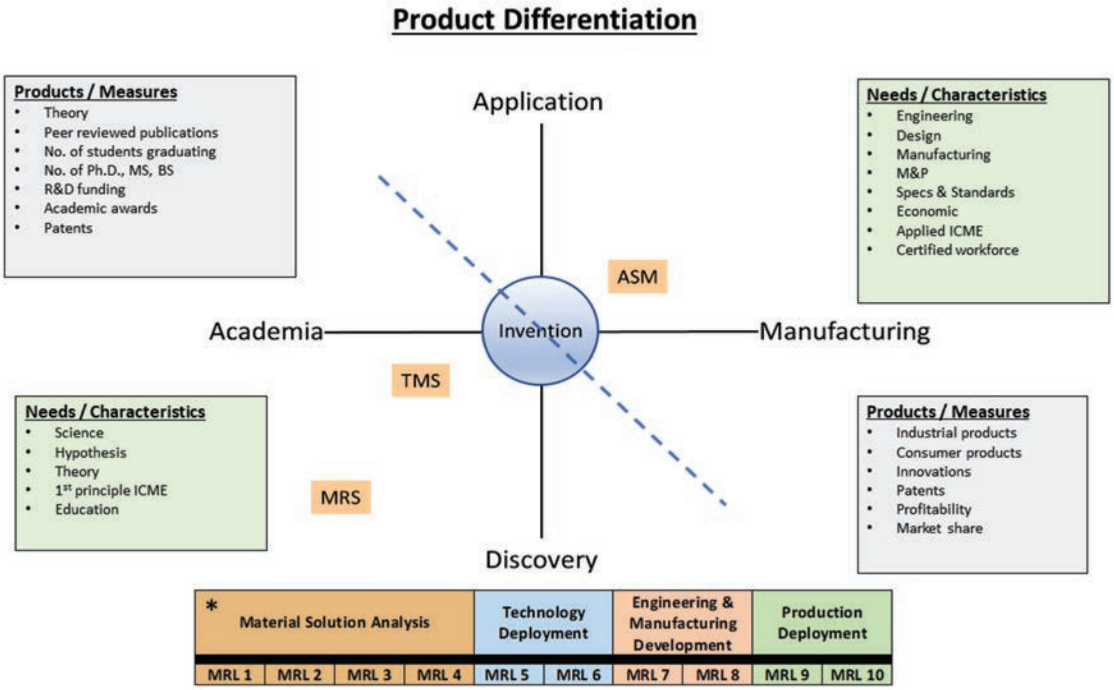


Fig. 1 – ASM product center of gravity.

FAS ANNOUNCES NOMINEES FOR OFFICERS AND DIRECTORS

The Nominating Committee of the Failure Analysis Society (FAS), chaired by Erhan Ulvan, announced nominees for FAS officers and directors. In accordance with the FAS Rules for Government, these nominees will be voted on at the FAS Annual Business Meeting in October at MS&T17 in Pittsburgh.

Nominated as a new director for a two-year term (2017-2019) filling the unexpired term of Daniel Dennies, is **Steven Bradley,** senior research fellow, Honeywell UOP. New directors nominated for three-year terms (2017-2020) are **Craig J. Schroeder,** senior engineer–metallurgy, Element, and **Thomas D. Traubert,** consulting engineer and district engineering manager, Engineering Design & Testing Corp.

Officers serve a one-year term (2017-2018). **Pierre Dupont,** account manager–industry, Schaeffler Belgium, succeeds as president of FAS, while **Burak Akyuz,** team lead–metallurgy and failure analysis, Applied technical Services Inc., remains on the board as immediate past president. **James F. Lane,** senior engineer, Professional Analysis and Consulting Inc., succeeds as vice president.

Nominated to an officer role is **Daniel P. Dennies, FASM,** principal, DMS Inc., as secretary. **Roch Shipley, FASM,** principal engineer, Professional Analysis Consulting Inc., is nominated to continue serving as treasurer.

Continuing on the board as directors are Amber M. Dalley, Erik M. Mueller, and Ronald J. Parrington. Retiring from the Board are Donato Firrao, FASM, Tim A. Jur, and Erhan Ulvan.

Daniel Grice, materials engineer, Materials Evaluation & Engineering, is reappointed to a second one-year term as the emerging professional board member. New student board member **Rachael Stewart,** working on a master's degree in metallurgy and materials science at the Colorado School of Mines, will serve a one-year term.


Bradley

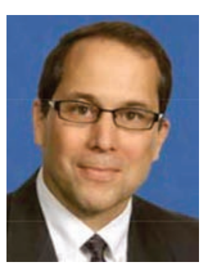

Schroeder


Traubert


Dupont


Akyuz


Lane


Dennies


Shipley


Grice


Stewart

FROM THE FOUNDATION

Materials Matter: A New Middle School Program


Schwartz

Numerous studies have revealed an achievement gap in STEM knowledge and a reduced interest in STEM careers among middle school students. Regrettably, there is little time in the middle school classroom for science as reading and mathematics predominate; however, children spend only ~20% of their time in school, while learning is a continuous process. Consequently, more and more STEM activities for this age group are being targeted for these out-of-school hours.

The ASM Materials Education Foundation has launched an out-of-school program entitled Materials Matter, which encourages middle school students to see the world around them as one in which science is transformed into technology through engineering. Students work in small groups and use hands-on experiments to explore concepts of physical science with common structural materials including metals, ceramics, polymers, and composites while learning to draw conclusions and apply basic engineering principles.

The new program was tested at three rather different sites: Roper Mountain Science Center in Greenville, S.C., a mid-size science center; University of Washington in Seattle, and the Museum of Science and Industry in Tampa, Fla., one of the larger science museums. ASM master teachers trained local staff who reported enthusiastic participation by students and immediately scheduled the program for following years. The Seattle program for summer 2017 was filled to capacity within two hours of being announced and they have scheduled a second session.

In 2017, seven locations will offer Materials Matter. Our target in future years is hundreds of science centers and museums across the country, in addition to other organizations that offer out-of-school STEM programs.

As the ASM Materials Education Foundation continues to expand our program suite, it is imperative to garner support. Through your generous contributions, we can continue to inspire and excite students to explore new worlds through hands-on discovery and to become the STEM pioneers of the future.

Lyle H. Schwartz, FASM
ASM Materials Education Foundation Trustee

WOMEN IN ENGINEERING

*This profile series introduces leading materials scientists from around the world who happen to be females. Here we speak with **Margaret Flury,** principal materials engineer at Medtronic.*


Flury

What does your typical workday look like?

I do failure analysis for Medtronic's restorative therapies group. We examine everything from technology and development prototypes to manufacturing items to returned product (not a majority of our work!). We can look at individual parts, whole devices, or even systems. I love to be in the lab, examining the failed items and setting up testing to try to recreate the failures. Of course I do have to spend some time writing reports and attending project meetings as well.

What part of your job do you like most?

Definitely working in the lab—I love dissecting failed parts, experimenting, using a lot of fun technical equipment, and trying to figure out what happened to make the item fail. I've even been able to participate in a few animal studies. I love interacting with the project team members to learn the history of the item and what it was exposed to. It is amazing what you can learn when there are so many different perspectives on an issue.

What do you least like to do?

Check emails. When I returned from maternity leave, I had over 900 to go through.

What is your engineering background?

I went to college at Michigan Technological University and received my B.S. in materials science and engineering. From there, I worked for Engel Metallurgical, an independent consulting and testing engineering firm where I did failure analysis and materials testing. We had clients from pretty much every type of industry, attorneys, and insurance companies. While at Engel, I obtained my Professional Engineer license in the state of Minnesota.

Upon moving to Medtronic, I started in the neuromodulation materials engineering group. I did a lot of product development work, where my focus was ensuring that the materials selected were both biocompatible (the materials don't harm the body) and biostable (the body doesn't harm the materials), all while having the desired properties for the function. After a few years, a position opened up in the neuromodulation failure analysis group, and I jumped on it, as my passion is failure analysis. With an internal business reorganization, neuromodulation became the restorative therapies group, and we became exposed to more product lines, enhancing the fun.

What attracted you to engineering?

I got quite a few scholarships to attend Michigan Tech, so I gave in to my parents and finally visited the campus. Luckily I fell in love with the school and decided to attend. I actually first applied to their liberal arts program. After deciding to attend and realizing they are better known for engineering, and because I liked math and science in high school, I switched my major to engineering. On the 10-hour drive to Michigan Tech to move in, I asked my mom what an engineer actually did. I was a bit clueless, but smart enough to take a general engineering course to learn what the different kinds of engineers do. One of my friends was majoring in materials engineering and encouraged me to check it out further. I talked to the academic advisor and learned that you could pretty much work in any industry. I liked that I could choose a major without really deciding that I was going to design cars or bridges for the rest of my life. I'm so happy with my choice and still love the wide variety of industries I can work for.

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

Find an area that you really like or are passionate about working in. Engineering is a lot of hard work, but if you like what you are doing, it turns out to be a lot of fun work. Also, talk to as many people you can in the field you are interested in—about what they do and about themselves. You never know when a new friend will become a great contact for help, references, jobs, work, or anything else. Not only does having personal connections make it easier to find what you need, it also makes your work a lot more fun.

Hobbies?

Running, playing with our daughter Nora and our dog Walter, fishing.

Last book read?

"Sherlock Holmes and the Case of the Brash Blonde" – I'm a sucker for super cheesy chick lit mysteries. They are quick, easy, mindless reads. Also, "Ina May's Guide to Childbirth." My husband and I had our first child in December 2016, so I thought I'd prepare a little. That was a while ago. After she was born, I didn't have much time to read!

Do you know someone who should be featured in an upcoming Women in Engineering profile? Contact Vicki Burt at vicki.burt@asminternational.org.

MD CORNER

Growing Membership and Revenues


Mahoney

If you have accessed the 2017 ASM International Strategic and Operating Plans though our website at www.asminternational.org/about/strategicplan, you know that our foremost key performance indicator is growing membership and revenue.

I am pleased to update you on progress thus far in 2017 against these critical goals. At the end of March, overall membership stood at 24,988, up from 24,203 at the end of February. We are making gradual but consistent progress in increasing membership, as we have reallocated resources to support new and reinstated memberships through personal contact. In prior years, resources were not consistently applied to this important member service. Our current resource allocation will continue for the foreseeable future and should make significant progress toward improved membership and service levels.

Month to month through the first quarter of 2017, we have also grown our revenues. In January, we generated $860,000 in product and service sales. In February, revenues were $952,000, and in March, $1,024,000. At this writing, April's target of $1,455,000 looks achievable. We believe our ramp in revenues is due to improved execution of marketing and sales processes for our current products and services. We expect this to continue.

We also expect improvement in membership and revenue growth to continue because we have worked diligently with our sales and marketing associates to simplify and clarify the ASM value proposition. We have boiled down the many benefits of ASM membership into two basic categories: professional development for members and improved materials performance for organizations that members serve.

Also, we are improving our ability to convey our value proposition to the marketplace. You will hear more about this as we roll out a new communications program. However, you will not hear about the value proposition from us. Instead, we are collecting individual success stories from members and materials performance success stories from companies served by members. Their voices will substantiate the two value components and we will relay those stories to you.

Thank you for your ongoing support for the ASM Renewal.

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

CHAPTERS IN THE NEWS

San Diego Celebrates 75th Anniversary

The 75th anniversary celebration of the San Diego Chapter was held on April 19 at the historic Cosmopolitan Hotel in Old Town San Diego. ASM President Bill Frazier attended the event and gave an overview of "Additive Manufacturing: A Disruptive Technology." He also awarded a special ASM coin to Professor Ken Vecchio, University of California, San Diego for his long and continuing service to the Chapter, students, and community.

Chapter Chair Juan F. Preciado and ASM President Bill Frazier.

Happy Anniversary, San Diego!

Mohawk Valley Highlights Quantum Dots

ASM's Mohawk Valley Chapter together with ASME's local chapter hosted Dave Socha, research technologist at Indium Corp., Clinton, N.Y., at its March dinner meeting. Socha gave a presentation on quantum dots, an emerging technology that uses different size nano-spheres to create various colors from a single color light wave, as from an LED. This emerging technology will soon be incorporated into high-end television screens, giving them more richly colored images. It is also being considered for solar cells and other light-emitting and light-absorbing ultra-efficient photovoltaic devices.

From left, Bob Whitney, Dave Socha, and Jim Fesko.

Hartford Holds Student Night

In April, the Hartford Chapter hosted its annual Student Night. As part of the evening's festivities, Alpha Sigma Mu CT Alpha Chapter inductees were recognized for 2017. From left, Harold Brody, Steven Churchill, Drew Cietek, Claudia Chavez, Keara Frawley, Andrew Nguyen, Michael Gingrave, and Carl Rizzo.

Chicago Presents NASA Lecture on AM Powders

The Chicago Regional Chapter capped off another successful technical calendar with a highly attended talk on April 18 by Chantal Sudbrack of NASA Glenn Research Center about a "New NASA Effort in Certifying 718 Powders for Additive Manufacturing" at Jak's Tavern.

From left, Kathleen Mullin, Mary Hawgood, Guiru Nash Liu, Chantal Sudbrack, Dana Frankel, and Kirtana Sandepudi.

Oak Ridge Hosts Industry Night

In April, the Oak Ridge Chapter hosted a successful Industry Night at the Joint Institute for Advanced Materials on the University of Tennessee, Knoxville campus. Twenty materials science companies from the area participated in this popular networking event and Swagelok even had a special exhibit on wheels: The company brought its demonstration trailer and parked it in front of the building so attendees could watch videos and see several pieces of equipment firsthand.

2017 East Tennessee Industry Night at the University of Tennessee.

Suez University Interviews Frazier

The Suez University Material Advantage Chapter, Egypt, recently interviewed ASM President Bill Frazier for its student newsletter. Included below is an excerpt.

Suez: Being president of ASM international must be a struggle. Any advice for those who want to follow in your footsteps?

Frazier: The president is the society's chief volunteer. It is important to remember that ASM is a society of professionals who have come together to accomplish great works for the common good that cannot be achieved independently. I would be quick to remind him or her that our shared values of transparency, integrity, technical excellence, diversity, and constancy of purpose are the great enablers. Further, it is these core values that must guide our decision-making, allowing us to maximize our value to all of society by working at the intersection of design/engineering, manufacturing, and materials. I would also emphasize that volunteering to be the president or a trustee of ASM is signing oneself up for a lot of hard work. If one is not willing to work assiduously on behalf of the society, one should not step up.

Suez: Please describe your contribution to corrosion-resistant alloy development.

Frazier: Working in the area of corrosion can be very humbling. The physics and thermodynamics of corrosion are clearly not on one's side. The lower free energy state of the corroded product works relentlessly and inexorably against protective corrosion measures. For decades, we have struggled to make wise material choices, protect corrosion susceptible alloys, and inhibit the kinetic pathways of corrosion. Our efforts have met with incremental improvement but have not resulted in corrosion-free products.

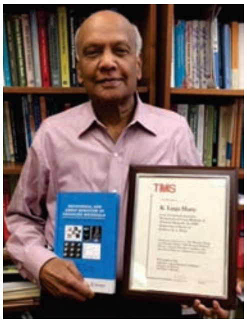
I believe that in addition to pursuing improved coatings, paints, and sealants, we need to look at the system as a whole—as an electrochemical system. Three advances in technology are required: New inherently corrosion-resistant alloys need to be developed; modeling and simulation tools need to be developed that can predict the electrochemical response of the entire suite of material used in a system; and we need new structural materials and coatings with designed-in electrical properties, e.g., a dielectric coating allowing current to flow in one direction but not another or materials that allow EMI to pass while inhibiting direct current flow.

Suez: As a partner in Material Advantage, do you believe the program prepares students to face future challenges?

Frazier: ASM is a strong supporter of Materials Advantage (MA). It benefits students in a number of ways, such as providing a peer forum for students to gain experience working in a chapter for their common good and giving students access to content from ASM and our sister societies. I would, however, like to see a greater number of students converting to full ASM membership upon graduation and joining one of our professional chapters. MA chapter members should know that ASM's professional chapters welcome student participation and engagement on chapter committees.

MEMBERS IN THE NEWS

Symposium Honors Murty at TMS


Murty

During the spring TMS annual meeting in San Diego, a symposium was held in honor of **K. Linga Murty, FASM,** Progress Energy Distinguished Professor and director of graduate programs for nuclear engineering at NC State University. The symposium was titled, "Mechanical and Creep Behavior of Advanced Materials." Murty is a Fellow of ASM International, Fellow of the American Nuclear Society, and Life Fellow and Honorary Member of the Indian Institute of Metals.

Anderson and Apelian Receive MPIF Distinguished Service Award


Anderson


Apelian

The Metal Powder Industries Federation's (MPIF) Awards Committee announced the recipients of the 2017 MPIF Distinguished Service to Powder Metallurgy (PM) Award that recognizes individuals who have actively served the North American PM industry for at least 25 years and, in the minds of their peers, deserve special recognition. Among the 2017 recipients are **Eric Iver Anderson, FASM,** Ames Laboratory, and **Diran Apelian, FASM,** Worcester Polytechnic Institute. The awards ceremony will take place on June 14 during the Powdermet2017 conference in Las Vegas.

Hu Wins Two Awards at Michigan Tech


Hu

Yun Hang Hu, the Charles and Carroll McArthur Professor of materials science and engineering at Michigan Technological University, was awarded the 2017 Michigan Tech Research Award this year for outstanding research achievements in advanced materials and clean energy. He also earned the 2017 Bhakta Rath Award with his Ph.D. student, Wei Wei. This is the first time a faculty member has won both awards. The Michigan Tech Research Award, the highest research honor given at the university, commends Hu's internationally recognized work. He is well known for his significant contributions to nanostructured materials, memristive materials, catalysis, clean energy technology, and quantum chemistry calculations. The Bhakta Rath Research Award is a team effort, given out annually to a Ph.D. student-advisor duo based on the quality and significance of their work together.

Jarvis Wins Missouri S&T Poster Contest

MISSOURI S&T

Groundbreaking research by dozens of Missouri University of Science and Technology graduate students was recently featured at the university's eighth annual Graduate Fellows Research Poster Session. On March 13, Missouri S&T's office of graduate studies recognized the top presentations during an awards banquet. **Leiren Jarvis,** a Ph.D. student in materials science and engineering, won first place for his poster, "Extended Finite Element Modeling of Fracture Behavior of ZrB2-based Ultra-High Temperature Ceramics." Jarvis is investigating ways to make ultra-high temperature ceramics more fracture resistant for use in aerospace applications.

IN MEMORIAM

Varrese

Francis R. "Fran" Varrese, FASM, passed away on February 22. He was born in Norristown, Pennsylvania, and graduated from Ambler High School in 1957 where he was valedictorian, class president, and captain of the football team. In 1961, he graduated with a B.S. in metallurgical engineering from Lehigh University, where he received the Allen S. Quier Prize for outstanding progressive achievement in scholastic work from the metallurgical engineering department. Varrese was employed as a metallurgical engineer at Robert Wooler Co., Standard Pressed Steel Co., and Honeywell Inc.'s Ft. Washington facility. While at Honeywell, he was awarded several technical awards including the H.W. Sweatt Award, the company's highest award for engineers. Varrese was heavily involved with ASM both locally and nationally. He was known as "Mr. ASM" to the Philadelphia Chapter, serving as executive secretary/treasurer for nearly two decades. He was awarded the Society's Allan Ray Putnam Service Award in 1993 and became an ASM Fellow in 1978. He received several awards from the Philadelphia Chapter including the Young Member Award in 1974, President's Award in 1983, Delaware Valley Metals Man of the Year in 1986, Philadelphia Chapter Distinguished Service Award in 1988, Meritorious Service Award in 2000, and the Adolph Schaefer Special Achievement Award in 2001. He also presented the prestigious Albert Sauveur Lecture to the Chapter in 1981.

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STRESS RELIEF

WOOD YOU LIKE TO DRIVE?

French cabinetmaker Michel Robillard handcrafted a wooden replica of Citroen's 1948 2CV automobile using a combination of apple, pear, and cherry lumber. The fully functional vehicle took six years to build, including an undulating hood carved out of a single block and featuring 22 ridges honed with a wood chisel and sandpaper. The 2CV, which stands for "deux chevaux" (two horsepower), was launched as Citroen's competition against the Volkswagen Beetle. The vehicle is equipped with an original engine from Citroen's 3CV model, giving it the extra boost required to propel the heavier wooden structure. Besides the engine, the car's metal frame, wheels, and headlights are the only parts the Frenchman did not make himself. The car is not for sale: Robillard hopes to put it on display in an art gallery or see it featured in a big-budget advertisement or movie. *afp.com.*

Robillard spent six years crafting this fully functional, life-size 2CV Citroen out of apple, pear, and cherry wood. Courtesy of afp.com.

Jason Hoving and Ryan Kuhn place a giant Rubik's Cube into the lobby of the G.G. Brown engineering building. Courtesy of University of Michigan.

PUZZLE ME THIS

A giant Rubik's Cube newly installed on the University of Michigan's North Campus is believed to be the world's largest hand-solvable, stationary version of the famous puzzle. The 1500-lb, mostly aluminum structure was unveiled in April on the second floor of the G.G. Brown engineering building. It was imagined, designed, and built by two teams of mechanical engineering undergraduate students over the course of three years. The colorful cube is meant to be touched and solved, and the students worked hard to figure out a movement mechanism to enable that. They realized they could not simply scale up the design of the handheld cube because the friction would be too great. To keep friction to a minimum, they devised a setup that utilizes rollers and transfer bearings. The team considers the finished cube a fusion of art and engineering. *umich.edu.*

DRONES WEAVE MOTH-INSPIRED PAVILION

Researchers and students from the University of Stuttgart, Germany, employed robots and drones to weave a novel 39-ft composite pavilion inspired by moth webs. The pavilion is based at the school's Institute for Computational Design and Construction, and Institute of Building Structures and Structural Design. It is a singular cantilever structure created by laying 114 miles of glass and carbon fiber-reinforced composites. The design mimics silk hammocks spun by two species of moth larvae *(Lyonetia clerkella* and *Leucoptera erythrinella)* and the structure was manufactured offsite through a process the researchers call "multi-machine cyber-physical fabrication." During construction, two stationary industrial robotic arms are placed at the extremities of the structure, while a drone passes fiber from one side to the other. In addition, an adaptive control and communication system allows the robot and drone to interact throughout the winding and fiber laying processes. The team believes this prototype process could be developed to construct other composite structures in the future. *www.itke.uni-stuttgart.de.*

Composite pavilion inspired by moth webs. Courtesy of Ghinitoiu.

3D PRINTSHOP

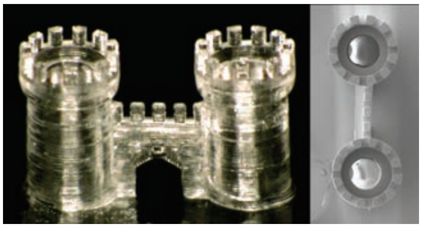
Low-cost Ti-6Al-4V spherical powder produced at the University of Utah.

ROLLING BACK PRICES ON TITANIUM POWDER

Researchers at the University of Utah, Salt Lake City, are working on a potentially disruptive manufacturing technology that could dramatically reduce the cost of titanium (Ti) powders. Additive manufacturing requires low-oxygen content powders, which in the case of Ti, has proven difficult and expensive to make. Utah researchers, in cooperation with Boeing and Arconic Inc., developed a way to turn low-cost commercial TiO_2 into low-oxygen Ti powder, and they are beginning to scale up and validate the process for industrial applications. The work, led by Professor Z. Zak Fang, is jointly funded by the Advanced Research Projects Agency-Energy (ARPA-E) and Utah's two industry partners. *http://powder.metallurgy.utah.edu.*

KIT RESEARCHERS DEMO GLASS PRINTING PROCESS

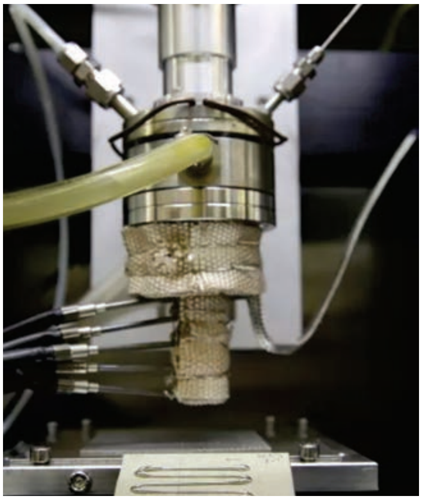
Nearly four years ago, as interest in 3D printing peaked, Karlsruhe Institute of Technology (KIT), Germany, began working on a process that at the time may have seemed out of step. Instead of studying an advanced alloy or engineered polymer, KIT scientists set their sights on printing with glass and they are now disseminating the results of their work. The key to the glass printing process is a photosensitive slurry made by mixing nanoparticles of high-purity quartz with a small amount of liquid polymer. The mixture is cured by means of stereolithography, followed by removal of any remaining liquid including the polymer. As a final step, the structure is solidified by sintering, causing the glass particles to fuse. To see a video of the process, visit *http://bit.ly/2pG7WZJ.*



Complex glass structures produced at KIT demonstrate the capabilities of a 3D printing process that uses stereolithographic techniques. Structures just a few centimeters in size with features on the order of a few microns can take almost any imaginable form.

METAL 3D PRINTING REINVENTED

Printed metal parts are often plagued by gaps, cracks, and other defects, making validation a slow and expensive process. Most efforts to address the problem focus on improving powders, but Lawrence Livermore National Laboratory (LLNL) and Worchester Polytechnic Institute (WPI) are taking a different approach with *direct metal writing,* a process that extrudes metal directly onto the part. Instead of using powder as the starting material, researchers use an ingot that is maintained in a semisolid state so it behaves like a solid at rest, but flows like a liquid under an applied force as when extruded through a nozzle. The resulting metal beads harden uniformly as they cool, minimizing the presence of oxide and residual stress in the final part. Having proven the concept using bismuth-tin, the collaborators are now moving on to aluminum alloys. Aluminum has greater application potential, but its higher melting point will complicate its use. To see a video of the direct metal writing process, visit *http://bit.ly/2p9nHrf.*



A 3D printer developed by LLNL and WPI employs a direct metal writing process that uses semisolid liquid metal instead of powders.

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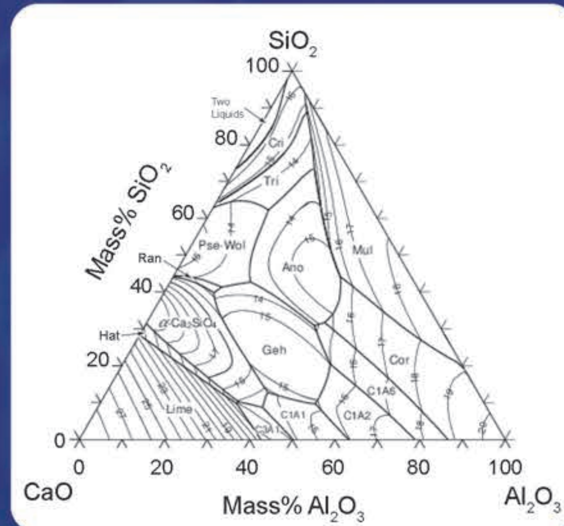
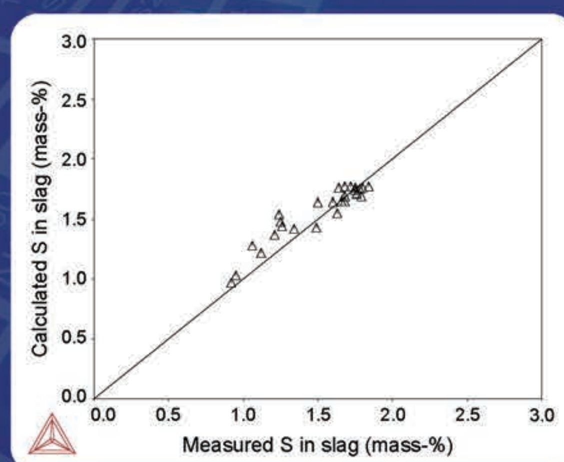


Calculated phase diagram of the CaO-Al2O3-SiO2 system[4] using the TCOX database. Ano: anorthite, C1A1: CaO.Al2O3, C1A2: CaO.2Al2O3, C1A6: CaO.6Al2O3, C3A1: 3CaO.Al2O3, Cor: corundum, Cri: cristobalite, Geh: gehlenite, Hat: hatrurite, Mul: mullite, Pse-Wol: pseudo-wollastonite, Ran: rankinite, Tri: tridymite.

Version 2017a now available

- ✓ **12 New and Updated Databases,** including TCOX7, the metal oxides database which is suited to ceramics. Other updated databases: TCFE9 and MOBFE4 (steels), TCHEA2 (high entropy alloys), TCCU2 and MOBCU2 (Copper alloys), TCSLD3.2 and MOBSLD1 (solders), SLAG4.1 (slags), NUCL15 and MEPH15 (Nuclear materials) and TCNI8.1 (Ni Superalloys).
- ✓ **DICTRA available in the Graphical Mode** for the first time ever as an add-on module known as the Diffusion module.
- ✓ **Expanded Property Model Calculator.** The calculator which allows users to predict and optimize properties of materials based on models stored within the software has been expanded so that users can now develop their own property models using Python as a language.



Measured* and calculated sulfur composition in typical ladle slags at 1823 and 1873 K for the quaternary Al2O3-CaO-MgO-SiO2 system using the TCOX database.
*C. Allertz, PhD thesis, KTH Stockholm, 2016.

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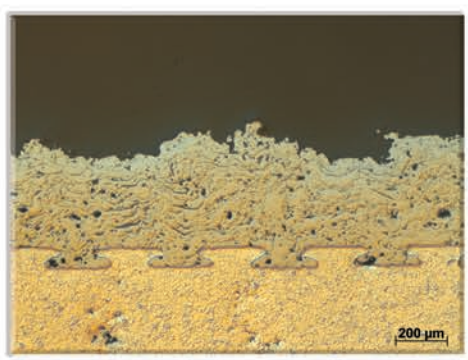

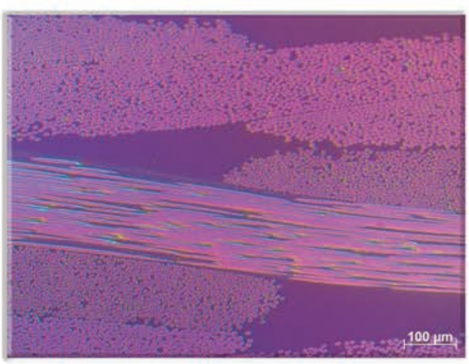

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